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Infrastructure for the Circular Economy: The Role of Policy in System Change

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Statement of Originality

This is to certify that the copy of my thesis, which I have presented for consideration for my PhD degree, embodies the results of my own course of intellectual thought, study and research, has been composed by myself and has been seen by my supervisor before presentation. Work by others is appropriately referenced.

I would like to dedicate this thesis to my father, who would have been as proud to see it completed as I was of him.

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ABSTRACT

The concept of a Circular Economy has gained policy traction as a mainstream solution for preserving and renewing. This work sought to understand which policy instruments have been successful, might still be necessary, and are most likely in the future to deliver a high penetration Circular Economy for materials, wastes and associated energy. Waste related policy decisions in England over the past 20 years were reviewed, exploring the regulatory means that had achieved the current 44% diversion of municipal wastes from landfill.

The hypothesis is that to achieve a far-reaching Circular Economy, at a greater scale, across different sectors and for a wider product range, suitable physical infrastructure (waste treatment assets) must be available to circulate those materials in the economy. Furthermore, the study set out to value financially and in terms of social and economic benefits that could be derived from a circular approach across the whole economy. We found the financial value to be significant at circa 1.5% of English GDP or £32bn and 72,000-175,000 jobs. It was demonstrated by calculation that DEFRA analysis (for England) underestimated the capacity gap for infrastructure by 11.3 million tonnes per annum in 2014.

The policy findings were that the early implementation of blunt instruments such as a landfill tax and separate collection of recyclables did allow for diversion performance of approximately 45-50% recycling and composting, the remaining 50% of which was progressively treated by energy from waste rather than landfill. It is apparent that policies that drive system changes are effective in bringing about ecological transformations of how societies, economies, and governments operate at all levels. This **ecological transformation** is undoubtedly difficult to achieve since it will require consumers, manufacturers, regulators, policymakers, media, and business all to move differently and together, but nevertheless it is critical at a global scale.

Chapter 1: Introduction

1.1 Background

It has long been established that we live beyond our means, with respect to resources, on a planetary scale (Bennett, 2015, European Commission, 2012). The consumption of materials and energy results in widespread pollution, deterioration of environmental quality, and is unsustainable at current levels given likely population growth (Fisher, 1971, Brundtland, 1987). Whilst much of the known local air pollution sources such as acid gases, organic pollutants, or greenhouse gases such as CFCs are controlled by strict point source emission regulations in most parts of the world, it has been known for some time that carbon dioxide emissions are causing climate change which in turn will cause planetary scale consequences (Travis, 2020). In the field of solid waste arisings, a long-standing *waste management hierarchy* (Cleary, 2009) remains relevant with reduction, reuse, recycling, recovery, and disposal being the respective sequentially important goals, and the evidence suggests that this hierarchy tends to be consistent with achieving higher levels of environmental benefit (Stegemann, 2016).

However, the *holy grail* of waste management has more recently been focussed on a ***Circular Economy*** where all wastes are in some way looped back around to a useful end point, or indeed a new starting point, often with natural cycling processes cited as the analogous model (Andersen, 2007, Braungart, 2009). The idea of the circular approach in the terms we use throughput this work first appear in the literature in 1966 where Boulding (Boulding, 1966) talks about the *circular ecological system*, however, the term was not really coined as an economic construct until much later in 1989 when the **Circular Economy** is explicitly referenced by *Pearce et al* (Pearce, 1989). The *Circle Economy's Circularity Gap Report* revealed in 2021 that only 8.6% of our material flows are circular, and that to keep the planet thriving over the next few centuries we would need to at least double that to 17%, if we are to curb the related carbon emissions from materials use and address the growing impact of climate change (CGRi, 2021).

Significant policy debate has taken place in more recent years as to whether energy recovery from solid wastes itself constitutes a circular approach (i.e., using wastes that cannot be materially recycled or composted as a fuel). Within the framework of this thesis the assumption is taken that it does, by necessity, given the obvious limitations of physical recycling and technologies available. From a purely pragmatic, science-based position, entropy will always introduce losses to a system (Sá Earp, 2015), and therefore 100% recycling is unachievable. This work considers energy recovery, after thorough and useful recycling and composting, to be a beneficial alternative to landfill deposit. Indeed, if the energy derived from wastes, either heat or electricity is directly used to produce new materials, as it is when waste biomass energy plants are used to power paper mills, then these wastes are genuinely contributing to a circular approach.

The overall aim of this thesis was to investigate policy options as leverage points for the circular system to emerge at scale. The importance of a system change is that only this level of change is likely to yield significant results widespread throughout the economy (Boons, 2013). Therefore, a primary measure of whether a Circular Economy is successful is the **scale** and **spread**, or penetration, it makes into the whole economy of a jurisdiction. This research focussed on policies that can deliver infrastructure sufficient in scale and type for the Circular Economy to be dominant and to make recommendations about how to engage the public, for these policies to gain political traction. This work considers both practical challenges associated with realising circular strategies as well as their business model implications, the business model being a result of the strategy (or policy) (Brennan, 2015). Kyriakopoulos (2019) proposes inter-enterprise circulation, regional circulation, and social circulation to also be relevant aspects of a successful Circular Economy. The work of Kyriakopoulos (2019) as well as the research of Purnell 2021, Ekins 2019, and Beaurain 2021, expound that **scale** and **spread**, as well as **self-sustenance** (sustainability) are principle to a functioning Circular Economy. This is particularly pertinent when we consider that classical economies are connected via supply chains with interacting system dynamics. With this in mind, we designed three over-arching 'tests' to determine the success of policies in delivering a Circular Economy strategy.

To test the resulting Circular Economy that would emerge from the policies discussed herein the following tests were applied; **(a) is the industry likely to utilise materials 'at a scale' which could be considered industrialised; (b) is the practice widespread across industry sectors, and (c) is the practice self-sustaining from an economic perspective, when taking into account relevant fiscal instruments currently in place.**

By way of example, there is a robust and widespread Circular Economy in place for paper (fibre) with over 70% being repurposed, see Figure 1.1 below, since it is economically valuable to collect and cycle back into the production of new fibrous products particularly whilst separate municipal collection is a regulatory requirement. This is true for fibrous material across sectors, at national scale and it is economic to do so. In fact, paper recycling is a dominant feature of the paper economic cycle.

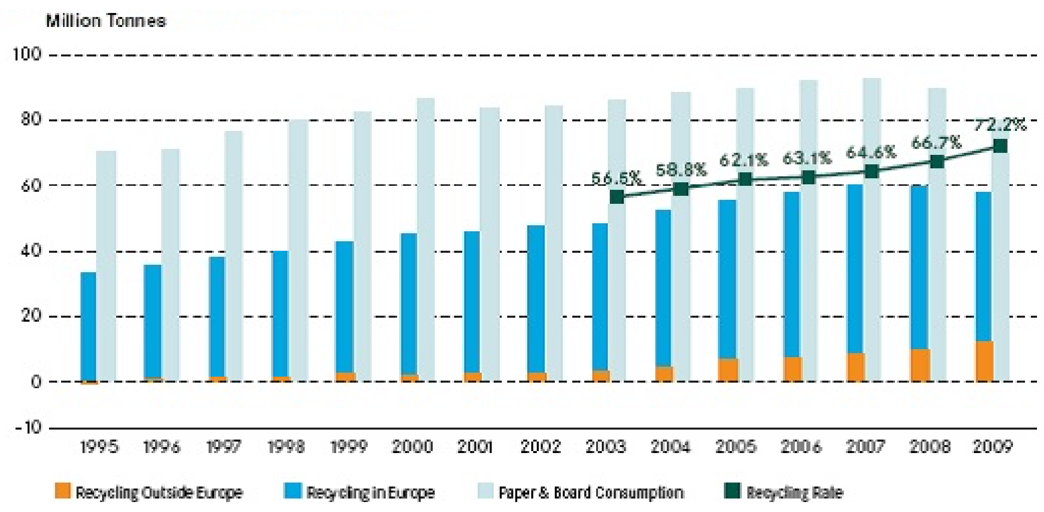


Figure 1.1 European paper recycling levels from 1995-2009, demonstrating high penetration of circularity into the paper economy (Cabalova, 2011).

Whilst the same is true for most metallic waste streams, it is certainly not the case for most plastic materials which are currently only recycled piecemeal, limited to individual and isolated formats (e.g., PET bottles) or in some cases a 'token' effort rather than a business model based recycling system (i.e. only 8% of plastic is recycled globally, Brooks, 2020). A good example of 'token' effort is where plastic potato chip bags are recovered and recycled, which gains much publicity but constitutes a very small level of recycling percentage compared to material placed on the market (Guardian Online, 2018).

The compatibility between material recycling and / or energy recovery processes and a Circular Economy which relies wholly on physical material circulation is a matter which remains outstanding in terms of current thinking, particularly when many materials are not currently recyclable (Allwood, 2014). The question remains as to how pragmatic, or beneficial, it is to insist upon 100% material recycling of organic (green and food wastes) and technical materials (plastics, metals, glass, wood), compared to accepting that a residual fraction for energy recovery (use as a fuel) could be optimal. This appears to be a matter of how much societal funds authorities wish to divert towards such practices as sorting waste and consideration of the net measurable benefits of marginal increases to material recycling (Becker, 1993). It is relevant to consider generally that there will be diminishing returns from requiring everything to be recycled indefinitely, and that materials which claim to be infinitely recyclable may have inherently high carbon impacts in the first place [e.g., glass], (Grimmond, 2019). Complex life cycle assessment is required, and these calculations and considerations are complex, and arguably unattainable in many real-world scenarios. Therefore, the implementation of a "system" that drives the decision process in the right direction is considered the optimum approach to gain the most overall benefit in any given economy (Hasselbalch, 2019).

In order to adopt an inclusive approach this work applied a broad definition of the Circular Economy, that is, ***recovering what was previously discarded as waste into useful resources in the economy as fuels for electricity of heat, organic products such as compost and fertilisers or replacement of otherwise virgin materials such as primary paper, plastic, glass and metals***. We have by choice not directly investigated design, prevention, reuse, and repair practices to any large extent – other than in terms of the impact policy drivers may have in these areas – but we do recognise that these aspects have wide application, potential benefits, and that they should be carefully considered, including the overall net life cycle impacts which are by no means intuitive or obvious. We do consider the concept of 'product to service' adaptations in Chapter 6 when evaluating the value of the Circular Economy and this has some relevance to waste prevention. It is acknowledged that digital technology, such as distributed ledger applications, digital twins, artificial intelligence and machine learning, or other advanced and developing asset tracking methods will potentially play an increasingly important role in the future of waste management, as they do in other industrial fields. A current weakness of the supply chain is that whilst data tracking of materials and products is coherent from mine to doorstep (from the point it is mined as a raw material, all the way through to placement in a home), after that the chain of control is lost and the material is a waste. It could be anticipated that the practitioners of geography, mathematics, and digital disciplines will ultimately collaborate more intensively in the waste field with the more traditional engineers and chemists of today to elicit a full duty of care across the supply chain.

The discussion around policy in this work is considered particularly relevant to the United Kingdom (UK) jurisdiction, albeit the principles could be applied anywhere, whereas regulation, environmental performance and national statistics quoted are usually referring to England only. It is specified where the information refers to the United Kingdom of Great Britain and Northern Ireland only or otherwise. Specifically, the Infrastructure Study in Chapter 5 covers only England (since England is the boundary of the analysed DEFRA report, the UK Department of Environment, Fisheries, and Rural Affairs). The Valuation of the Circular Economy in Chapter 6 also covers England to remain coherent with the waste flows considered in Chapter 5, particularly considering that the Landfill Tax relevant to England differs legislatively to the Scottish Landfill Tax. The main policy discussion of Chapter 7 refers to the latest policy proposals of DEFRA, and therefore represents a discussion around mainly English waste policy, however, the devolved administrations are aligned with similar and parallel initiatives. It is of note that Wales is performing well in terms of its resource management strategy, outperforming England in terms of recycling rates and this is touched upon throughout the report as well as in the conclusions of Chapter 10.

1.2 Thesis Framework and Approach

With the three tests of a successful Circular Economy in mind, that of *scale, spread and sustainability*, a framework was developed which set out the structure and component parts of this thesis. To ensure *scale*, *spread* and *sustainability* a **system** is required which can be applied universally across a defined jurisdiction, geography, or economic boundary, which obligates all commercial enterprises within that boundary, as well as the public authorities which interact with the relevant material flows (Pearce, 1989, 1993).

Therefore, it follows that we are seeking a new system to be derived, installed and accepted, via regulatory means so that all players within that economy are compelled to comply, that public and therefore political acceptance would be required as well as technology development supportive of the proposed regulatory system. Subsequently business models would be derived from the regulation (Kitching, 2015), allowing physical infrastructure to flourish which would derive economic and environmental gains for society.

Alioni, 2020 and Ikiz Kaya, 2021 et al introduce **driving factors** and **policy enablers** as concepts for circular economies to thrive. That approach was adapted here, adopting **drivers**, which here includes the *policy*, *communications,* and *technology* elements, since it is required to gain public acceptance for a wide policy application, taking heed of any technological influence that may help or hinder the policy intent; **enablers**, which includes the *business models*, *financing* and *infrastructure* derived from the policy, and on the basis that without a viable business model the activity would not be self-sustaining. It was considered appropriate, given the objectives of a Circular Economy (i.e., financial and environmental benefit), to add **outcomes** to the framework. The addition of **outcomes** catered for measurement of the potential benefits both in environmental and financial terms, both as a forecast to inform and incentivise the policy construction, but also for providing a feedback loop to decision makers post implementation.

Since we are seeking to develop a wide adoption of circular principles throughput the economy and in all industrial sectors (scale and spread) the policy would need to be broadly applicable and accepted across a wide audience and viewing this through the lens of the **drivers** and **enablers** was considered a useful way to assess the penetration of the policy throughout the economy since the policies we consider are, largely, agnostic to any particular industrial sector.

Figure 1.2 below sets out the key components of this thesis categorised into **drivers**, **enablers** and **outcomes** describing how they interact and how they are dealt with in relevant Chapters.

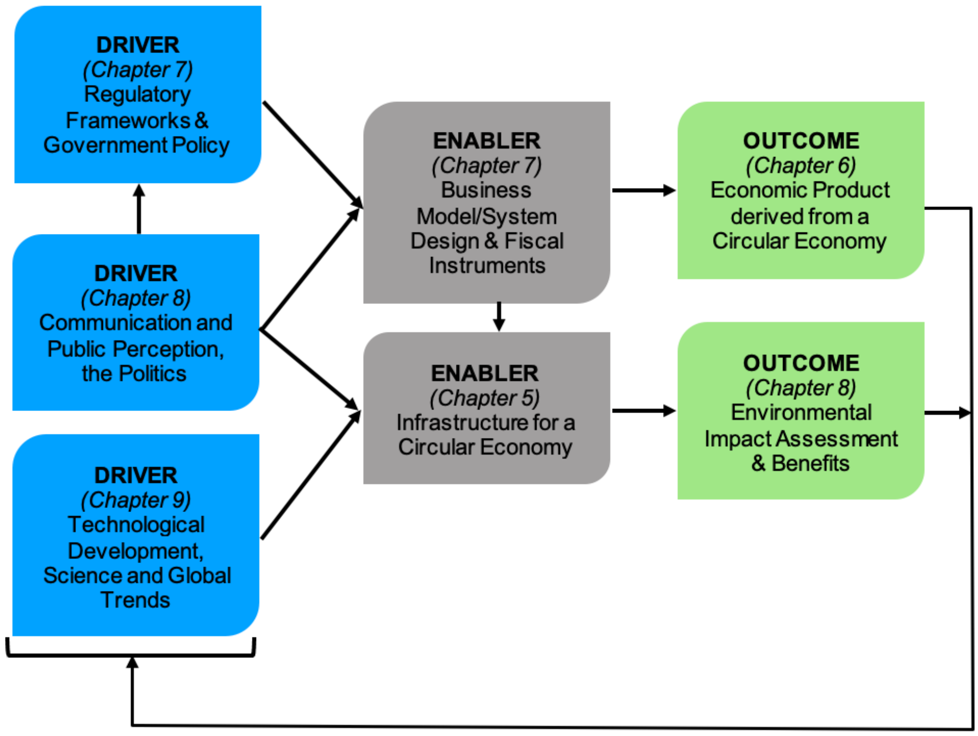


Figure 1.2 Drivers, Enablers and Outcomes for a Circular Economy

In order to both facilitate planning for the right infrastructure but also incentivise either public or private development the right **policy and regulatory framework** would be needed to facilitate the flow down of fiscal instruments, system design and subsequently commercially viable **business models** to drive the new economy. We determined here that policy would be a primary **driver**, and the subsequent business models an **enabler**. Furthermore, this system would be influenced and impacted by the development of **science, technology** and other **societal global trends** and so technology also **drives** the Circular Economy.

The principles of a Circular Economy contribute to the 17 UNEP goals of sustainability (UNEP, 2006), and include consideration of barriers and opportunities which relate to *public policy, and public communication and perception*. Thus, it was determined that in order to develop suitable infrastructure it would be necessary to first **plan and communicate** effectively in order to drive policy makers who would be supported and that planning determinations could be effectively gained by developers. That public perception and resulting policy would **drive** the circular activities or financing and infrastructure construction which in turn enables the Circular Economy to exist and present the economic and environmental outcomes.

The Circular Economy demonstrably requires physical collection, preparation, transformation, and circulation of materials, as well as transformation into energy forms, using physical and industrial infrastructure. Whilst other aspects of a Circular Economy are important (e.g., the service economy) the focus of this work was with respect to delivering a physically present Circular Economy, since the delivery of local or regional **infrastructure** (built operating assets) take many years and must be planned far in advance (e.g., 30 years). Clearly, infrastructure **enables** the Circular Economy (to exist and function) and the requirements for infrastructure are determined in Chapter 5. Infrastructure by its nature also has wide application in an economy (e.g., roads, electrical networks), it can be used across the economy, as can waste treatment assets. This fitted well with the tests that required both *scale* and *spread*.

Public engagement, communication to the public and resulting public perception will impact political will to implement policy, and thus **drive** the delivery of a Circular Economy. and the resulting rapid change in industry and commerce as well as in the home and how citizens live, with a primary **outcome** being **environmental benefits**.

The decision to focus on the here and now of infrastructure development was considered compatible with the application of future technology given the insights from the technology analysis in Chapter 9. Given we are discussing a system change, one might ask why *system dynamics* does not play a greater role in devising this work. The justification for this is considered in the policy section, Chapter 7, which goes to the explanation that historically relatively straight forward interventions have led to many of the successes to date in delivering a Circular Economy, and whilst the economy is a complex system, relatively blunt measures can be implemented at the right location in the economy to be impactful (e.g., a landfill tax). This is a relatively upstream approach and at a national level applying overarching fiscal (tax) means. Whilst system dynamics would no doubt offer further insights, the approach adopted here remained focussed on the descriptive analysis and inference of trends based on demonstrated evolution of environmental performance, as well as the financial case for infrastructure development. In other words, blunt policy measures which allowed England to move from around 10% recycling to c.50% recycling were studied to infer what impact new policy measures would have on business decisions.

Research work has been conducted between 2014 and 2021 to investigate each component of the framework described in Figure 1.2 through the common lens of the Circular Economy. The work is then integrated deriving the findings and conclusions to demonstrate how these parts contribute towards guiding us in to a more circular system.

Chapter 2. Background to Solid Waste & Literature Review

2.1 Introduction

Solid waste, "the stuff we throw away", is a striking by-product of civilisation, with archaeological studies showing that as early as 6500BC, North Americans in Colorado were producing 2.4 kilos of waste each day (Young, 2010). Waste generation is the result of resource use and historically has increased with population. However, in the past century as the world's population has grown, it has also become more urban and affluent, with resource use and the resulting waste generation linked to economic activity. As a result, waste production has risen tenfold, with solid waste being generated faster than other environmental pollutants, including greenhouse gases (Hoornweg et al., 2013).

The waste problem is particularly acute in emerging cities, with landfills such as Laogang in Shanghai (China); Sudokwon in Seoul (South Korea); Jardim Gramacho in Rio de Janeiro (Brazil); and Bordo Poniente in Mexico City (Mexico) competing for the title of the world's largest depository (Decker et al., 2002). According to the UN, by 2050, the world population will have reached 9.7 billion inhabitants (UN, 2015; Lutz et al., 1985), with more than 70% of them living in cities (World Health Organisation, 2013). Most of this population growth is projected for Asia and Africa (UN, 2005), bringing a remarkable increase in predicted GDP per capita, with the global economy in 2025 reaching $90 trillion, from a base of $62 trillion in 2015 (UN, 2015). This increase in global population and GDP will present real challenges to resource security, limiting the supply of raw material and energy necessary to fuel the economic activity behind the equivalent predicted increase in GDP (Lutz et al., 1985). This is particularly true since economic output (GDP) is strongly linked to resource use, put another way, *more people want more things.*

Waste management has a key role to play in both delivering public health and environmental protection and contributing inputs to address the estimated lack of future resources whether through material or energy recovery. A modern waste management approach needs to address the escalating nature of waste production, offering solutions that require a long-term vision (Modak et al.,2011). In the UK, since 1999 the European Union Landfill Directive has required all member states to reduce the amount of biodegradable municipal waste sent to landfill. There has been a pressing need to divert waste away from landfill. This has been achieved by increasing efforts on waste reduction and increases in the amount of waste we reuse, recycle or use for energy recovery, enabling England (as part of the UK) to meet its target under this Directive of sending less than 10.2 million tonnes of waste to landfill annually by 2020 (Brown et al., 2017).

However, while government and industry have been working to meet this demand, the rate of planning approval for new facilities has been well below what is required (DEFRA 2011a, GIB 2014, NIC, 2018, Price 2001). At the heart of this problem seems to be local public opposition to the development of new waste facilities (Wolsink and Devilee, 2009).

2.2 The Need for Waste Management Infrastructure

The management of wastes has evolved significantly over time (DEFRA, 2013a). Since the industrial revolution, and more recently the post war consumerism of the 1950s, population density, industrial intensity and complexity, as well as growth in home packaging waste, has led to the need for what is termed today as 'modern waste management' provision (Atkinson and New, 1993). In the absence of such provision, discarded wastes can generate impacts on human health in terms of clinical hygiene or exposure to toxic elements (Giusti, 2009). There is also the practical, logistical challenge of physically removing the material. The issue of waste management has become much wider in the past few decades simply due to the increasing quantities of materials used and consumed, and the estimated lack of future resources (Modak et al., 2011). In light of the ever-growing consumption and demand for raw materials, the need to manage environmental resources more sustainably is becoming increasingly important (Voulvoulis et al.,2013).

Waste management was highlighted as a priority in the first European Union (EU) Environmental Action Plan, adopted in 1972, and was recognised in law in the 1970s when the first Directives were ratified, requiring reduction in landfilling of wastes and proper management thereof (EU Commission, 1999). Waste management principles defined by EU waste legislation require waste to be managed without endangering human health, harming the environment, causing nuisance through noise or odours, or adversely affecting the countryside or places of special interest (EU, 2008).

Waste management must also be an integral part of resource management by turning wastes into resources, and therefore has dual aims of health and resource efficiency (Figure 2.1). Member States of the EU are bound by a number of Directives to not only reduce the amount of waste going to landfill but also to increase the recoverability of this waste through recycling (Brown et al., 2017): the European Commission (EC) Landfill Directive (99/ 31/EC) requires Member States to reduce the amount of Biodegradable Municipal Waste (BMW) sent to landfill to 35% of 1995 levels (European Commission, 1999), while the revised Waste Framework Directive (2008/98/EC) requires a 50% recycling rate for household waste, and waste of similar nature to household, by 2020 (European Commission, 2008).

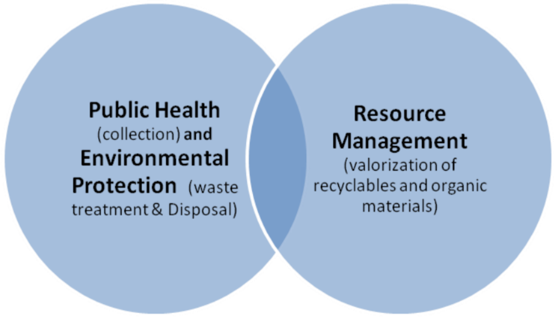


Figure 2.1 The dual aim of waste management

Another issue that drives the need for waste management infrastructure is the complexity of waste generation and management. When 'throwing away' waste, system complexities and the integrated nature of materials and pollution quickly emerge. Solving one problem, if not well executed, often introduces a new one, often of greater cost and complexity (World Bank, 2009). A household typically will generate waste comprising food and garden waste; packaging (including paper, card, metals, plastic and glass); electronic equipment; some hazardous streams such as oils and batteries; and bulky waste such as construction materials, furniture and textiles (Slack et al., 2009). In addition, a mixed residual waste containing all of the above will exist, as well as composites of them (Gray, 1997; Williams, 2005; Modak et al., 2011).

Typically, the different material streams grouped together and collected according to their frequency of arising (Williams, 2005; Modak et al., 2011), require technologies such as composting; recyclables sorting; energy recovery, either by anaerobic digestion or thermal methods; specialist treatments for electronic and hazardous wastes; and landfill for residual non-usable materials (Williams, 2005; Slack et al., 2009). This constitutes a significant infrastructure investment and is therefore potentially controversial due to the investment cost (of public monies), the physical presence and aesthetics of the 'factories', the alternatives that must be considered, and the complexity of the delivery mechanisms that are in the public spotlight (Burnley, 2007; Gray, 1997; Williams, 2005).

Figure 2.2 below illustrates the variety of materials found in different household waste streams. Over the past 100 years, there has been a noteworthy shift from largely dust and ash (since householders would burn materials in the fireplace), to a complex mixture of materials including wood, plastic, textiles, glass, paper and metals (Atkinson and New, 1993), linked to the growth of convenience shopping.

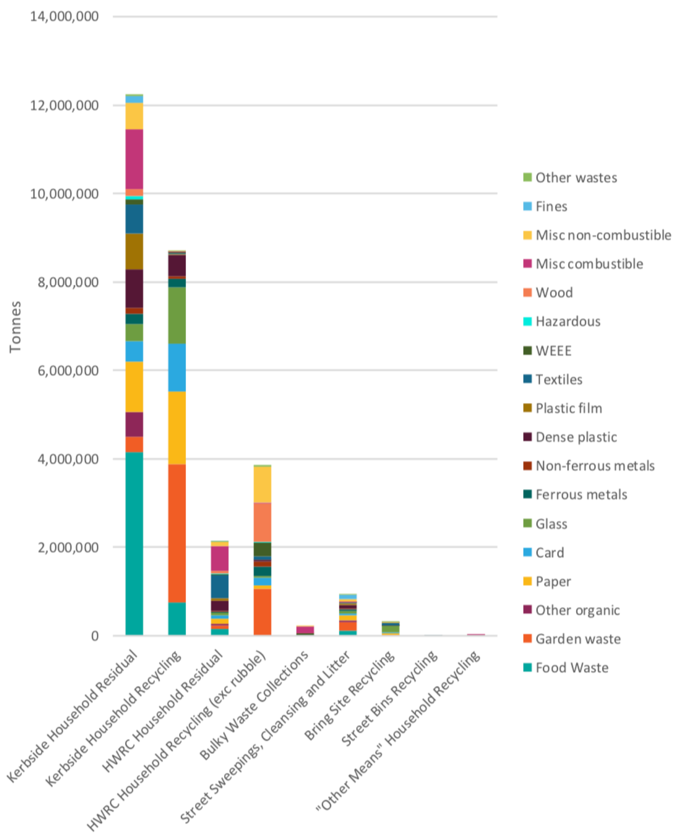


Figure 2.2 National waste composition estimates for the United Kingdom, all household waste and recycling streams, 2017 (in tonnes), (*with permission*, WRAP, 2019)

2.3 Value of the Circular Economy

To recover the economic value embodied in modern waste streams, a relatively complex network of collection, containerisation and logistical options, plus suitable treatment and transformation processes are necessary (Atkinson and New, 1993).

Several organisations have attempted to assess the financial and economic value of the Circular Economy if it were to be adopted as the mainstream system across different jurisdictions and geographies. Roland Berger, PWC, KPMG, EMF (Ellen MacArthur Foundation), et al (EMF, 2015, PWC, 2021, KPMG, 2020, Roland Berger 2019) all compute, model and assess various ways to determine the financial value of the Circular Economy, all arriving at significant consequences.

The dominant share of the value invariably arises from re-introducing discarded materials back into the supply chain and avoiding primary mining and preparation activities largely due to the energy, water and labour costs associated to those raw material production processes. Whilst the inherent worth of the materials within the current economic system plays a major role in determining the value of the Circular Economy it is not the only important financial parameter, since environmental costs associated to landfilling can also be measured in financial terms (OECD, 2011).

2.4 Public Policy

In Europe at least, EU environment policy dates back to the European Council meetings of 1972 where the heads of state governments unanimously agreed to the need for an environment policy to underpin rapid economic expansion. Environmental Public Policy has developed ever since with landfills requiring properly engineered solutions since the 1970s.

To ensure full implementation of European waste legislation, new (or less progressed) EU Member States have been provided with considerable funds for infrastructure projects, with 4.6 and 6.2 billion Euros set aside from EU funds for urban and industrial waste infrastructures for the periods 2000-2006 and 2007-13 respectively (ECA, 2012). However, aged or out-dated infrastructure also exists in the rest of Europe and most of the developed world, partly due to insufficient maintenance but critically also due to the inherent limitations of the technologies applied (Modak et al., 2011), and presents significant new infrastructure needs.

The situation is similar across the UK, as crumbling transport, energy, telecoms and water infrastructures need addressing (Armitt, 2013). Despite some relatively good progress with waste infrastructure delivery due to regulatory targets, it is expected that in the next 20 years, materials, resources and energy security for the country's growing population and the need for renewed industrial growth will create additional 'waste infrastructure needs' (Modak et al., 2011). For example, the drive towards a Circular Economy that boosts global competitiveness, fosters sustainable economic growth and generates new jobs while decoupling economic growth from natural resources, requires infrastructure able to process waste into a resource (Chen et al., 2010).

2.5 Communication & Life Cycle Assessment

To deliver new infrastructure, it is critical to obtain public acceptance of that infrastructure, more so if it is the type of infrastructure that is widespread and, in many locations, as is the case for waste processing. Petts holds that a deliberative process, one where not only the decision is articulated but that the thinking behind the decision is shared and problem solving is conducted in parallel with the public, can lead to better buy in and can exploit local knowledge leading to better decisions. There is some evidence that when sharing wider plans with local representatives the process of achieving development agreements with authorities can be expedited (Petts, 2000, 2001, 2004, 2006).

Media attention has focussed on the evils of plastics in the past few years, effectively demonising what can be a highly efficient material. This dynamic is epitomised with the press around '*more plastics in the ocean than fish*' by 2050 (EMF, 2016), when presented by the EMF at Davos in Switzerland in 2016. Whilst not in itself evidence that plastics are worse than any other material it set in motion a global awareness of waste, and particularly plastics, which has inspired much public debate. The reality of environmental performance of products is complex, seated in their origin (how the raw materials are prepared), their transport, manufacturing into final retail products, the consumption phase as well as the final arising as waste and reuse, recycling or other disposal method. Even for the simplest products this analysis is multifaceted and in most cases the data is not readily available and when it is the process is hampered by temporal difficulties (e.g., which time horizon to consider for landfill emissions), (Albers, 2020). Real environmental performance can probably only be determined by some independent estimation process since otherwise it is commonplace to see converse results from very similar studies which have taken slightly different battery limits for the study (Doan, 2020).

These problems and principles were analysed by reviewing some 72 published papers on life cycle assessment (See Appendix 8) and discussion in Chapter 8, in order to elicit some key themes concerning packaging and its virtues, versus commonly held public or media views.

2.6 Summary

Waste management contributes directly, on average, some 3% to global carbon emissions. Whereas improper waste management can have more acute impacts and contribute above 10% of the greenhouse gas emissions (GHG) of a geography (UNEP, 2018). More widely environmental services, including water and energy services is likely to contribute 10-20% to the relevant climate emissions (Roland Berger, 2019). Considering the forecasts from business as usual, the related carbon emissions and resulting widespread physical impacts on planetary parameters such as sea level and climate, change is obviously required. The system changes required to bring about what is effectively *Ecological Transformation* of how societies, economies, and governments at all levels operate, a phrase coined – for this use - by Veolia in the 2020s (Veolia, 2020).

Carl Sagan (Sagan, 1995), posited in his book *The Demon Haunted World* that our society relies on technology, and with that we have the power over nature which we should heed caution to, and yet we have set up our civilisation with the majority of its citizens without the knowledge required to properly evaluate the usefulness or relevance of those technologies. This paradigm manifests itself when it comes to waste, since citizens tend to question and reject the requirement for recycling and other treatments of waste. In terms of achieving an ecological transformation of commerce, and how to do so, we must gain public support for the technologies required, if they are to initially obtain planning permissions. This transformation is undoubtedly a challenge to achieve since it is the economy of the supply chain. It will require consumers, manufacturers, regulators, policymakers, media, and business all to move together, in alignment and yet each with different costs and implications for their organisations, but nevertheless it is demonstrably critical at a planetary scale.

Chapter 3. Aim, Objectives & Contribution of the Thesis

3.1 Introduction & Aim

The aim of the thesis was to determine for England which policies and regulatory or fiscal tools have shown to be or are likely to prove successful in creating the conditions which facilitate business to develop a circular economic model more widely and as a mainstream activity - a system change for a Circular Economy.

Focusing on solid household and commercial wastes, the scope was to research policies that can deliver infrastructure sufficient in scale and type for the Circular Economy and in terms of public support for these policies to gain political traction. Its research findings could then offer insights as to how to implement these policies successfully considering competing public pressures and future technology developments.

The scope of the DEFRA report is to cover England and therefore the majority of the quantitative research is limited to England, including the valuation of the Circular Economy.

3.2 Objectives

Objectives were established around the required infrastructure, determining the size of the prize (the value of the circular approach), policies either in place or which are envisaged, public perception and potential impacts from new technology, as well as making overall policy recommendations. The rationale for the six objectives reflects the dimensions of the Circular Economy for which the literature indicates there is significant importance for delivery. Breaking down the aim of this Thesis into these manageable portions, we set out the six complimentary objectives linked to the **drivers**, **enablers** and **outcomes** as discussed in Chapter 1.

Objective 1. Determine infrastructure needs for a Circular Economy

Infrastructure, the cornerstone of enabling the Circular Economy, necessitates an estimation of the infrastructure needs. Objective 1 aimed to provide important verification on how much relevant infrastructure was present in the England regions and how much was therefore still needed to enable for a more robust Circular Economy. The initial analysis was conducted in 2014 and became a critique of the 2014 DEFRA approach to infrastructure needs in England, determining why DEFRA had concluded no further infrastructure was needed, when 10 million tonnes was still being sent to landfill. This apparently political decision transmitted a devastating signal to planning authorities and infrastructure developers and financiers – *to stop developing* – and this deserves unpacking.

Some analysis was also latterly undertaken to validate the 2020 actual position with further evidence reviewed. Out of this work emerged a robust methodology for establishing effectively how much infrastructure a given territory needs for a sustainable Circular Economy.

Objective 2. Assess the value created from the transition to a Circular Economy

The Valued created both financially and indirectly via jobs is an outcome of the implementation of the Circular Economy. Objective 2 was to then calculate the financial benefit of the transition to a Circular Economy, based in part on the infrastructure developments suggested, but also more widely across a Circular Economy landscape. Focusing on the England as a case study and using European and UK National statistics on material flows, GDP value of industrial sectors, and material and energy valuations from published indices, the contribution to GDP from using resources in a closed loop system in the English economy was calculated.

The Ellen MacArthur foundation has already determined that the value of the Circular Economy to the global economy was cost savings of €600billion a year and €1.8trillion more in other economic benefits (EMF, 2015), and PWC has highlighted a much wider opportunity of up to $1.8trilllion (PWC, 2021), whereas this work sought to localise this to England and also provide material and sector specific guidance on where the main value might be derived. The number of jobs that could be created from a Circular Economy with resources used in a closed loop system were also estimated.

Objective 3. Determine the role of policy in shaping the Circular Economy and enabling wider systems change

The Policy is considered the principal driver of change for a Circular Economy to commence. Objective 3 was to understand the role of policy in bringing about this Circular Economy. This objective required an investigation into how policy can create the conditions for business to grow a circular approach, taking advantage of synergies between industries and their material flows and considering taxation on virgin materials to level the commercial playing field. The investigation centred on what policies could be adopted to extend landfill diversion beyond the existing levels and to increase the recycling and composting components of the diversion.

Recognising the need for wider systems change for the Circular Economy to emerge, several tools were researched both from the perceptive of the producers and of the policy makers, by looking at DEFRAs most recent Resources & Waste Strategy, 2018, which seeks to implement a range of new policies in answer to the forthcoming EU Circular Economy Directive. Whilst not bound by this post *Brexit*, DEFRA is seeking to stay ahead of Europe believing that these new requirements would optimise the economy overall, shifting the cost from general taxation to producers, particularly under an Extended Producer Responsibility scheme, Deposit Return Schemes supplemented by an HMRC approach to taxation on use of recycled commodities in new packaging. The potential impact of a plastics tax was also investigated as a policy inventive focusing on costs and benefits to the consumer.

Objective 4. Determine the role of public engagement in the Circular Economy transition – Impact of plastic packaging as a case study

Public engagement (a driver), the ability to influence this by demonstrating the health and environmental benefits, as well as the resulting actual or anticipated environmental benefits (outcomes) formed the 4th Objective. The work set out to understand the role of public perception when applying environmental policy. As a case study a detailed review of the life cycle impacts of packaging was conducted by reviewing previous work in this field to establish the science of packaging life cycles and the issues surrounding the communication of the science. The first step was to understand the objective value of different packaging and then how it is portrayed and played out in the media, in a study to explore how policy interacts with science in cases where the subject is highly complex and controversial in terms of communication.

Objective 5. To consider future technology scenarios and trends which may impact policies

Since policy in this field takes decades to enact and deliver it was important to consider technological changes which was adopted as Objective 5. To ensure that the policy recommendations suggested by this research are realistic and that the findings remained up to date with developments in this fast-changing sector, here we considered what impacts will or could rapid technological change have both in the wider environment (digitisation, home working etc.) or within the waste field (gasification, energy) and with respect to the proposed policy frameworks and tools.

Objective 6. Make overall recommendations to decision makers

In order to bring together the work Objective 6 was formulated to provide recommendations that consider policy options, incentives and tools, communication matters, and technology impacts over time to geographies or authorities with an ambition to implement a Circular Economy in their region.

These six Objectives can be mapped onto the Thesis structure as shown in Figure 3.1 overpage.

Figure 3.1 below Maps the thesis structure against the six stated Objectives.

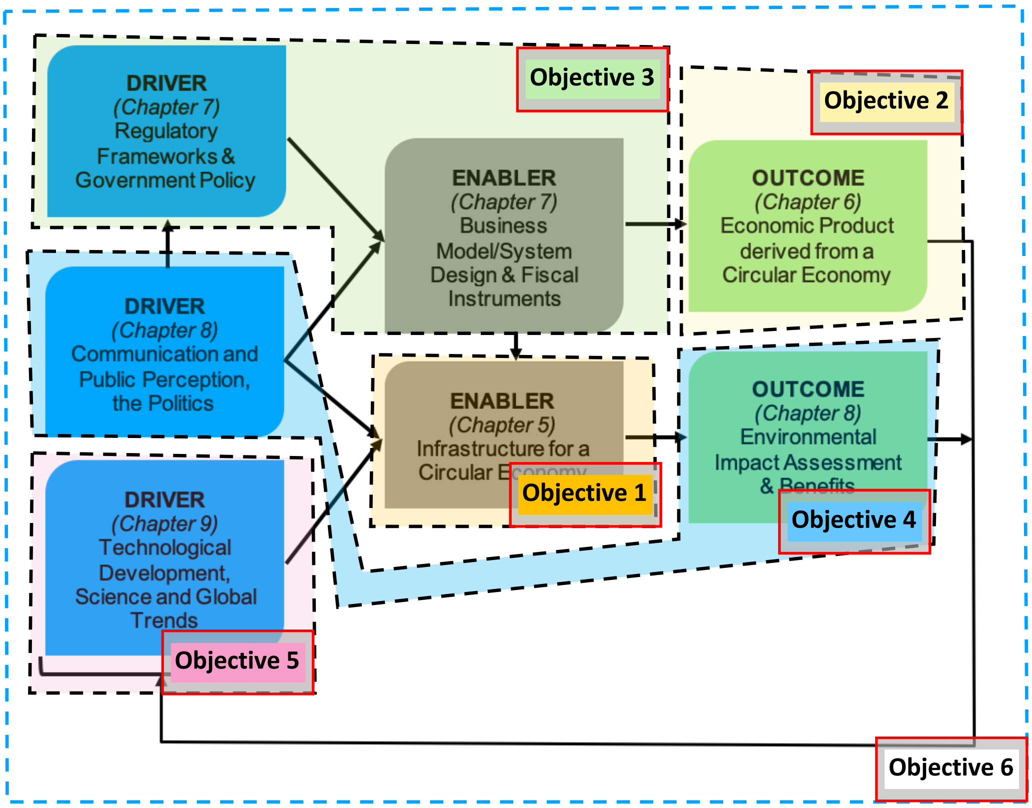


Figure 3.1 Thesis Structure mapped to the six Objectives

<u>Key to Table 3.1</u>

Objective 1 is discussed in Chapter 5 which covers the infrastructure sizing as an Enabler.

Objective 2 is discussed in Chapter 6 which covers the valuation of the Circular Economy as an Outcome.

Objective 3. is discussed in Chapter 7 which covers both regulatory frameworks and policy (Driver) as well as business models and fiscal instruments (Enabler). These two parts, both driver and enabler were discussed together since they are closely linked, for example a policy of introducing a landfill tax, the relevant legislation, and the fiscal instrument itself which imposes the tax and derives a business model are considered as one concept.

Objective 4 is discussed in Chapter 8, which covers Public Perception and Communication (Driver) as well as Life Cycle Assessment and Environmental benefits (Outcome). Again, these two parts are discussed together since the environmental impact is both a factor which initially convinces the public, an enabler of policy, but also an outcome of the intervention itself.

Objective 5 is discussed in Chapter 9 regarding technological development and global trends in that respect (Driver).

Objective 6 is discussed in Chapter 10, the conclusions to the Thesis, which bring all the topics together under a common theme of policy pertaining to the Circular Economy.

3.3 Contribution to the Knowledge Base

The unique contributions of this thesis to the knowledge base have been to:-

Suggest better methods of determining infrastructure needs both at a national level but allowing regional and compositionally relevant technology choices to be made.

By conducting an analysis and critique of the DEFRA approach, where our intention was to understand the method rather than criticise the logic behind the method per se, we were able to determine important criteria for future work in this area. DEFRA as a government body had set out to provide clarity on a very specific point, that is, was there sufficient capacity to comply with the EU Landfill Directive and diversion of biological waste. It turns out this is a very different question to simply is there enough infrastructure and emphasises the importance and relevance of the question being asked.

We determined that there is a lack of infrastructure in geographical pockets of the England, based on composition of waste flows. The infrastructure study has contributed to knowledge concerning calculation of gaps in capacity for heterogeneous waste sources and can be applied in other countries than England to determine suitable infrastructure requirements for chosen ambitions.

Provide a valuation for the Circular Economy in terms of England GDP and Jobs.

The financial value of a transition to a Circular Economy was established for England. We determined that there is an opportunity in England for £32bn of financial value and 175,000 jobs in the sector. We also determined the financial impact of a tax on virgin plastics packaging on consumers and its affordability. The quantification of value at a relatively granular scale for both materials and sectors compared to other work (EMF, PWC) could allow more targeted exploitation by policy makers, regulators, and entrepreneurs in realising that value.

Provide a review of the historical government policies leading to the initial moves away from landfill, and their limitations, as well as the current and future policies in play.

Regulatory frameworks were reviewed, and landfill taxation and separate collection policies indicated that as a blunt policy measure landfill tax kick started infrastructure construction across England, however a limiting factor became the composition and recyclability of materials, which required new policies such as taxation on plastics. This work has also determined potential business interests in supporting the environmental regulation of their sectors.

Contribute to public communications thinking in this field.

The study of public communication actions determined the strategies that have been more successful that others, in terms of transparency and information provision to local communities in order to gain favourable planning determinations in suitable timescales, for key infrastructure. Also, policy was reviewed identifying and flagging the most useful tools of financial incentive (landfill tax) and taxes on commodities use.

The complexity of life cycle analysis was explained demonstrating that there is no clear answer for most items and sensible considerations need to be made, particularly no one material should be singled out since they all have similar impacts.

Understand likely future technology trends that may impact current policy thinking.
Two studies into future visions of technology confirmed that likely future scenarios are in line and run parallel to the policies discussed in this paper. It is likely that the policy frameworks discussed will be more relevant under future scenarios than less. We determined availability of technology and potential futures for industry and technology would support environmentally sustainable developments in recycling, and energy services.

We also established that energy was a recurring concern of industry and business and that arguably the role of energy from waste was linked to the success of policy instruments in energy savings, carbon savings and waste efficiency.

Forecast the likely impacts of the incentives and regulatory tools, suggesting policy that would assist other geographies.
The England government strategy was analysed, and the key pillars were explained in terms of potential impact and success, which was considered high and supported.

3.4 Summary

The overall contribution of this thesis is to provide an evidence-based guide to policymakers, investors, and industry as to the outcomes and benefits of different policy measures with the expectation that they will be inspired to address the ecological transformation of business and industry required to avert the global decline of nature.

Chapter 4. Methodology of this Thesis

4.1 Introduction

The overall aim of this work was to investigate, with a critical theory approach, policy options which are leverage points for the circular system to emerge. It was determined from the broad literature review that *drivers*, *enablers*, and (predicted) *outcomes* would be useful in bringing together the disparate fields of infrastructure, valuation, policy, public perception, and technology. These areas of analysis required different techniques and methods, both quantitative and qualitative which were deployed to complete the work and for each main component of this thesis.

4.2 Methodology of each Component Part

Both quantitative and qualitative methods were deployed. Where it was necessary to categorise, measure and identify a resulting quantum from data, quantitative methods were applied, by and large utilising existing national statistics and published industry figures for England or the UK. For communications, policy and technological progress aspects of the work qualitative research methods gathering case studies, utilising focus groups and interviews allowed the relevant categorisation of the information allowing a hypothesis to develop. The precise methods, rationale, and analysis method for each section of the work are described below.

4.2.1 Infrastructure Requirements Method

Needs: This thesis addressed different elements of a Circular Economy hypothesising that infrastructure is a central theme and primarily addressing what has been built in the past c.20 years and what needs to be built in England in the next c.30 years. In order to establish the infrastructure that is still required, of what type, and in which location is it best delivered the existing principal infrastructure reports were examined, and particularly the DEFRA infrastructure report (DEFRA, 2015), since this report had a significant influence on financing of new facilities, as well as credibility due to its timing and source.

Rationale: The principal assumption of this work is that this infrastructure is central to the success and underpins the ability to cycle materials around the economy, at scale, and by all. Whilst it is recognised that prevention, reduction, refill, and direct reuse are higher in the waste hierarchy (and therefore in principle more desirable), and have an important role, there will be an on-going need to manage material flows in and out of business and households, and this research is focussed on the use of those materials which at some point must be either cycled around or otherwise disposed of.

The infrastructure study herein, Chapter 5, focused on England and a review of DEFRA methods in their calculation methods and confidence in sufficient infrastructure forecasting. The proposition of this work, that infrastructure is essential for a Circular Economy to be established and maintained, recognises that manufacturing can partly be displaced by several "product to service" based switches, which themselves may reduce consumption. However, there is a residual requirement for the right infrastructure and physical assets which deliver products (and/or services) which loop around materials, energy and water which remains coherent with the former concept of avoidance. We considered it appropriate to compute infrastructure needs based on regional and compositional data rather than by a national consolidated method given the local nature of waste arisings and the cost of transport.

Data Analysis: The main evaluation is by simple computation, albeit using a different method to the critiqued method of DEFRA and requiring consolidation and cross referencing of multiple existing public databases on waste arisings. The infrastructure requirements calculation analysis took the form of a review and critique of the DEFRA methodology, followed by an alternative methodology proposed utilising the same background datasets, but applying a regional and waste stream approach. This quantitative alternative comprised of utilising the waste dataflow information at a regional level to build up waste flows for each region of England and designating which waste treatment would be suitable for that material type. National statistics and local authority published data were utilised. A new dataset was introduced, that of the available capacities in each region, obtained from the published Environment Agency registers of authorised waste facilities. The regional arisings (in tonnes per material) were designated to different treatment options based on suitability (acceptance criteria) and compared to the regional authorised capacities. This allowed the shortfalls to be calculated, identified, and subsequently consolidated into a capacity gap for England. The capacity gap was reported as a national figure, however, this analysis provided it at regional levels. The methodology for the infrastructure calculations is described in greater detail in Chapter 5. This process was arithmetic in principle (the arising and the capacity in each region), but overlayed with the new dimension of material type and its suitability to the treatment centres in existence, which was a novel approach.

4.2.2 Financial and Job Valuation Method

Needs: An understanding of the financial and job-related outcome of a shift towards a substantial Circular Economy is useful in convincing both the public and the policy or decision maker that this is a worthwhile goal. Clear, unequivocal, substantiation of the financial value to be derived as a forecast of the impact is an important outcome to ensure policy is delivered.

Rationale: The resulting infrastructure that allows the flows of fuels and materials results in economic products, economic value and jobs and environmental benefits which can be measured or approximated. The literature survey elicited several previous assessments of Circular Economy value which were largely materials or commodities value based. This study reproduced this approach by quantitative analysis of existing national datasets, utilising largely the same materials flows determined in the infrastructure survey. This aspect of the work was unique and allowed a connection to be made between infrastructure and resulting value, as well as high confidence in deliverability since we are sure the materials are available and that the facilities could process them. Therefore, this method linked infrastructure to value of the Circular Economy directly. Furthermore, additional elements of value were assessed, such as product to service contribution, avoidance of tax. Computational methods were deployed for each of the 6 identified vectors, which were selected based on the size of their potential economic size using the national and EU statistics data on GVA. The complexity and scope of the work meant that simulation was not a practical method across all the industrial sectors of interest since it spanned the supply chains. This analysis goes beyond descriptive analysis and seeks to calculate mathematically the financial contribution in £ of six vectors of the Circular Economy.

Data analysis: This thesis considers the value created by and from a Circular Economy in terms of economic product. This was estimated in terms of financial value to the economy as well as direct jobs, given the importance of creating value when setting policy, as realised in England. Several quantitative methods (we call them vectors here) were used to calculate the value of converting wastes back into economic products. GVA or Gross Value Added was used as a common metric across the six vectors of *Tax avoidance, Commodity value, Energy value, Chemicals recycling initiatives, Products to service contribution, and Waste sector contribution*. Tax avoidance was measured by using HMRC data on tax paid for waste streams to landfill and considering the quantities that would be avoided, this determined a financial value in GVA. Commodity value contribution was calculated based on inventories of material types that would be utilised by each industrial sector if they were materially recycled compared to deposited in landfill. Material values were associated to the waste streams and combined to associate a monetary value to the streams if they were to replace raw virgin materials. To account for losses and materials degradation some materials would not be materially recycled but rather be used for energy recovery and thus energy produced from those materials was valued at commercial energy rates in the present market. Chemical recycling initiatives were added to test the significance of chemicals in the product chain since product data suggested chemicals are high value. Whilst important the addition of chemicals was not particularly dominant, and commodities value remained the dominant feature of the results. Products to services comprised a semi-quantitative analysis in that is sought examples of conversions of materials manufacturing to service-based approaches of some significance and success, and then scaled their application to industry and commerce at rates anticipated in the literature. The value contribution of the waste resources sector, which would grow as a result of processing of materials (in addition to their value) was included in the analysis and estimated based on reported industry growth trends. These assessments and estimates were measured in GVA and combined to produce a total contribution of the Circular Economy. The rationale for GVA is justified in the relevant Chapter.

Job estimates were based on previous research by *Friends of the Earth* (Friends of the Earth, 2010), informed by other industry published data, and scaled to take into account the forecasted commodity infrastructure this study predicted.

Some specific aspects of these methodologies for the valuation work are described in detail in Chapter 6.

4.2.3 Policy, Regulatory Frameworks and Business Models Method

Needs: Policy & systemic change tools are required to influence producers, manufacturers, and citizens, and to provide incentives for change. Options were analysed in the context of the latest DEFRA thinking which is taking place in consultation with industry, called the *Resources and Waste Strategy 2019.*

Rationale: The work reviewed how policy and regulation facilitated change, how communication played a role (or not) in the transition across the country and the limitations of current policy, regulation, and business system design. A historical analysis of the past 20 years and assessment of cause and effect of EU and UK policy against England's performance in recycling and composting versus disposal informed a forecasting analysis of the latest policy drivers proposed by DEFRA.

Data Analysis: The policy work was largely based on studying various policy interventions over the past 20 years and by observation of impacts, some minor mathematical calculations where useful, for example of the packaging regulations impact on packagers compared to local authorities, and which was backed up by documentary evidence of where targets were or were not being met.

4.2.4 Communication and Public Perception Method

Needs: It is important to have the public in support, since public discontent with the technologies proposed when determining planning applications and operating permits can be a significant barrier to putting in place the right type of infrastructure (Kirkman & Voulvoulis, 2014).

Rationale: In the context of public communication this thesis explores how to implement the right system, what that looks like in both public policy and business case terms, and what technologies are likely to make up that solution. Looking in detail at the UKs recent developments in policy, will determine whether this could be a vision for the future on a wider global scale.

Data Analysis: Our method then assumes that the communications of policy to the public, in the context of waste infrastructure, is important to delivery of that infrastructure (Kirkman, 2017). The deficit model (Seethaler, 2019) was considered appropriate since it was known to be important in public decision making; it implies we cannot assume that simply more information on a topic will change recipient views. It appears to be more paramount what the existing views, beliefs and drivers are for the people involved, rather than the amount of new information provided. Therefore, principles can be determined in terms of style, method, and delivery of the communication rather than quantity, in soliciting an improved outcome, and they were investigated. A literature review and assessment of significant case studies was undertaken where the case could be assumed to be widely application to the wider economy and where some scaling is evident.

4.2.5 Life Cycle Assessment Method

Needs: We sought to consider public policy and infrastructure delivery through the lens of public perception and what circumstances which may elicit better responses from the public to what are largely environmental objectives and improvements.

Rationale: This work applied 'life cycle inventory' science to the case study of plastics to determine how this plays out in front of citizens through the media, plastics being chosen as a case due to the high public profile of that material.

Data Analysis: 72 papers on Life Cycle Assessment of packaging materials were reviewed and evaluated to determine trends and common conclusions across a wide variety of methodologies. The intent was to determine what is actually the optimal packaging in a given format (drinks container), and what is the public perception.

4.2.6 Technological Review Method

Needs: Technology development in the wider community and industry were investigated seeking to determine global trends that may have an impact on today's policies.

Rationale: This research took the form of direct studies with industry via focus groups and direct interview of expert witnesses (number listed and industry listed in Appendix 10), to consider future trends, modes and types of **technology** that may be relevant to the next 30-year timescale up to 2050. The timeline was based on both the fact that infrastructure can be invested in for a 10-to-30-year period for business cycle financial returns, and also high current attention on 2050 climate change targets for which a Circular Economy will contribute

Data Analysis: This evidence is 'blue sky' and long-term views elicited from academic and industrial experts. These studies considered both municipal and industrial futures considering how citizens may live and how industries may operate and are useful guides to ensure these futures are not blocked by todays polices and solutions or vice versa. Emergent from the technology discussion was the unilateral topic of *energy* which appears to be pervasive in all aspects of the Circular Economy and the work considered scenarios for fuel, energy and materials which are likely to remain an important part of the global economy far into the future.

Chapter 5. Infrastructure needs for a Circular Economy

5.1 Introduction

The objective of this infrastructure study was to critique the 2014 DEFRA study into infrastructure needs for England. We sought to determine why DEFRA had concluded, on the face of it, that no further infrastructure was needed, whilst at the same time industry were reporting that more than 10m tonnes of recoverable wastes were still being sent to landfill in the forecast (DEFRA, 2013d). The DEFRA study covered England, and our work is limited to those regions.

The first analysis provided important verification as to how much relevant infrastructure was present in the England regions and how much was therefore still needed for enabling a more robust Circular Economy. This analysis indicated that England was moving towards meeting the DEFRA targets, which emanated from the relevant EU law, but that there was still at least 11.3 million tonnes of residual and potentially recoverable solid waste going to landfill every year which could generate value as a resource through recycling as a material or recovery as a fuel, aggregate or organic material (compost, fertiliser). Our initial analysis was conducted in 2014, with additional analysis in 2020 to validate the earlier work, which subsequently indicated that whilst some more infrastructure has been developed there remains recoverable waste still going to landfill. In effect, the need for infrastructure persists some 7 years post the signal from DEFRA that sufficient infrastructure would be available at that time.

Important learnings were established in this work to assist future infrastructure analysis elsewhere. It is also important to note that DEFRA sought to deploy policies that would very specifically **meet the Landfill Directive requirements**, and whilst this acts to deter biodegradable waste from landfill, it does not necessarily provide for a robust Circular Economy, albeit it could warrant a critical step in that journey.

Why this infrastructure gap persisted for so long was considered a result of policy drivers and public communications limiting the ability of developers to obtain planning permissions in reasonable time periods. The public policy supported the development of all kinds of infrastructure, but the planning developments were hindered by political interference, particularly for “Energy from Waste” infrastructure. The English regions contribute the larger proportion of UK wastes accounting for some 85% of the 2014 arisings.

In February 2013 (revised in October of the same year) DEFRA published a paper, (DEFRA, 2013d), setting out the analysis used to:

(1) Forecast waste arisings and treatment capacity in England in 2020,

(2) Assess the amount of Biodegradable Municipal Waste (BMW) that goes to landfill.

The purpose of the DEFRA analysis was to judge whether England would meet the diversion levels necessary to comply with the EU Landfill Directive. The Directive dictates that the amount of BMW sent to landfill in 2020 must be reduced to 35% of 1995 levels (i.e., to 10.2m tonnes). The DEFRA report indicated that in the next seven years England would be over-equipped with waste infrastructure, to achieve the Directive requirements. The DEFRA report had the impact of deterring local waste planners, and encourage political interventions, with respect to authorising new facilities. To form a view of the England infrastructure needs we reviewed this work in some detail. An objective of the work was to evaluate how sensitive the DEFRA findings were to the assumptions made and whether the limitations in their approach may restrict their wider application to support decision making. The methodological approach is critical as the potential of the findings to support decision making will depend on the validity of the assumptions and the calculations used.

The framing of the overall DEFRA approach was questioned, and concerns were raised with regard to the limitations in the forecast model used in terms of uncertainty and assumptions adopted, suggesting that their findings could be misleading, particularly when used for the types of decisions for which they provided support. However, rather than directly challenge the result of DEFRA, this study investigated the DEFRA data on waste arisings, not to dispute the underlying figures, but to review the methodology used to estimate capacity needs across England and seek enhancements to the approach.

5.2 Methodology

The DEFRA methodology was studied, assumptions tested, and alternative approaches based on waste composition and geography explored to determine alternative scenarios. The DEFRA assumptions were tested by conducting alternative computational evaluations at a regional level which determined alternative conclusions, the work then went on to articulate why alternative conclusions can be drawn and are they more robust than the DEFRA method. Additional and complimentary study was completed later in 2019/2020 to validate some of the 2014 analysis and to validate that subsequently more facilities have been constructed and that there remained an infrastructure gap despite reductions in total waste volumes. The data collected by Tolvik (Tolvik, 2019a/b) evidenced in some way the validity of the infrastructure study herein, particularly with respect to Energy from Waste infrastructure.

In order to calculate future infrastructure needs, this study considered:

- the **composition** of different waste streams rather than aggregating material types;
- the **regional location significance** of facilities (rather than taking an aggregate of facilities the England);
- the **technologies** necessary to deliver the necessary infrastructure for **different materials**.

Findings demonstrated that considering quantities of materials arising at a regional level was more useful, using compositional data for household and specific waste-streams for Commercial and Industrial sources.

By 2019 more infrastructure had been built and was still planned and yet export of residual waste (albeit lower volumes) still persisted and there remained no overcapacity or detrimental impact on recycling (albeit recycling has plateaued at circa 44%).

The root cause of this, a lack of local infrastructure, appears to enforce that DEFRAs model was flawed in determining the amount of infrastructure that would be needed to treat all wastes effectively for a number of reasons:

1. the data analysis methods were flawed as detailed in this Section, but also
2. many facility developments fail for financial or planning reasons (and so many more developments are needed than final infrastructure required)
3. there is more commercial waste existing than expected which supplements municipal waste
4. DEFRA only considered biodegradable fractions of waste with inherent limitations in the accuracy of that parameter

The outcome of the DEFRA policy direction to stop further infrastructure funding was that export of waste outside the UK continued and diversion from landfill was retarded with more than 10 million tonnes of recoverable waste still going to landfill (in the period 2015). Whilst the policy of deferring new facilities has avoided further PFI (government funds under the Private Finance Initiative subsidy) funding requirements, nevertheless purely private financing initiatives (private debt and equity) has now prevailed in developing additional facilities which continue to develop to take up the slack between landfill and recycling respective of needs and technical possibilities.

The UK is bound by the EC Landfill Directive (99/31/EC) which sets mandatory targets for the reduction of biodegradable municipal waste (BMW) sent to landfill. Additionally, the Government has established national targets for the recovery of municipal waste and recycling / composting of household waste. In order to establish whether sufficient infrastructure treatment capacity is expected to be in place to meet these targets, the need to forecast waste arisings and infrastructure treatment capacity in England in 2020 has emerged. However, such efforts and the on-going discussion as to whether there will be sufficient capacity in England in the future are rather misleading, particularly as they centre around the question of overcapacity or under-capacity of residual waste treatment. For example, a recent report on Commercial and Industrial (C&I) waste, commissioned by the Chartered Institution of Wastes Management (CIWM) (Ricardo–AEA, 2013) concluded that, by 2020, there would not be enough waste processing capacity in the UK. This was contrary to the DEFRA forecasting report (DEFRA, 2013d) as well as other studies, which earlier that year had indicated that in the next seven years England would be over-equipped with waste infrastructure.

DEFRA's forecasting report (published in February 2013 and updated in October 2013) set out the analysis used to forecast waste arisings and treatment capacity in England in 2020, which are used to assess the amount of BMW that goes to landfill and so judge whether England was expected to meet the diversion levels necessary to comply with the EU Landfill Directive. This provided estimates of the likelihood of meeting the Landfill Directive target and the impact from withdrawing DEFRA's provisional allocation of financial support for those PFI projects that were yet to reach financial close. A Monte-Carlo analysis was used (*in the DEFRA research*) that produced a wide range of outcomes including both surpluses and deficits. From these, the probability of meeting the target was estimated. As a result, it was decided to withdraw the provisional allocation of Waste Infrastructure Credits to a few remaining local authority-led projects still in procurement.

Implementation of EU Directives such as the Landfill Directive is affected by changes in the definition of municipal waste. Until recently the UK had used a different definition of municipal solid waste (MSW) from that used in most other EU countries, and included only those wastes arising from households, plus litter and street sweepings, that were collected by the local authority. This inconsistency caused problems in the implementation process. In 2011 the Government amended the definition of MSW to match the EU definition (Table 5.1) and to bring into the municipal waste category those wastes that are similar in composition to household waste but arise from commercial and other sources. To simplify data capture and comparison for the Landfill Allowance Trading Scheme (LATS), a scheme that briefly allowed quotas to be traded into landfill against the Directive, a new category of waste was created – Local Authority Collected Waste (LACW). LACW was formerly called MSW (Municipal Solid Waste), and previously household waste made up around 90% of MSW in England but then reduced to 50% or less using the new MSW definition.

According to the Directive *the amount of BMW sent to landfill in 2020 must be reduced to 35% of 1995 levels, or 10.2m tonnes*. In this context 'Recover' means to obtain value from waste through recycling, composting, other forms of material recovery, and recovery of energy.

Table 5.1 European Waste Legislation targets & the definition of waste

Waste Framework Directive targets: Under the Waste Framework Directive, Member States are currently required to recycle or reuse a minimum of 50 per cent of household waste by 2020. However, what constitutes household/municipal waste has been interpreted differently by different Member States and there is ambiguity about the materials that count towards the target. The Commission recently invited views on issues such as whether to have a single target and calculation method based only on the quantity of municipal waste collected, which would mean that there would also need to be a consistent definition of 'municipal waste'; should targets reflect environmental weightings for materials (for example, through reference to greenhouse gas savings achieved through recycling)?; should recycling targets be extended to include additional waste streams such as wood, food waste and textiles?; should businesses be required to sort a range of waste materials for recycling and composting/anaerobic digestion?	**Landfill Directive targets:** The current target is that by 16 July 2016 the weight of biodegradable municipal waste going to landfill must be reduced to 35 per cent of 1995 levels for each Member State, although ones that were landfilling more than 85 per cent of their waste in 1995 have an extra four years to meet this target. Issues identified by the Commission include the inconsistency of targets between Member States due to differences in their respective definitions of 'municipal waste'; and questions around whether landfill diversion targets encourage disposal (e.g. through incineration) rather than recycling or re-use in line with the waste hierarchy. Possible solutions suggested recently for consultation included: e a single definition of 'municipal waste' (as for the Waste Framework Directive) and establishing a legal obligation for reporting on municipal waste; further tightening existing targets, e.g. moving progressively towards zero biodegradable municipal waste being sent to landfill; introducing targets for the progressive reduction in the amount of residual waste arising (rather than focusing on what to do with it when it has arisen).

The approach that DEFRA and the Welsh Assembly Government (WAG) has taken is to apply the 50% target to an aggregate of all waste from households. Moreover, “Recycling” is defined in Article 3(17) of the Waste Framework Directive as: *“any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations”.*

It is important to investigate whether the information available to decision makers is sufficiently strong and reliable and how underlying assumptions for the findings and for choosing a specific strategy have been tested, so that decision makers can be assured that they are making the best possible choice. This is important in the context both of meeting the legally binding targets as well as maximising the overall delivery of benefits from resource management. The aim of this study is therefore to provide a better insight into infrastructure needs for resource management, testing a number of assumptions and limitations of the forecast method used in the DEFRA report and examining their implications in terms of the report’s main findings (DEFRA, 2013d).

Waste Framework Directive targets: Under the Waste Framework Directive, Member States are currently required to recycle or reuse a minimum of 50 per cent of household waste by 2020.

However, what constitutes household/municipal waste has been interpreted differently by different Member States and there is ambiguity about the materials that count towards the target. The Commission recently invited views on issues such as whether to have a single target and calculation method based only on the quantity of municipal waste collected, which would mean that there would also need to be a consistent definition of 'municipal waste'; should targets reflect environmental weightings for materials (for example, through reference to greenhouse gas savings achieved through recycling); should recycling targets be extended to include additional waste streams such as wood, food waste and textiles?; should businesses be required to sort a range of waste materials for recycling and composting/anaerobic digestion?

Landfill Directive targets: The target was that by 16 July 2016 the weight of biodegradable municipal waste going to landfill must be reduced to 35 per cent of 1995 levels for each Member State, although ones that were landfilling more than 85 per cent of their waste in 1995 have an extra four years to meet this target. Issues identified by the Commission include the inconsistency of targets between Member States due to differences in their respective definitions of 'municipal waste'; and questions around whether landfill diversion targets encourage disposal (e.g. through incineration) rather than recycling or re-use in line with the waste hierarchy.

Possible solutions suggested recently for consultation included: a single definition of 'municipal waste' (as for the Waste Framework Directive) and establishing a legal obligation for reporting on municipal waste; further tightening existing targets, e.g. moving progressively towards zero biodegradable municipal waste being sent to landfill; introducing targets for the progressive reduction in the amount of residual waste arising (rather than focusing on what to do with it once it has arisen).

5.3 The assumptions used in DEFRA's 2020 Forecasting Report

An infrastructure capacity model was developed *by DEFRA* to forecast waste arisings and treatment capacity in England to establish whether sufficient capacity is expected to be in place to meet the requirements of the EU Landfill Directive targets for BMW. The target requires that the amount of BMW sent to landfill in 2020 is reduced to 35% of 1995 levels.

Figure 5.2 below illustrates this process: the forecast level of residual BMW arising in 2020 is compared to the forecast level of residual BMW treatment capacity in 2020; the difference between these two quantities is then compared to the Landfill Directive target.

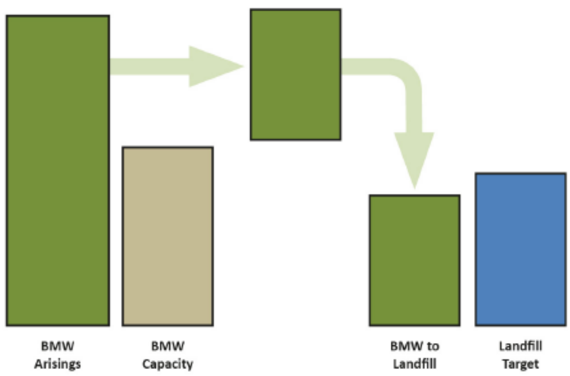


Figure 5.2 Illustration of the model process (DEFRA, 2013d)

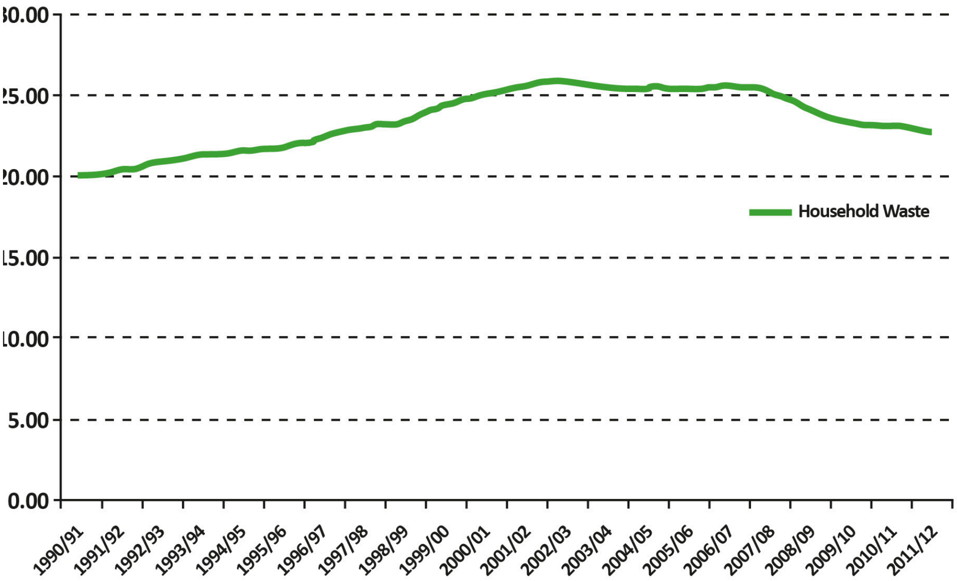


Figure 5.3 Household waste arising data 1990-2012 (DEFRA, 2013b)

Household waste arisings data are taken from, DEFRA's quarterly statistics database from English Local Authorities (LAs) on the waste they collect, treat and where it is recycled or disposed.

Household waste levels have fallen since an assessment of the provisional financial support for PFI projects was published in the 2010 Spending Review 2010 (SR10) (HM Treasury, 2010). In 2009-10 household waste arisings were 23.7 million tonnes. The forecast produced for SR10 predicted total household waste arisings of approximately 23.5 million tonnes in 2011-12, compared with the observed outturn of 22.9 million tonnes in that year, a 3% reduction since 2009-10 (DEFRA, 2013b) (Figure 5.3).

Data for LAC&I waste arisings in England are not regularly collected. The most recent data are from the 2009 *'Commercial and Industrial Waste Generation and Management Survey'* (Jacobs, 2011).

In the 2009 Jacobs survey, arisings were estimated to be 47.9 million tonnes. The municipal component of this C&I waste is estimated to be 24.7 million tonnes (DEFRA, 2013b). At the time of the analysis at SR10, the latest available data was from the previous survey, in 2002-03, which showed LAC&I waste arisings of 67.9 million tonnes. Since SR10 was completed results from the 2009 C&I waste survey have become available. These indicate that LAC&I waste arisings have fallen by a substantial 29% compared to the 2002-03 survey. The 2009 survey data also showed arisings are lower than forecast at SR10. In the previous analysis the estimate for 2008-09 was approximately 56.3 million tonnes of C&I arisings in total, which constitutes approximately 27.6 million tonnes of municipal LAC&I waste (DEFRA, 2013d).

The municipal component of local authority C&I waste (LAC&I) is defined as that which is similar in nature and composition to household waste. Therefore, for both household and C&I waste there have been larger actual decreases in arisings than forecast at SR10.

The approach adopted by DEFRA to evaluate biodegradable waste going to landfill relied on aggregating compositional and regional tonnages across England into a global composition, see Figure 5.4.

DEFRA considered the total amount of waste for industrial, commercial and municipal to contain fixed percentages of a biodegradable component and fixed the amount they were allowed to landfill under EU law, leading to a Landfill Target (of what could be landfilled to be compliant with the Landfill Directive).

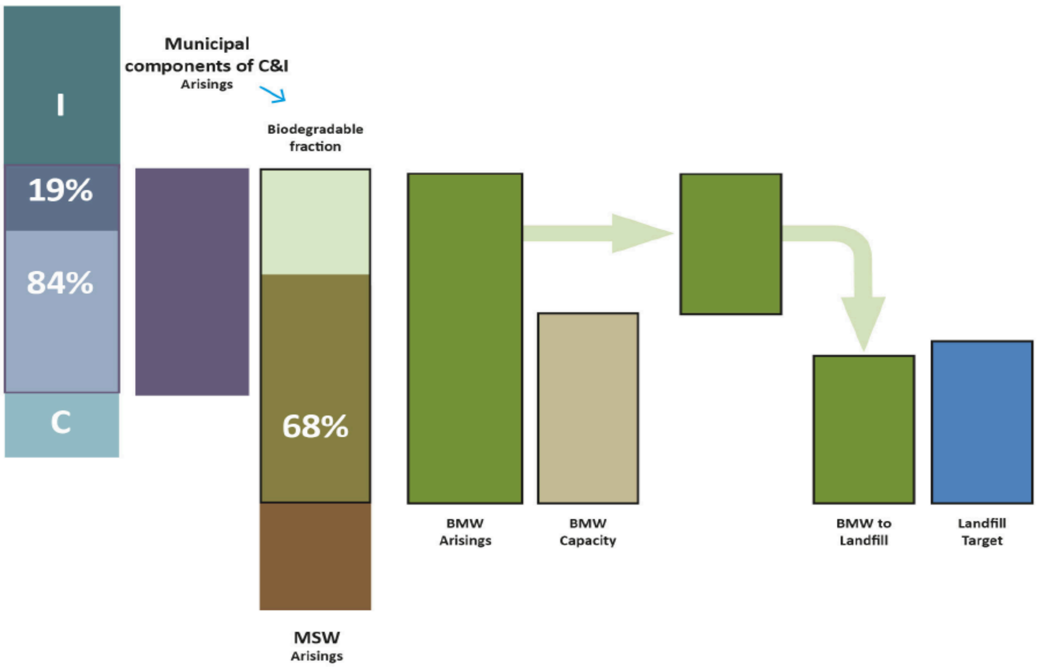


Figure 5.4 The approach used by DEFRA (2013d) to calculate total MSW arising and the treatment capacity gap

The central assumption was that the biodegradable content of municipal waste is 68%. For the year 2020 a range of 55% to 75% was used.

This broad range reflects the fact that the biodegradable content may vary over time and that a shortage of data makes predicting these changes to 2020 especially uncertain. The range was not symmetric, and this was attributed to compositional studies indicating that biodegradable content is more likely to be lower than 68%.

This capacity modelling had the following limitations:

- the biodegradable fraction of MSW (68%) was considered with no further composition analysis that might have enabled distribution of components to appropriate treatment options.

- all treatment capacity required for this fraction was split between EfW (Energy from Waste) and MBT (mechanical biological treatment), whereas other treatment options could also have been considered (as per the previous point above).

- the C&I component of MSW was calculated and then treated as MSW, whereas although it is of similar nature, the composition may be different, with different biodegradable fractions.

- projected capacities were aggregated to calculate total diversion for England, concealing regional differences that could have been useful.

- estimated landfill diversion demand was not corrected by considering the amount of biodegradable waste going to landfill through other routes (e.g., cover materials).

All household waste was assumed to be municipal. The municipal component of C&I waste was estimated using data from the DEFRA 2009 survey as 84% for commercial waste and 19% for industrial waste. For the 2020 municipal content of C&I waste, a range of 79% to 89% was used for commercial waste and 15% to 23% was used for industrial waste. Unlike household waste for which there is data every quarter and where trends can be discerned, the lack of regular data means the municipal content of LAC&I waste in 2020 is particularly uncertain.

It was assumed that the municipal content is equally likely to be anywhere within these ranges. DEFRA forecasted in 2013 that household waste would gradually fall to reach 22.6 million tonnes in 2020. This was given as a central scenario of the modelling, with the minimum and maximum being 20.3 and 24.9mt respectively (Figure 5.5).

Similarly, the C&I component of MSW was forecast to be 23.1 million tonnes (central scenario), with the minimum and maximum scenarios being 20.7 and 26.4mt respectively (Figure 5.6). The likelihood of meeting the 2020 Landfill target was forecast under two scenarios: either with provisional financial support given to all the projects or with support withdrawn for some.

In the latter case, the probability of the projects being successful was reduced. The results are presented in Table 5.7 below. In both cases, overcapacity was projected in 2020. This data was used by DEFRA to adopt the conclusion that it was **highly likely** an overcapacity would exist **with or without financial Government support**, and DEFRA recommended to retract further funding support, which it did.

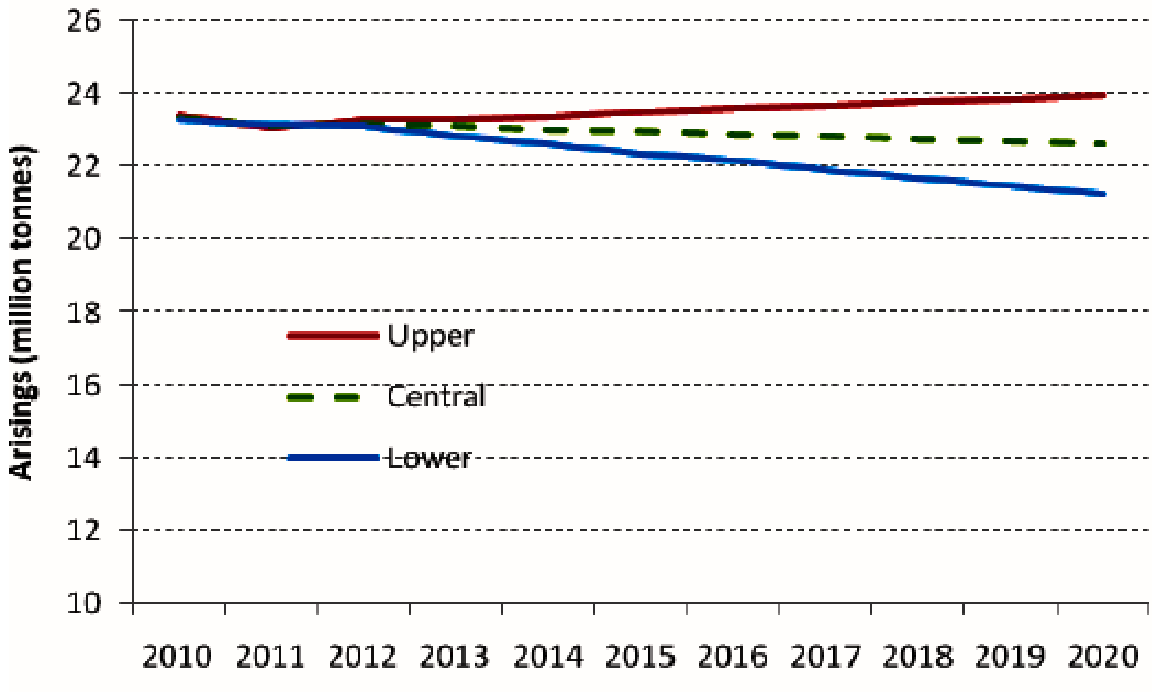


Figure 5.5 Household waste arising forecasts (DEFRA, 2013d)

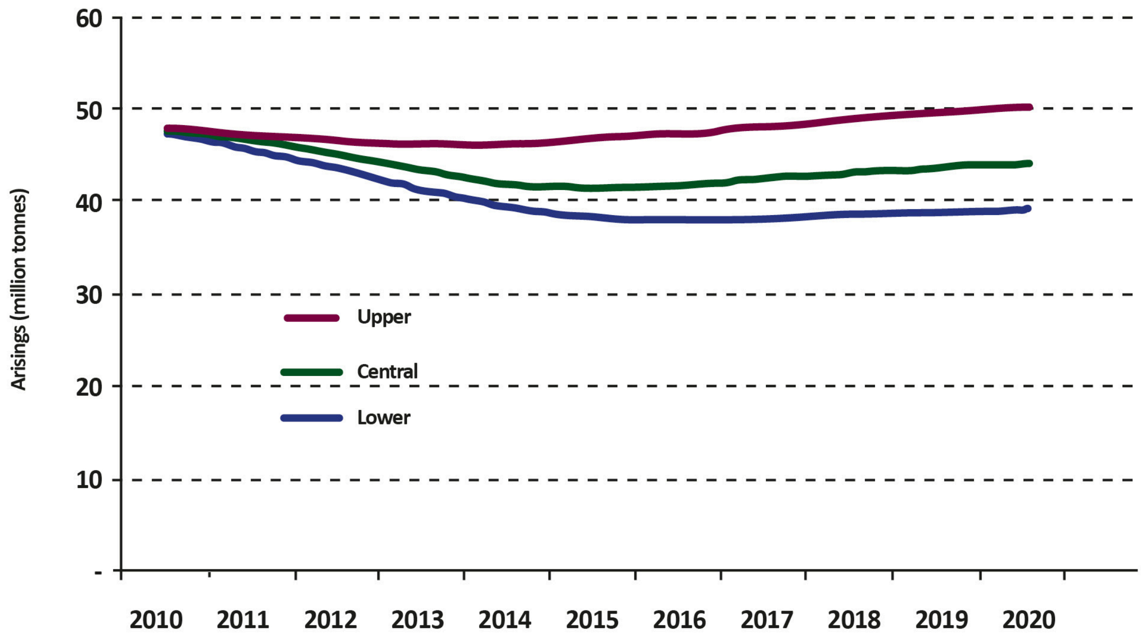


Figure 5.6 C&I waste arising forecasts (DEFRA, 2013d)

Table 5.7 Facility forecasting results in DEFRA's 2020 Forecasting Report (DEFRA 2013d)

Option	Likelihood of meeting target	Average surplus (mt)
Provisional support withdrawn	93.2%	2.1
Support given	95.0%	2.3

Table 5.8 below summarises the assumptions that were used in the DEFRA study (DEFRA, 2013d). By reviewing these and identifying their limitations, it was possible to find ways to address them. Overall, it is suggested that too little attention was paid to the compositional characteristics of the waste which is important in assessing real treatment requirements.

Table 5.8 Review of the assumptions of DEFRA's 2020 Forecasting Report (DEFRA, 2013d) **and possible ways to address their limitations**

Assumptions of Defra model	Addressing the limitations
68% of LACMW was considered to be biodegradable.	The sum of the waste fractions that are biodegradable and could be treated by different facilities.
Targets refer to 68% of LACMW, assuming that it is one well mixed stream.	Targets refer to quantities calculated from the sum of biodegradable fractions of LACW composition.
The municipal component of C&I waste was defined as that which is similar in nature and composition to household waste.	The municipal component of C&I waste is defined as those streams that are similar in nature and composition to household waste.
84% of commercial waste and 19% of industrial waste was defined as the above.	The sum of the above fractions is considered instead.
The biodegradable component of the municipal component of C&I waste is used as 68%.	The biodegradable municipal component of C&I waste is that which can be treated by the same facilities as BMSW.
In summary, Defra treated the household and LAC&I components as one waste, of 68% biodegradability.	This study considers waste composition and matches it to appropriate facilities to identify where exactly any gaps or surpluses are.

Most of the discussion of DEFRA's 2020 Forecasting Report focused on uncertainties, with some concluding that DEFRA's approach should be refined to better reflect the uncertainty inherent in forecasting demand and capacity. For example, although reference was made to the fact that the probabilities emerging from the model were conditional on the data available at the time and were calculated assuming that government had no flexibility to react to new or better future data, this was not taken further or explicitly acknowledged when interpreting the results. This is particularly problematic as the whole purpose of the analysis was to predict whether the EU and Government targets will be met. In other words, even if the uncertainty was not an issue, the findings of this work alone should perhaps not have been used to justify decisions on local authority led projects still in procurement, but instead to trigger the need for Municipal Waste Management Strategy revisions considering the evidence emerging from the work.

Variations between local authority collections, market uncertainties with regard to resources recovery, and even regulatory changes regarding definitions all increase the uncertainty of any stochastic attempt to calculate or predict future infrastructure needs, to the degree that any benefit in doing so, is overshadowed by the potential costs attached to the resulting underestimation or overestimations of those needs.

To be able to understand infrastructure needs in the future, it is necessary to start with understanding those needs now, as it is the difference between the infrastructure now in place and that required in the future that will determine those ‘needs’.

DEFRA and others (Table 5.9) applied the same principle of summing permitted and planned capacities in order to determine national infrastructure needs.

In this approach:

i) it was assumed that waste could be easily and practically transported across the entire country for treatment;

ii) there was a failure to account for the waste composition or the need for different technologies for different waste; and

iii) the data for planned infrastructure included projects that will never be built because there is not enough waste regionally to supply them.

By way of example, there may be a planned facility in the North West (where there is a lot of capacity already), that will never be built, and yet no facility will get planning in the South East as results from the national study indicate that there is sufficient capacity.

A literature review of several capacity studies indicated that for a constant residual waste arising industry considers there is significant volume of residual waste which could be otherwise treated if the capacity existed. Indeed, additionally up to 3 million tonnes of shredded waste (known as Solid Recovered Fuel or Refuse Derived Fuel) is being exported to Europe and further afield for energy recovery purposed (Highway-Higham, 2017).

Table 5.9 References to Capacity Studies

Tolvik continues to produce annual reports on residual waste suitable for energy recovery and variously reports a capacity gap of between 6 to 10m tonnes per annum (Tolvik, 2019 a/b). Tolvik reports are focused on Energy Recovery from residual non-recyclable wastes.

Eunomia, Eunomia conducts regular residual waste infrastructure reviews and calculates that the gap is closing and that by 2030 there will be an overcapacity (Eunomia 2013, 2015). However, there is an assumption that residual waste will drop from circa 25 million to 10million tonnes, a reduction which has not been evidenced in any country to date.

SUEZ's Mind the Gap 2017-2030, predicts a 13.6 to 2.4m capacity gap assuming infrastructure continues to be built at the current pace of investment and construction capacity, and includes all types of infrastructure including new recycling and composting facilities (Hayward-Higham, 2017).

Biffa, The Reality Gap UK residual waste treatment capacity – making sense of the arguments from September 2015 proposes an infrastructure gap of 15m tonnes (Rhodes, 2015).

ESA, UK Residual Waste: 2030 Market Review Final November 2017, Tolvik, 6m tonnes gap (ESA, 2017 a report by Tolvik).

5.4 Addressing the Limitations of DEFRA's Forecasting Approach

The aim of this part of the work was to evaluate how sensitive the DEFRA findings were to the assumptions made in the approach and as to if the possible limitations in their forecasting method might restrict their wider application to support decision making. Calculations have been performed for assessing infrastructure needs, addressing each of the assumptions of the DEFRA approach and developing figures better adapted to the data.

In this study the aim of the calculations was to consider;

(i) quantities of materials arising at a regional level using compositional data, rather than considering all wastes to be the same with agglomeration across English regions;

(ii) forecasting total quantities of material arising and the consequent demand for technologies and facilities;

(iii) with more informed assumptions about how inputs are directed to different facilities (e.g. sorted recyclables go to MRFs, residual material goes to ERFs),

(iv) subtracting from the above the relevant existing treatment capacity, the composition of the waste remaining untreated and the associated future infrastructure treatment needs can be calculated for each region.

Data from 2009/10 was used to calculate how close the predicted values were to the real and known values of a previous year. The year 2009/10 was the period studied by DEFRA, making the results directly comparable. Under the modified definition of MSW, the analysis refers to LACW, Local Authority Collected Municipal Waste, and Local Authority Commercial and Industrial Waste (LACMW and LAC&I). The significance of Collected Municipal Waste is because some households do have arisings of say, green waste, but will treat that at home in home composting, whereas LAC&I is typically commercial wastes from shops or residences that operate a business which fall under the jurisdiction of the local authority to collect and are municipal-like in their compositional make up. LACMW arisings data was sourced from *WasteDataFlow*, while information for LAC&I was taken from the 2009 Jacobs C&I survey. The details of the calculations undertaken in this study are presented in Table 5.10. The assessment of infrastructure needs was performed by first distributing waste streams to suitable treatment options according to their nature in order to determine the treatment requirements, and by further comparing these requirements with available capacity to determine the amount and composition of untreated waste.

Table 5.10 Calculations for estimating capacity needs

1	Data from 2009/10 were used to evaluate the significance and impacts of the Defra study . Under the modified definition of MSW, the analysis refers to LACW (LACMW and LAC&I). LACMW data were sourced from WasteDataFlow, while information for LAC&I waste was taken from the 2009 C&I survey.
2	Using compositional analysis for MSW (Defra, 2009) the various components of LACMW and their respective arisings per region were calculated.
3	Selected C&I waste streams were identified as having a similar nature to MSW: animal and vegetable waste, non metallic wastes and discarded equipment. The total arising for C&I similar to household waste used in this study was 25.4 mt, being very close to the relevant arising used by Defra (24,7 mt). Having the same starting point, i.e. arisings, enables the comparison of the results produced by the two different methodologies. With appropriate LAC&I waste streams being much more homogenous than LACMW, it was not difficult to calculate treatment capacity needs without detailed compositional data.
4	Per region, the treatment requirements per technology for both LACMW and the similar C&I was then calculated.
5	Environment Agency data (permitted facilities to the end of March 2010) were used to calculate capacity for the following technologies in each region: AD, Composting, MBT, Incineration, MRFs, WEEE.
6	Comparing the calculated capacity above (5) to the treatment requirements per technology (4), the remaining (untreated) materials and future infrastructure needs can be estimated.

This analysis took a regional approach. It is suggested that the spatial dimension is critical in order to be able to match offer and demand of materials. Moreover, the location defines the actual local environmental and social impacts. The selection of the most suitable and at the same time environmentally beneficial treatment option depends on the type of material as well as the transport distance for treatment. There is therefore a need to consider what materials are present in each location and where suitable treatment facilities are located. The proximity principle is of importance, and it is not acknowledged in aggregated nationwide assessments.

5.5 Conclusions and Discussion

The findings of this work were to determine that some significant shortcomings in the DEFRA calculation methods could lead to a wide regional and geographical underestimate of capacity requirements which was reflected in the fact that financial funds and waste management companies continued to invest in facilities. This methodological approach by DEFRA could still be considered rational from their viewpoint to distance themselves from further PFI related investment, a poisoned brand*, and to avoid further need for public funding. This study concludes that additional funding for new infrastructure is and will be required as Landfill is reduced over time.

If a Circular Economy is considered important then the valuation in financial terms and jobs was considered a useful factor to determine, in order understand the relative impact on the economy. Furthermore, what technology would be needed or would be prevalent as far out as 2050, would ensure that any policy did not lock out the potential futures.

**PFI- The Private Finance Initiative became a poisoned brand in the UK since some projects concerning the building of hospitals and schools were plagued with media stories citing, inter alia, '£333 to change a lightbulb', whereas no such similar evidence or claims were presented around waste projects which were largely considered to have diverted the required amount of waste away from Landfill and passed the risk to the private sector* (Independent, 2018).

5.6 Materials Arising at a Regional Level using Compositional Data

Compositional information for LACMW (DEFRA, 2009b) was used to calculate the arisings of the various components of LACMW per region (Table 5.11 and Table 5.12). A material specific approach to waste arisings is important to determine what treatment infrastructure is required. The approach in the current study defined the municipal component of C&I waste as those streams that are similar in nature and composition to household waste. This is more flexible and adaptable to regional variation and can then be estimated by calculating the regional arisings on the basis of the data for appropriate waste streams. For the municipal component of C&I waste, the regional arisings were calculated based on information provided by the 2009 C&I waste survey.

The aim was to:

- determine the MSW component of C&I waste arisings by selecting C&I waste types that were of similar nature to household waste.
- obtain a total for the MSW component of C&I waste arisings which would be as close as possible to the figure provided by DEFRA (25.4 million tonnes).

Using similar total LAC&I waste arising as DEFRA would enable the direct comparison of the results produced by the two approaches, highlighting the impact of the different assumptions used.

The C&I survey reported C&I waste arisings in the following waste categories: animal and vegetable waste, chemical sludges, common sludges, discarded equipment, healthcare wastes, mineral wastes, mixed wastes, non-metallic waste and non-waste. In order to address the first objective as stated above, we selected the following waste streams for inclusion in the analysis: animal and vegetable waste, discarded equipment and non-metallic waste. The survey also reported how the various LAC&I waste streams were treated in England. A number of treatment options were provided i.e. landfill, thermal treatment with energy recovery, non-thermal treatment (MBT-mechanical biological treatment), recycling, composting, other thermal treatment (such as clinical waste incineration), land recovery, transfer stations, reuse and unknown.

Only the first five of these technologies were selected as relevant while the rest were grouped as other (some left as unknown). This selection of waste streams and treatment practices gave a LAC&I arising of 25.4 million tonnes for England (as 2009 C&I waste survey excluding animal and vegetable waste and discarded equipment reported as recycled), relatively close to the 24.7mt reported by DEFRA. Waste to landfill only decreased minimally between 2009 and 2010. It fell by less than 2% between 2009 and 2010 and has fallen by around 46 per cent since 2000 (DEFRA, 2013d). One of the principal reasons is considered to be the implementation of the Landfill Directive, the other is probably the financial recession of 2008. Many older landfill sites that did not meet the stringent requirements of the Directive had to close by July 2009 at the latest and diversion targets for biodegradable municipal waste to landfill increase year on year.

Animal and vegetable waste and discarded equipment reported as recycled were excluded from the C&I arisings in this study, as they would most probably not refer to the treatment of dry recyclables, but other practices and facilities not included in our study when existing infrastructure was taken into account. Remaining capacity at landfill sites fell by just over two per cent during 2010. Overall, since 2000 landfill capacity has fallen by 21 per cent. Overall inputs through permitted treatment facilities have increased by over 18 per cent. The main increase was through sites for physical and biological treatment. There was also an increase of around two per cent (81,000 tonnes) in the waste going through composting plants. The arising of LACMW and LAC&I, as well as their estimate combined arisings for England, is shown in Table 5.12 and illustrated per compositional component in Figure 5.13 and Figure 5.14.

Table 5.11 LACMW and LAC&I waste arisings for 2009-10 (‘000 tonnes)

	England	East Midlands	East	London	North East	North West	South East	South West	West Midlands	Yorkshire and Humber
LACMW	26,228	2265	2842	3791	1396	3649	4215	2714	2731	2624
C&I	25,385	2494	2580	3487	1088	4448	3610	2447	2565	2666
Total	51,613	4759	5422	7278	2484	8097	7825	5161	5296	5290

Table 5.12 LACMW composition & arisings (‘000 tonnes) per component and per region

	% of MSW	East Midlands	East	London	North East	North West	South East	South West	West Midlands	Yorkshire and Humber	ENGLAND
Sanitary	2.51	57	71	95	35	92	106	68	69	66	659
Other Waste	2.32	53	66	88	32	85	98	63	63	61	609
Fines	1.66	38	47	63	23	61	70	45	45	44	436
Furniture	1.34	30	38	51	19	49	56	36	37	35	351
Mattresses	0.25	6	7	9	3	9	11	7	7	7	66
Textiles	2.83	64	80	107	40	103	119	77	77	74	741
Misc non-combustible	2.82	64	80	107	39	103	119	77	77	74	740
Food	17.84	404	507	676	249	651	752	484	487	468	4678
Other organic	1.73	39	49	66	24	63	73	47	47	45	453
Garden	14.08	319	400	534	197	514	593	382	385	369	3693
Wood	3.73	84	106	141	52	136	157	101	102	98	977
Misc Combustible	2.37	54	67	90	33	86	100	64	65	62	621
Soil	0.18	4	5	7	3	7	8	5	5	5	49
Paper	16.65	377	473	631	232	608	702	452	455	437	4367
Card	6.04	137	172	229	84	220	255	164	165	159	1585
Glass	6.64	150	189	252	93	242	280	180	181	174	1741
Metal	4.3	97	122	163	60	157	181	117	117	113	1127
Plastics	9.99	226	284	379	139	365	421	271	273	262	2620
Hazardous	0.53	12	15	20	7	19	22	14	14	14	137
WEEE	2.19	50	62	83	31	80	92	59	60	57	574

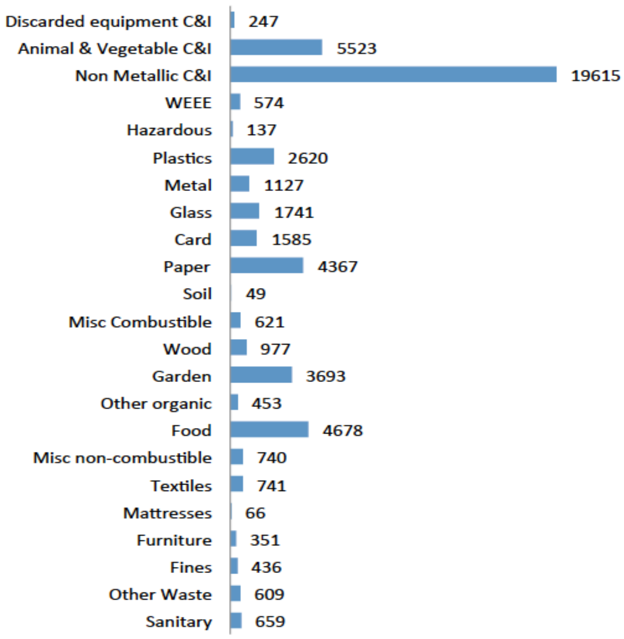


Figure 5.13 Calculated composition of arisings in England for 2009-10 (‘000 tonnes)

Table 5.14 LAC&I waste streams used for the purposes for this analysis ('000 tonnes)

	Animal and vegetable waste	Discarded equipment	Non metallic wastes	Total LAC&I (LACMW alike)
East Midlands	739	21	1734	2494
East of England	581	27	1972	2580
London	640	38	2809	3487
North East	240	11	837	1088
North West	800	32	3616	4448
South East	636	43	2931	3610
South West	540	25	1882	2447
West Midlands	665	26	1874	2565
Yorkshire	682	24	1960	2666
ENGLAND	**5523**	**247**	**19615**	**25385**

5.7 Material Arisings and Consequent Technologies and Facility Demand

The LACMW arisings of the different materials were distributed to suitable treatment options according to a maximum recycling scenario (Table 5.15), producing the theoretical treatment requirements for LACMW (Table 5.16).

Table 5.15 LACMW composition & preferred treatment option according to biodegradability

Treatment option	LA Household waste composition	Assumed biodegradability
AD/Composting	Food	100%
Composting	Garden	100%
AD/Composting	Other organic	100%
MRF	Paper	100%
MRF	Card	100%
MRF	Glass	0%
MRF	Metal	0%
MRF	Plastics	0%
50% recycling, 50% incineration	Textiles	50%
Incineration	Wood	100%
WEEE treatment	WEEE	0%
Other treatment	Hazardous	0%
100% Incineration	Sanitary	50%
50% recycling, 50% incineration	Furniture	50%
50% recycling, 50% incineration	Mattresses	50%
Incineration	Misc Combustible	50%
50% Recycling, 50% Landfill	Misc non-combustible	0%
Landfill	Soil	0%
100% incineration	Other Waste	50%
100% incineration	Fines	50%

Table 5.16 Treatment requirements for LACMW ('000 tonnes)

	England	East Midlands	East	London	North East	North West	South East	South West	West Midlands	Yorkshire and Humber
Recycling (MRFs)	12390	1070	1343	1791	659	1724	1991	1282	1290	1240
AD & Composting	8826	762	956	1276	470	1228	1418	913	919	883
Incineration	4021	347	436	581	214	559	646	416	419	402
WEEE	574	50	62	83	31	80	92	59	60	57
Landfill	417	36	45	60	22	58	67	43	43	42
Total	26228	2265	2842	3791	1396	3649	4215	2714	2731	2624

While the 2009 C&I survey provided the arisings of all the C&I waste streams in each region it did not provide information on how these are managed regionally. At a regional level, the survey did however report how all of the C&I waste was treated in that year. It was therefore possible to determine the regional requirements per technology for all the LAC&I considered in this study (Table 5.17), as well as more detailed information on the regional arisings and distribution to treatment options of each LAC&I waste stream.

Table 5.17 Calculated treatment requirements for LAC&I ('000 tonnes)

	England	East Midlands	East	London	North East	North West	South East	South West	West Midlands	Yorkshire and Humber
Incineration	537	57	55	71	23	91	73	52	56	59
Other residual treatment (MBT)	318	39	33	39	14	47	40	31	37	37
Recycling	12478	1103	1255	1787	532	2300	1865	1197	1192	1247
Composting	447	57	47	53	19	67	54	44	52	54
Unknown	2069	204	211	284	89	357	295	200	211	218
Landfill	5013	487	509	692	215	883	718	483	504	524
Other	4522	547	470	559	196	703	566	440	513	528
Total	25385	2494	2580	3487	1088	4448	3610	2447	2565	2666

The treatment requirements for LAC&I and LACMW were calculated separately in order to assess treatment requirements. The treatment requirements for LACMW were calculated on the basis of compositional information, whereas for LAC&I for which compositional information was unavailable, the requirements were calculated on the basis of how it was managed in that year. The calculated arisings per region are illustrated in the Appendix 2 – Infrastructure Study detailed regional analysis. The results (arisings and requirements) of the separate analyses for LACMW and LAC&I are presented in the figures below. Figures 5.18, 5.19, 5.20, 5.21 illustrate the treatment requirements for LACMW per technology grouping and Figure 5.22 shows the requirements for LAC&I. Overall Recycling for non-metallic waste seems to be the treatment that outweighs the others for all waste streams. This was expected since the C&I waste component that is similar to the household waste was being used.

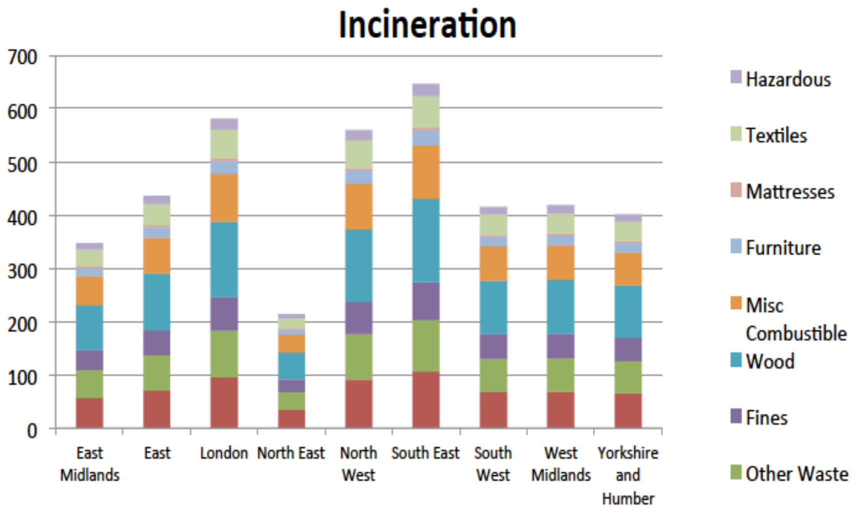


Figure 5.18 Breakdown of LACMW materials requiring residual treatment in 2009/10 per region ('000 tonnes

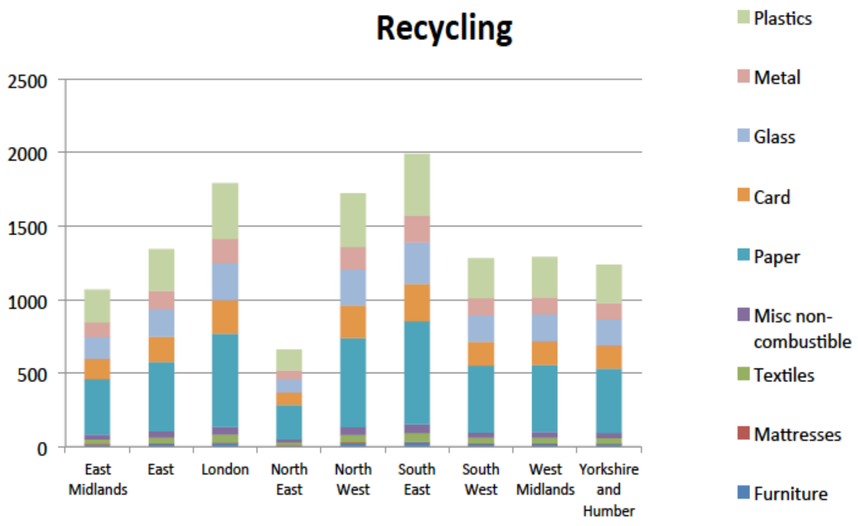


Figure 5.19 Breakdown of LACMW materials requiring recycling in 2009/10 per region ('000 tonnes)

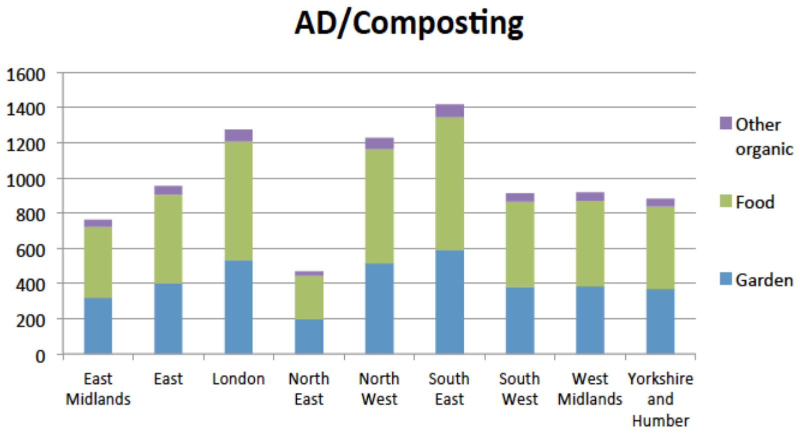


Figure 5.20 Breakdown of LACMW materials requiring AD/Composting in 2009/10 per region ('000 tonnes)

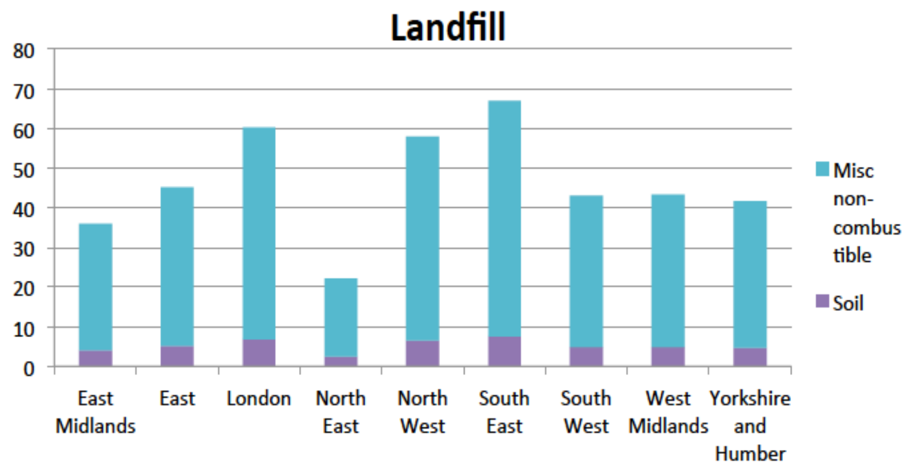


Figure 5.21 Treatment requirements for LAC&I streams in 2009/10 calculated on the basis of how it was managed that year ('000 tonnes)

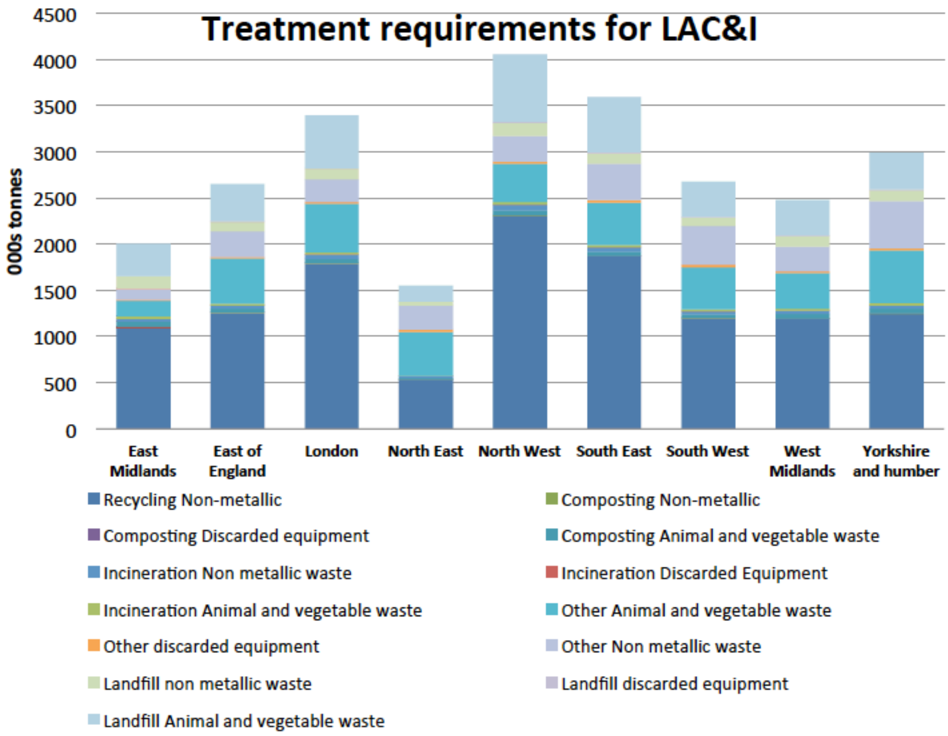


Figure 5.22 Breakdown of LACMW materials requiring landfilling in 2009/10 per region ('000 tonnes)

5.8 Assessment of Infrastructure Availability

The entire waste management system was considered, recycling and residual waste treatment being interdependent. The amounts and types of materials that were recycled inevitably affected the amount and nature of the waste that required residual treatment. The approach that is used by DEFRA is in line with a more general disconnection in the UK in the management of recycling and treatment of residual waste. Recycling infrastructure is dealt with by WRAP whereas residual treatment facilities by WIDP. They are treated as two different things rather than interconnected. The need to link recycling and energy recovery is also acknowledged in a statement by the Environmental Agency for England and Wales: "The number of energy from waste plants needed depends on the rates of recycling and composting achieved, the use of other treatment methods, the growth in municipal waste and the size of any proposed energy from waste plants" (Environment Agency, n.d.).

In the primary study here undertaken in 2014, the existing infrastructure capacity was calculated using EA data on permitted infrastructure at the end of March 2010. The main classification that this database applied was that of main technology types and those that were selected as relevant to the study were: Composting, AD, MRFs, MBT, Incineration, and WEEE. The data were inspected for suitability, for example excluding facilities that were stated to never have become operational or not yet having been built, those that appeared to be treating other types of wastes such as agricultural waste (based on EA database and other publicly available information), or fractions of their permitted capacity for multi-activity sites treating also other types of wastes. The permitted projected capacities were aggregated in order to provide the maximum available capacity for the treatment of waste (LACMW and the selected C&I which is of a similar composition) in that year.

The consolidated results are presented in Table 5.23 and represent the combined capacity for the treatment of LAC&I and LACMW.

Table 5.23 Infrastructure availability as per permitted capacity ('000 tonnes)

Regional capacities/technology	WEEE Treatment	MRF	AD	MBT	Incineration	Composting
East Midlands	507	725	165	125	260	927
East of England	459	1,191	82	415	0	1,195
London	459	1,822	0	562	1,088	353
North East	93	1,100	0	195	375	162
North West	410	1,240	0	541	127	1,214
South East	247	2,449	120	200	1,468	761
South West	212	440	170	150	4	553
West Midlands	308	1,029	5	0	1,140	871
Yorkshire and the Humber	345	555	552	165	431	780
Total	**3,040**	**10,552**	**1,094**	**2,353**	**4,893**	**6,817**

5.9 Infrastructure Treatment Capacity Needs

This study compared the available infrastructure in each region with the treatment requirements for all LACW as the sum of LACMW and LAC&I treatment requirements per technology. The combined picture of LACW – including LACMW and the municipal component of similar C&I - can be seen in Table 5.24.

Furthermore Table 5.25 compares the treatment requirements for LACW with the infrastructure availability for 2010. As can be observed under the maximum recycling scenario there was a deficit in all technologies for that year apart from Incineration. This is reasonable given that this scenario assumes near perfect segregation of materials for recycling and therefore the theoretical minimum quantity of material available for ERF. Currently such effective segregation would be impossible to achieve within any kind of practical affordability envelope due to technological limitations and the difficulties of encouraging effective sorting by households. Further it does not account for the benefits of an integrated energy strategy that includes waste to energy which may limit an authorities ambition to recycle. Finally, it is important to note that this approach underestimates infrastructure treatment capacity requirements as all LAC&I that went to landfill was not included, even if there is great scope to divert some of this in the future.

Table 5.24 Combination of all LACW (LACMW and LAC&I) treatment requirements per technology ('000 tonnes)

		East Midlands	East of England	London	North East	North West	South East	South West	West Midlands	Yorkshire and Humber	England
LACMW	MRF	1069	1342.5	1791	658.5	1724	1991.5	1282.5	1290	1240	12389
	AD/C	762	956	1276	470	1228	1418	913	919	882	8824
	Incineration	336	419.5	560.5	206	540.5	624	401	404.5	389	3881
	Other	62	77	103	38	99	114	73	74	71	711
	Landfill	36	45	60.5	22.5	58.5	67.5	43.5	43.5	42	419
	Total arising LACMW	**2265**	**2840**	**3791**	**1395**	**3650**	**4215**	**2713**	**2731**	**2624**	**26224**
LA C&I	Thermal treatment (energy recovery)	57	55	71	23	91	73	52	56	59	537
	Non thermal treatment (MBT)	39	33	39	14	47	40	31	37	37	318
	Recycling	1103	1255	1787	532	2300	1865	1197	1192	1247	12478
	Composting	57	47	53	19	67	54	44	52	54	447
	Unknown	204	211	284	89	357	295	200	211	218	2069
	Landfill	487	509	692	215	883	718	483	504	524	5013
	Other	547	470	559	196	703	566	440	513	528	4522
	Total Arising LAC&I	**2494**	**2580**	**3487**	**1088**	**4448**	**3610**	**2447**	**2565**	**2666**	**25385**

Table 5.25 Comparison of treatment using data in Table 5.23 & 5.24 (LACW = LACMW+LAC&I) and infrastructure availability or Available Capacity (AC) for 2010 ('000 tonnes)

		East Midlands	East of England	London	North East	North West	South East	South West	West Midlands	Yorkshire and Humber	England
Recycling	**LACW**	2172	2597	3578	1191	4024	3856	2480	2482	2487	24867
	AC	725	1,191	1,822	1,100	1,240	2,449	440	1,029	555	10,552
	Capacity need	**1447**	**1406**	**1756**	**91**	**2784**	**1407**	**2040**	**1453**	**1932**	**14315**
Incineration	**LACW**	393	474	632	229	631	697	453	461	448	4418
	AC	260	0	1,088	375	127	1,468	4	1,140	431	4,893
	Capacity need	**133**	**474**	**-456**	**-146**	**504**	**-771**	**449**	**-679**	**17**	**-475**
Composting - AD	**LACW**	819	1003	1329	489	1295	1472	957	971	936	9271
	AC	1092	1277	353	162	1214	881	723	876	1332	7911
	Capacity need	**-273**	**-274**	**976**	**327**	**81**	**591**	**234**	**95**	**-396**	**1360**
Other	**LACW**	852	792	986	336	1206	1015	744	834	854	7620
	AC	632	874	1021	288	951	447	362	308	510	5393
	Capacity need	**220**	**-82**	**-35**	**48**	**255**	**568**	**382**	**526**	**344**	**2227**
Sum											**17,427**

When the data above is compared with the EA relevant data, for example, on incineration (Table 5.26), for the same year, there is further validation that available infrastructure has been incorrectly calculated, with the surplus on incineration in Table 5.27 probably down to the type of data used (permitting capacity). Similarly, the sum of all regional needs (indicating lack of infrastructure in 2009/10) is equivalent of the amount of LACW that was sent to landfill for the same year (as reported by the EA). This is as expected, since landfill was not included in our infrastructure treatment capacity. This confirmation of regional variation offers further validation for the approach (Figure 5.27). The further comparison of the findings of this approach and the one in DEFRA's forecasting report demonstrate the limitations of the latter approach.

Table 5.26 EA data on actual incineration inputs for 2010 (thousand tonnes) (source: EA waste database)

Incineration Type	North East	North West	Yorks & Humber	East Midlands	West Midlands	East of England	London	South East	South West	England
Municipal and/or Industrial & Commercial*	296	84	383	157	979	0	891	1.236	2	**4.028**

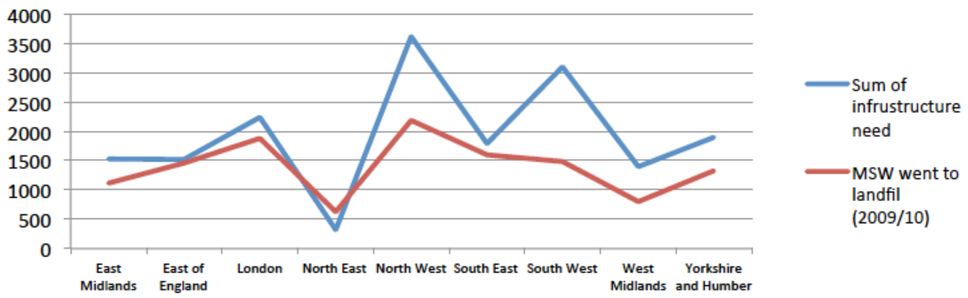


Figure 5.27 Sum of calculated infrastructure need per region in comparison to MSW in landfill (2009/10) (thousand tonnes)

The forecasting approach used by DEFRA clearly underestimated infrastructure needs (see Table 5.28).

Using initial arisings for LACW corrected to the same levels, and applying the assumptions in their methodology, it becomes clear why an overcapacity was forecast, and based on the improvements of the method delivered here, it is evident why it is misleading. With the approach used here, by taking into account that only animal and food waste and non-metallic wastes are biodegradable (100%), it can be calculated that out of the 10.2 million tonnes that can go to landfill according to the EU Landfill Directive, the amount of biodegradable waste totals 4.04 million tonnes allowing another 6.15 million tonnes to go to landfill.

As can be seen in Table 5.28, with DEFRA's approach there is an estimated overcapacity of 3.8 mt by subtracting from the capacity need the BMW that can be sent to landfill to meet the targets. But in this study the initial arising is altered to 46.18 million tonnes (theoretical required capacity) after subtracting the BMW that goes to landfill. Then after subtracting the potential BMW that can still go to landfill to meet the targets (6.15 million tonnes) there is clearly a total deficit in available capacity equal to 11.28 mt.

Therefore, it seems that DEFRA's approach to forecasting may have underestimated capacity needs. In addition, with recycling treatment requirements around 24,867 thousand tonnes and Composting or Anaerobic Digestion 9,271 thousand tonnes for all LACW, this approach ensures that government national targets for recycling / composting of household waste are addressed.

Although non-metallic waste is not 100% biodegradable, at the same time it was assumed the discarded equipment is 0% biodegradable. That way we take the worst-case scenario regarding the biodegradability of those waste streams.

Table 5.28 Comparison of calculated Capacity Gap with DEFRA's approach and that of this study (2009/10) (thousand tonnes)

	Defra approach	Imperial approach
Total LACW 2009/10 arising	51,609 (corrected to the same amount for better comparison)	51,609
Available Infrastructure Capacity (EA Data)	28,749	28,749
Theoretical required capacity	35,094 (based on 68% biodegradability)	46,176
Capacity need (before sending to landfill BMW allowed)	6,345	17,427
BMW allowed to landfill to meet 2020 target	10,200	6,150 (reduced by the amount of BMW already sent above)
Capacity need after landfill (2020 target)	**-3,855 (overcapacity)**	**11,275 (undercapacity)**

To further determine the relationship between treatment requirements and available infrastructure, as a better indication of capacity needs, the types and quantities of materials that remain (after use of existing available capacity) requiring treatment were estimated per region. The results regarding compositional analysis are provided in Appendix 4.

The aim of Appendix 4 analysis was to evaluate how sensitive the DEFRA findings were to the assumptions made in DEFRA's 2020 Forecasting Report and if their approach might restrict the wider application to support decision making. The methodological approach is critical as the potential of the findings to support decision making will depend on the validity of the assumptions and the calculations used. The methodological approach used in this report to address the limitations of DEFRA's 2020 Forecasting Report offers many advantages. First and foremost, this study focuses on regional analysis to determine appropriate infrastructure needs and estimates arisings of waste materials and their treatment needs. Therefore, it helps empower local authorities to make best use of existing infrastructure and determine demand for additional infrastructure. Findings demonstrated that using quantities of materials arising at a regional level was more realistic, using compositional data for household and specific waste-streams for Commercial and Industrial sources.

A more robust approach for forecasting total quantities of material arising and the consequent demand for facilities was proposed that addressed the main limitations of adding different tonnages. A more appropriate method for calculating treatment capacity requirements for each region was proposed. This way, more informed assumptions about how inputs are prioritised to different facilities can be made (e.g. sorted recyclables go to MRFs, residual material goes to ERFs), so that by subtracting the relevant existing treatment capacity from calculated regional requirements, the composition of the waste remaining untreated and subsequent future infrastructure needs could be more reliably estimated. It is important to remember that the provision of treatment plants (location, type and scale) required to address these needs is determined by a combination of factors e.g. the characteristics of the area: spatial density of waste arising, composition of the waste, the presence of manufacturing industries in the area that could recover recyclates and generally the presence of other end users for the outputs of the processes (e.g. energy), and the arisings of different waste streams that could be merged in single treatment.

There is need for integrated planning of household, commercial, business and (where relevant) agricultural wastes. Equally importantly, waste management needs to be integrated with energy strategies to maximise the regional benefits that can be delivered from waste management facilities. This approach can provide economic benefits particularly where waste streams that require treatment are mixed and options for further segregation/recycling are costly and/or likely to perform poorly. Moreover, it will be possible for these facilities to contribute to crucial and legally binding renewable energy generation targets. In DEFRA's 2020 Forecasting Report, the national aggregated figures do not reflect true needs. The assumptions made almost imply that waste can be transferred over whatever distance and to any facility in the country regardless of location, practical constraints and sustainability implications.

5.10 Further Follow Up Work in 2020

The initial analysis was conducted in 2014 and since then facilities had been planned, built and were operating. It was thought useful to look back on the research undertaken and ask the question was there really a capacity gap and had the financial and waste industry developers delivered more capacity in light of actual residual waste volumes arising.

Since around 2016, the consultancy Tolvik had started to compile useful annual capacity surveys and from a review of their literature it is evident that in 2019 more infrastructure had been built since the 2014 study. The capacity was far above DEFRA expectations, and the sector was still growing with planned facilities, whilst export of residual waste (albeit somewhat lower due to the local competition of new facilities) was persisting (Tolvik, 2019a). There remains no overcapacity or detrimental impact on recycling (albeit recycling has plateaued at circa 45%, which is understood to be related to two factors discussed later in this work, first the combination of what is actually recoverable from householders when a Deposit Scheme is not in place, and secondly the recyclability of the materials in the residual waste).

The result of this growth appears to enforce that DEFRAs model was flawed in determining the amount of infrastructure that would be needed to treat all wastes effectively for a number of reasons;

1. the data analysis methods were flawed as detailed in this Section;
2. many facility developments fail for financial or planning reasons, and so capacity does not arise;
3. there is more commercial waste existing than expected to supplement municipal waste;
4. residual waste volumes continue to grow rather than decline according to theories of decoupling which has not arisen.

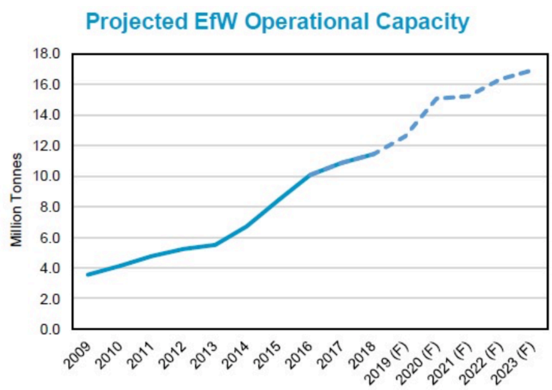
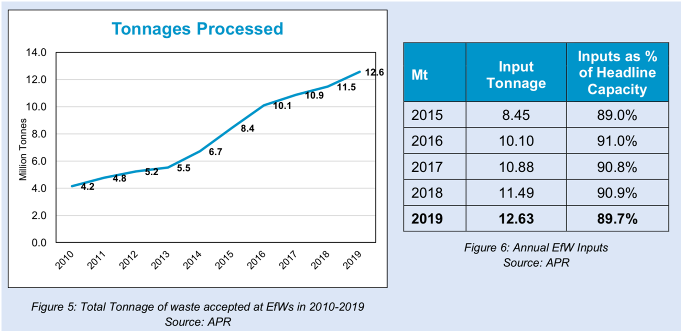


Figure 5.29 Rising EfW operational tonnage capacity (with permission Tolvik 2019a)

The capacity continues to steadily rise even after PFI credits have ended and DEFRA have indicated capacity is not required, as can be seen in Figures 5.29 and 5.30 reproduced from the Tolvik report of 2019(a). Figure 5.29 shows the increasing levels of capacity built year on year, whilst Figure 5.30 indicates a growth from 8.45mt to 12.63mt from our initial study until 2019.



Mt	Input Tonnage	Inputs as % of Headline Capacity
2015	8.45	89.0%
2016	10.10	91.0%
2017	10.88	90.8%
2018	11.49	90.9%
2019	**12.63**	**89.7%**

Figure 6: Annual EfW Inputs
Source: APR

Figure 5.30 Rising tonnages to energy from waste linked to new facilities (with permission Tolvik 2019a)

Further, the available landfilled material which could still be processed usefully via energy from waste and avoiding the negative impacts of landfill appears to remain significant, albeit regionally dispersed, something of importance in the planning of facilities. It is expected that final capacity will be required in the regions that do not have any capacity and are relying on dwindling landfill reserves. Figure 5.31 (Tolvik, 2019a) goes on to demonstrate that whilst landfill diversion continues to grow with the infrastructure growth there is still significant treatable waste remaining. The capacity gap remains despite a growing number of facilities. Based on this evidence we can conclude that the growth in new facilities beyond DEFRA expectations and incentives has saved many millions of tonnes of waste from Landfill, estimated from this data to be circa 11 million tonnes.

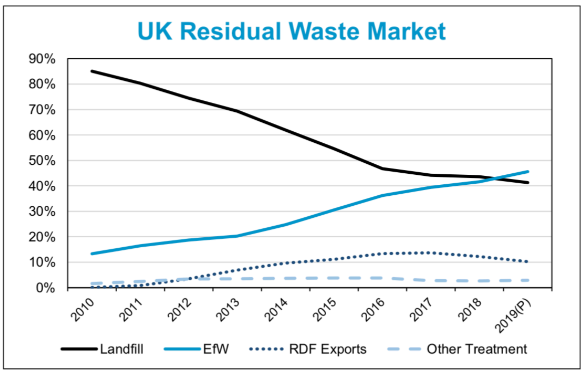


Figure 7: Development of the UK Residual Waste Treatment; 2019 Estimate
Source: Tolvik analysis

Figure 5.31 Landfill versus Energy recovery markets (with permission Tolvik 2019a)

Chapter 6. The value created from the transition to a Circular Economy

6.1 Introduction

Events related to climate and biodiversity decline indicate the world is currently facing an enormous challenge. Demand for raw materials has seen exponential growth with a fast-expanding global population and rising standards of living. Yet the resources on which we all rely are depleting fast. It's time for businesses to wake up to the reality of the throw-away economy and put more value on resources, and for this to happen business needs to see a financial driver, whilst governments need employment benefits.

The case for the transition to a Circular Economy should consider the economic and employment case which if significant and can encourage policy makers to act. The purpose of the Circular Economy is to extend the horizon of sustainable growth given there are physical limits on the world's resources (Daly, 1993). *McKinsey* demonstrated that such an approach could boost Europe's resource productivity by 3% by 2030, generating cost savings of €600 billion a year and €1.8 trillion more in other economic benefits (McKinsey, 2017).

In Australia, which has a similar demographic and waste arising composition to the UK and roughly half the population, a report by PwC determined that the case for Australia to 'go circular' and wholly embrace sustainable solutions could be $1.9 trillion ($1bn) in economic benefits over the next 20 years (PWC, 2021). Despite having half the population of the UK Australia produces more than half the amount of waste of the UK with one of the world's highest per capita waste production statistics. The PWC work embraced a wide net across waste, water and energy resources to capture the potential monetary value. In a report commissioned by the CSIRO (The Commonwealth Scientific and Industrial Research Organisation), *KPMG* estimates that a Circular Economy could provide Australia a $23 billion GDP boost (based on the downstream resource impacts of going circular), (KPMG, 2020). The UK government sized the value to the UK respectively between $9bn and $41bn depending on where the boundary is drawn (either focussed on household or wider industrial wastes respectively) (Defra, 2015).

Due to the large variations, boundary conditions, and potential for value from the Circular Economy this study proposed to use the known flows of materials used earlier in the report and working from the ground up aimed to size the value of the Circular Economy in the UK, across a number of vectors. The 2017 data from Eurostats indicated that from 2004 to 2017 material circularity had improved from 8.2% to 11.2% demonstrating that at that time Circular Economy penetration was relatively low, and further that much more penetration was evident in the metals sector than in the plastics sector, for example, with 21.8% and 2.5% respectively circulated back into the overall economies of those material groups (Eurostats, 2017).

As shown above, the value of a high penetration Circular Economy is predicted by EMF (Ellen McArthur Foundation), KPMG, McKinsey, PWC and others as being of several billion or trillion in value globally and we aimed here to conduct a UK based analysis from the bottom up, looking at material flows, taxes, industrial value and economic usefulness.

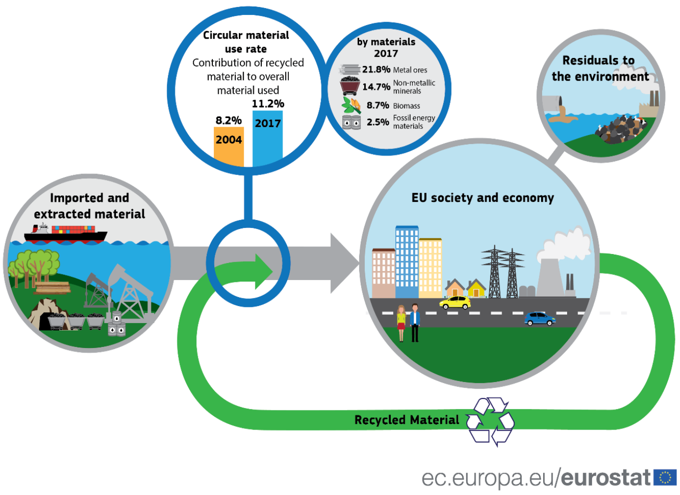


Figure 6.1 Circular Material use rates in the EU, 2017 (Eurostats, 2017)**.**

The approach applied here was to consider how can more material be circulated around the economy (see Figure 6.1) something the EU is now measuring and reporting using a similar methodology to the GVA (Gross Value Added) calculations we make in our assessment (Eurostats, 2017). GVA is a financial value (in this case in £) describing **the amount of goods and services that have been produced**, *deducting the cost of all inputs and raw materials that are directly attributable to that production*. GVA adjusts gross domestic product (GDP) for the impact of subsidies or taxes.

6.2 Methodology - The Circular Revolution

In order to quantify the value that could be created at a England zone level by moving towards a near 100% Circular Economy (i.e. zero to landfill and all materials recirculated to add value in the English economy) this study considered the different industrial sectors and value that could be created from additional materials diverted from disposal. The analysis has been adapted from the previous 'circular revolution' work (Kirkman, 2015). The methodology deployed here was to calculate the value of the waste streams currently being 'wasted' to landfill deposit and escaping the reuse and recovery methods available. Various methods were deployed, described below for each vector, to gain a sizing of the financial value of each contribution as well as job number benefits, and to determine where the main value lies, which would be more useful for establishing policy influence.

The contribution to GDP, as a result of a transition to a Circular Economy, was calculated based on the following **six vectors**, depicted in Figure 6.2. These vectors were considered the most important in that they cover different financial contributions as well as the scope of materials, chemicals and energy, products and services currently lost to the economy, and GVA can be considered to translate into GDP for this purpose. The significance of these six vectors was established from the Office of National Statistics industrial database as well as similar Eurostats which held data on which industries use which material commodities.

Figure 6.2 Six vectors of study for capturing value from moving to a CE

Whilst we recognise that there are alternatives to valuing environmental policy than Gross Domestic Product, such as various sustainability criteria (Raworth, 2017), GDP is a currently accepted tool for evaluating benefits and is most likely to arouse support in business and political decision makers. GDP is calculated by adding up money spent on goods and services, deducting the value of imports, and adding back exports; this includes any money earned through wages and profits, and the value of goods and services produced (UK Government, 2017, Statista, 2021). We adopted the **six vectors** by which the Circular Economy could contribute to GDP, which were aligned with the above definition.

The first direct measure was the **Landfill tax savings** from diverting materials from landfill. Whilst sales tax can be included in GDP, it is not generally considered to be a real Income (since you could increase GDP by increasing taxes and this would not benefit the country). However, in our calculation we consider that in any case reduction of landfilling will reduce the landfill tax receipts and reduce a cost that can otherwise be spent on goods. **Landfill tax avoidance** was measured by using HMRC data on tax paid for waste streams to landfill and considering the quantities that would be avoided, this determined a financial value in GVA.

The second vector is the counterpart to landfilling, that is, the **value of the commodities** and avoided imports arising from not landfilling and instead recycling or composting of those wastes back into the needed commodity (e.g., cardboard back to cardboard). These cycled materials are being used again to create a secondary value from the originally arising raw materials. **Commodity value contribution** was calculated based on inventories of material types that would be utilised by each industrial sector if they were materially recycled compared to deposited in landfill. Material values were associated to the waste streams and combined to associate a monetary value to the streams if they were to replace raw virgin materials. **The value of commodities and imports** were derived from the UK and EU government data on commodity quantity and value, as well as the waste arisings from Chapter 5 established as the England arisings. Data was extracted from these databases, sorted into material types, valued and aggregated by industrial sector.

A second part of the diversion from landfill, and vector three, is founded on the basis that not all diverted materials can be turned into material commodities due to quality or degradation and therefore the next best option is to convert those **materials into energy**, that energy has been calculated as displacing other energy resources and again creating secondary value from waste. **Energy produced** from those materials was valued at commercial energy rates in the present market.

The fourth vector was focussed on a high value area of the economy, that of **chemicals**. The chemicals industry contributes some £18bn (Statistica, 2021) to the England economy, circa 1% of GDP and in that respect is significant, particularly when you consider that GDP growth is usually targeted in the order of magnitude of 1-2% per annum. Whilst chemicals have been carved out of a much wider economy this is justified by the high value and used to demonstrate the order of magnitude value we can attach to such sectors. **Chemical recycling** initiatives were added to test the significance of chemicals in the product chain since product data suggested chemicals are high value. Whilst important the addition of chemicals was not dominant, and commodities value remained the dominant feature of the data.

The fifth vector is conversion of a **product to a service**, that is switching to models of reuse rather than primary production and offering up services rather than products. This can create value if the service incurs less costs than the use of repeatedly using raw materials, which may require imports, again which are deducted from GDP. **Products to services** was a semi-quantitative analysis in that is sought examples of conversion of materials manufacturing to service-based approaches, and then scaled their application to industry and commerce at rates anticipated in the literature.

Finally, we calculated the value created by the current **waste management sector (landfill,** in disposing of waste) which would be removed should we reuse these resources and added back in the new **resources-based sector** which would facilitate closing the loop in delivering the infrastructure, services, jobs and value creation to the GDP. The sorting, cleaning, and manufacturing of wastes back into industrial feedstocks is expected to yield a much higher contribution to GVA than the relatively low complexity 'agricultural' activity of landfilling, which largely constitutes pollution control processes (groundwater protection liners, gas and leachate collection, aftercare). **The value contribution of the waste resources sector**, which would grow as a result of processing of materials (in addition to their value) was included in the analysis and estimated based on reported industry growth trends. **Contribution of the Waste Management Sector** was semi-quantitative and based on industry published figures cross referenced between several industry sources.

These 6 vectors capture landfill losses directly, value of commodities on the market but go further to ascertain the value of energy, chemicals and products turned into services. This was achieved using data from material categories that were available from the UK national statistics office. These assessments and estimates were measured in GVA and combined to produce a total contribution of the Circular Economy.

The perspective in mind whilst conducting these calculations, assessments and inferences of value was to assemble a % GDP contribution and test its significance. Since Growth rates of 2-3% are considered very good for GDP any contribution >1% would be a significant contribution to this target.

Job estimates were based on previous research by *Friends of the Earth* and scaled to take into account the forecasted commodity infrastructure this study predicted.

6.3 Which resources were selected, and why?

The materials selected were those that most closely matched the arising waste streams which were analysed in the infrastructure study of Chapter 5, to ensure that these materials would indeed be readily available.

The analysis focused on generating value from commodities from households and commercial and industrial sources, in England amounting to 30% of total resource flows. The remaining 70% of all resource flows in England were from sectors such as construction, mining and quarrying, agriculture, forestry and fisheries where the waste flows are largely applied to land, stored or which are already contributing to GDP.

The majority of primary data was taken from Eurostat for 2012 (Eurostat, 2012) and the UK Office for National Statistics, *Regional economic activity by gross value added (balanced), UK: 1998 to 2017* (ONS, 2018). The methodology to calculate each category value was dependant on the category and is described in the results below.

Manufacture of food products; beverages and tobacco products	Manufacture of other non-metallic mineral products
Manufacture of textiles, wearing apparel, leather and related products	Manufacture of basic metals and fabricated metal products, except machinery and equipment
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment
Manufacture of paper and paper products; printing and reproduction of recorded media	Services (except wholesale of waste and scrap)
Manufacture of coke and refined petroleum products	Electricity, gas, steam and air conditioning supply
Manufacture of chemical, pharmaceutical, rubber and plastic products	Household waste

Figure 6.3 Material resources considered

This analysis focused on the above household and commercial & industrial resources in Figure 6.3, extracting that data from the ONS (office national statistics databases) to size the potential monetary value of an English Circular Economy.

6.4 Results of the Analysis

(i) Landfill tax savings: £0.975 billion

In this analysis we considered the landfill taxes paid per tonne in **2015-16** (£2.60/t inert, £82.60 active wastes), multiplied it by total waste flows to landfill, (inert at 10mt, active at 11mt) which matched reported landfill tax receipts for that financial year, at around **£0.935bn** (HMRC, 2021). We assume for this tax previously paid on resources lost to landfill can now be circulated back into the economy, boosting GDP. Additionally, part of the aggregates tax of $2/t could be mitigated. Receipts for the aggregates levy (a levy on mined quarry materials used in construction) were circa £350m in 2015/16 (HMRC, 2021). In this study of value, we assume circa 20mt of aggregate type energy sector inert materials are repurposed as aggregates which would reduce tax on aggregates by $40m bringing the total tax saving, and resulting GDP contribution, to **£0.975bn**.

(ii) Values of commodities and imports: £22.6 billion

Of the 72mt considered here 45.9mt of commodities can be recycled into Englands economy amounting to a value of £17.5bn based on individual material average commodity values. Likewise, reused materials also reduce the reliance on imports and can be exported if they are in surplus. The three largest material values in the imports displaced are mixed metals (£10.7 billion), plastics (£2.3 billion) and wood (£2.1 billion).

The value in £'000 of materials extracted from C&I and household resources, which reduce imports, is presented below. The figures are based on manufacturing (except machinery); electricity, gas, steam, air conditioning supply and services (except wholesale of waste and scrap). This reflects the high price scenario of commodities (Figure 6.4).

As imports are subtracted from GDP calculations, the commodities recirculated from these waste streams can be used to replace those imported materials and would contribute towards GDP. For commodities with a surplus it is assumed these can be exported to the same value. The net positive contribution to Englands balance of payments is an additional £5.1bn based on 13.7m tonnes considered.

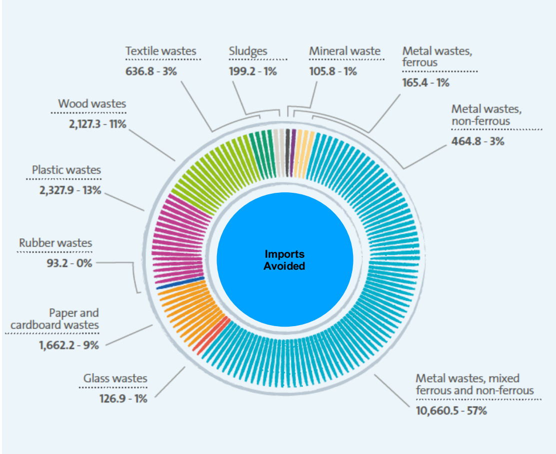


Figure 6.4 Material valuation of imports avoided (13.7m tonnes)

(iii) Energy values: £1.1 billion

Materials that cannot be reprocessed into commodities and are combustible (23,774,273 tonnes from earlier analysis on feedstocks across England) can be used to generate electricity, subsequently valued here at a conservative retail value of 10 pence per kilowatt-hour. The calculated valuation is estimated in Figure 6.5, for mixed ordinary waste and mixed organic wastes, representing what would be treated and recovered by **energy recovery (incineration)** and **anaerobic digestion energy recovery**.

Flow	Tonnes (2012)	kwh/tonne	Value/tonne	Value £m
Mixed ordinary waste	16,848,761	550	55	927
Animal and mixed food waste, vegetal waste	6,925,512	300	31	215
Total	23,774,273	-	-	1,142

Figure 6.5 Energy valuation

(vi) Focused chemical initiatives: £0.9 billion

Used chemicals such as spent solvents, acid/alkaline wastes and used oils are predominantly treated in hazardous waste treatment processes (consolidation, mixing, neutralisation) and then deposited in landfill as inert sludges. These materials, if segregated at source, could be reprocessed to generate an estimated value of between £415 million and £888 million per annum (Eurostat, 2012). In this valuation exercise, deriving the value from the unwanted chemicals and resources produced by an industry was included as a separate initiative, to demonstrate hidden value. We have estimated the value of four significant chemical waste streams: *spent solvents, acid/alkaline wastes, used oils and other chemicals*. The value is based upon the retail price point of common chemicals, for example ammonia. The calculations for England produce a value range between £415m and £888m per annum. Most of this value lies in the chemical, pharmaceutical, rubber and plastics sector (£137m to £292m) and the manufacture of basic metals sector (£58m to £124m). The analysis is based on current, 2012, production rates and does not account for further process and technology efficiency or chemical obsolescence from technology change.

(v) Products to services including imports: £3.2 billion

A defining feature of the Circular Economy is a move towards businesses offering a service rather than a product, which can be used to extend the valuable life of commodities (by distributing their use more effectively). One of the options for a more Circular Economy is changing the business models, by shifting from selling a product to offering a maintainable service. In this report, we have used this transition from products to services as an additional way of recovering value from commodities.

Figures on waste reduction are partly delivered by system or manufacturing efficiency and partly by the move to more reliable equipment (e.g., longer use of a domestic washing machine, repair of a mobile phone etc.). Based on 2004 to 2011 trends waste arisings have shrunk by 20%. EMF suggest that around 50% of waste reduction can be provided from product to service actions. We assume here that 10% of the future waste reductions will be achieved from product to service offerings. Our calculated figure consists of the flows (commodity and energy) not consumed by a switch to services (4.9mt, value £2.3bn) plus the reduction in imports that can be replaced by products and services amount to 2.4mt with a net benefit to balance of payments of additionally £0.9bn. This presents a value of P2S (products to services) of £3.2bn. Clearly, this would be impacted by the uptake of such service-based schemes to replace repetitive consumption, however, incentives would be provided, and case studies are more numerous over time.

Case studies exemplifying products to services include a diverse range of companies and products with some examples in Figure 6.6.

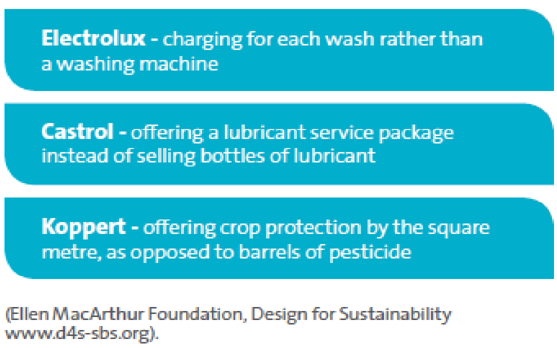


Figure 6.6 Case studied of products as services (Ellen MacArthur Foundation, 2015)**.**

(v) Contribution of waste management to the Circular Economy: £3 billion

We aimed here to test these estimates in terms of the net value of growing the Circular Economy which we believe would require a reduction in jobs at landfills and a growth in manufacturing type jobs which are more numerous and valuable per tonne of waste.

Our analysis determined that the value of the English Waste Management sector is up while the volume of waste is down suggesting an increase in Gross Value Added (GVA). Between 2004 and 2012, an additional £2.2 billion in value was added.

Using Eurostat figures for 2004 and 2011 (Eurostats, 2004, 2011), this analysis finds that the value of the Waste Management sector in England has increased while the volume of waste has decreased. This suggests an increase in the GVA (Gross Value Added) per tonne of waste for the waste management sector. Total waste has decreased from 298mt to 239mt, while GVA in the waste management sector has increased from €12.9 million to €13.1 million. GVA per tonne has increased from €43.2 per tonne to €54.9 per tonne. Comparing 2011 with 2004, the additional value is calculated to be €2.8 billion, or £2.2 billion with 2014 exchange rates, as shown in Figure 6.7.

Projecting GVA increases over time suggests a value of £3bn is sensible for additional value from the Circular Economy being expanded to all waste flows.

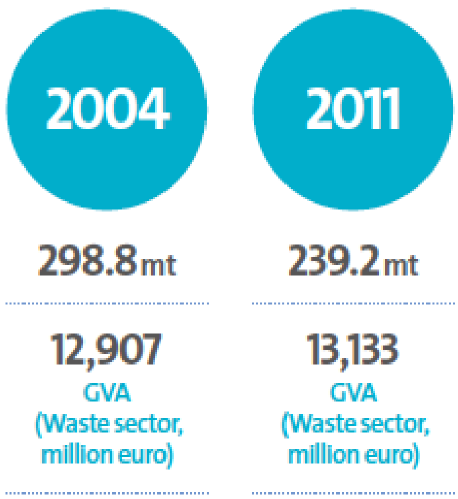


Figure 6.7 Estimation of existing market value

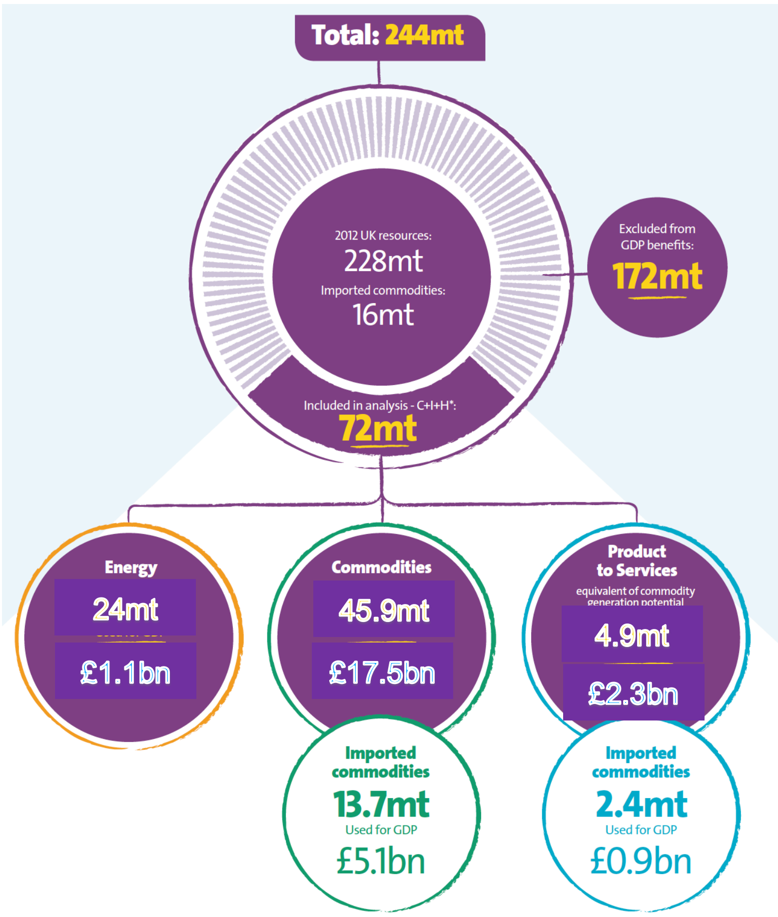
It is estimated, by DEFRA, that the core waste sector generated £6.8bn in GVA and supported 103,000 jobs in 2013 (HoCEAC, 2015). This is a conservative estimate scoping the waste sector based on the visible landfills, recycling centres and composting sites and excluding what may be relevant in the automotive and oil sectors where significant industrial recycling occurs.

It is also reported by the sector trade association that a Circular Economy, where England increasingly re-uses and recycles the resources it already has, could help generate 50,000 new jobs with £10bn investment, boosting GDP by £3bn (ESA, 2013).

6.5 Conclusions

The total commodity resources of England (Figure 6.8) consist of 244 million tonnes (mt) of material. This is comprised of 228mt of domestic resources and 16mt of imported resources. The 30% (72mt) included in this analysis focused on commodities from **commercial, industrial and household** sources. Of this, 23mt was generated from the energy sector, 1.8mt from commercial and industrial sources and 43mt from household sources.

Imported commodities accounted for 13.7mt of household sources. These could potentially be avoided by closing the loop on material wastes produced across England. The value of Products to Services was also analysed and calculated out to 4.9mt. The remaining 2.4mt of imported resources could be reduced by adopting products to services initiatives.



*C: Commercial Sources I: Industrial Sources H: Household Sources

Figure 6.8 Commodities & Energy summary valuation

To determine which sectors were more likely to be impacted or benefit from a more Circular Economy it was useful to investigate what share of value may be attributed to each sector. This may help levers and incentives resulting from policy be more prioritised. Analysis of GVA and waste generation of sectors illustrates the importance of sector activity for waste generation. Certain sectors hold more value in their non-utilised resources compared to others in terms of their share of the GVA pie (Figure 6.9). Resource flows in the economic sectors are not uniform, and thus the benefit (additional GDP) is not directly linked to the GVA value of that sector. The manufacture of coke and refined petroleum products, electricity, gas, steam and air conditioning supply, and services sectors yield lower values based upon their actual waste generation than that of their GVA ratio.

Sectors UK	GVA 2011 (£m, Eurostat)	Total waste kt	Value calculated from sector share of total GVA*	Value calculated on actual flows**
Manufacture of food products; beverages and tobacco products	19,925	3,294	299	464
Manufacture of textiles, wearing apparel, leather and related products	3,685	474	55	161
Manufacture of wood, paper, printing and reproduction	9,502	2,160	143	733
Manufacture of coke and refined petroleum products	2,438	189	37	87
Manufacture of chemical, pharmaceutical, rubber and plastic products; other non-metallic mineral products	29,763	4,343	447	805
Manufacture of basic metals and fabricated metal products, except machinery and equipment	14,051	2,144	211	1,317
Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment	27,516	732	413	587
Electricity, gas, steam and air conditioning supply	15,719	4,965	236	64
Accommodation and food service activities	32,905	3,415	494	423
Retail & wholesale	136,634	10,528	2,053	5,599
Public administration & social work	157,015	3,303	2,359	1,757
Education	76,115	1,693	1,144	900
Transport and storage	53,271	2,502	800	1,330
Other services	586,961	6,174	8,818	3,283
Totals	1,165,500	45,916	17,509	17,510

* This figure represents the value of a sector's waste resource flows if the total waste value was distributed among sectors

** 'Value calculated from actual flows' is the value of Commodities, Energy and Chemical Initiatives

Figure 6.9 Sectoral analysis of GVA and waste generation

Clearly, retail, food, transport, metals, chemicals and the public sector have high potential value.

6.6 Jobs Contribution

There were an estimated 103,000 jobs in the sector in 2013 (HoCEAC, 2015), and David Palmer-Jones CEO of Sita UK, one of the largest waste companies at the time estimated an additional 50,000 jobs would come of the development of the full Circular Economy. We conducted some calculations of job numbers which might be gained from recycling of materials from English (Commercial & Industrial) C&I and Household waste flows, where facilities are required to undertake sorting, and mechanical and biological treatments, all of which would require more skilled labour than currently existed in the sector. Using values from the report **More Jobs, Less Waste*** (Friends of the Earth, 2010), this report estimates that 175,000 jobs will derive from implementing Circular Economy principles. This is based upon recycling of certain materials, does not cover all materials or aspects of this analysis (such as products to services or energy recovery), and is thus very likely to be an underestimate. Using circa 27mt tonnes of materials maintained the consistency with earlier analysis as the amount of commodities that could be additionally circulated each year from the household stream (and were the flows requiring mechanical treatments, compared to 23mt of energy flows and 20mt of inert material flows which would require less manual labour.

6.7 Summary

When we set about these calculations, we were convinced that there were gains to be made from English businesses thinking more circular. However, the findings have far exceeded our expectations of the contribution that the Circular Economy could make in terms of GDP and employment. £32 billion (Figure 6.10) and 175,000 jobs (Figure 6.11), with concentrated opportunities in the plastic sector, makes a compelling business case for change.

The opportunity is there for business to benefit from designing products to take into account a second and third life and better supply chain pricing as the quality of secondary recycled materials becomes business critical. By promoting greater resource efficiency, we can help manufacturers protect their own supply chains and stimulate a growth in the market for recovered materials. Case studies that highlight some of the ways that this can be achieved to preserve resources and grow the economy through closed loop thinking.

The different elements of the 6 vectors were assembled to provide an aggregate financial value. Figures 6.10 and 6.11 above provides an overview of the materials and the jobs derived from their recycling. Businesses around England are taking action to implement strategies that are underpinned by circular approaches on a positive business case, meaning a System is in place which at least in part incentivises the Circular Economy.

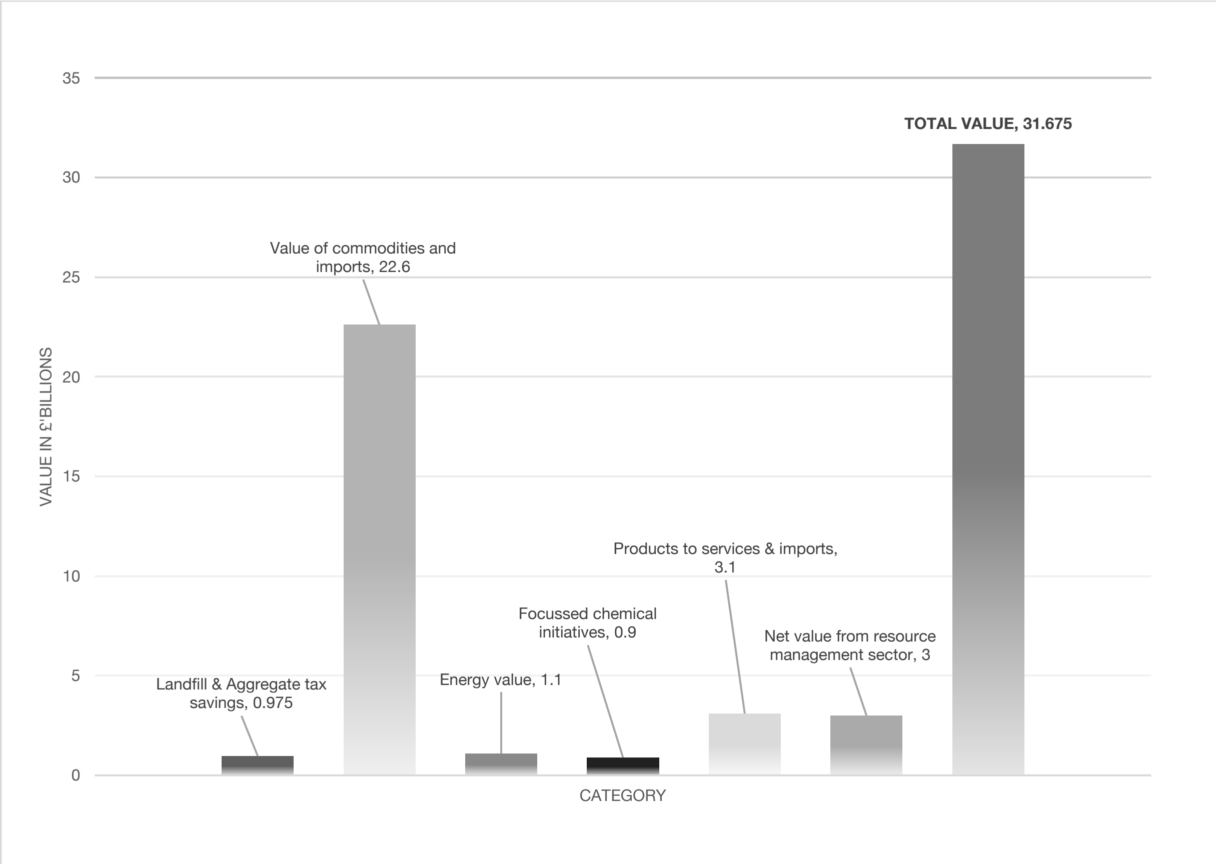


Figure 6.10 UK GDP Contributions: total £32bn

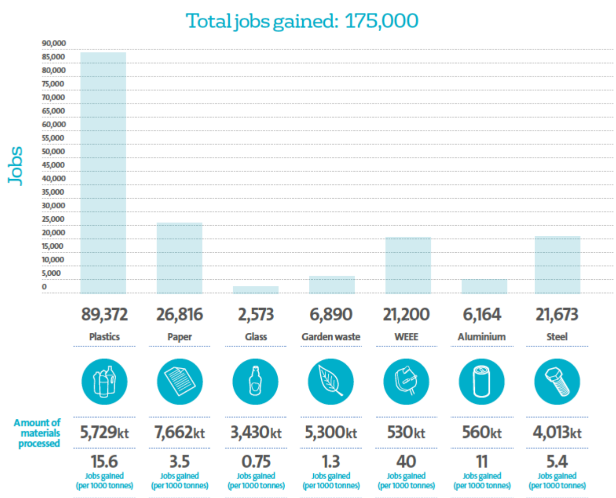


Figure 6.11 Total jobs gained from additional materials processed*

**Using 2010 data for the purposes of a calculation the latest job market profiling indicates this quantum remains relevant.*

The 175,000 jobs may not be entirely additional give some materials are switched from landfilling to recycling, but at the same time there would be additional jobs from products as a service and energy recovery. However, we have not included jobs covering the energy aspect of the flows since we expect that existing energy assets (such as coal fired power stations) would decline in line with new forms of energy production. We would also expect these jobs to be of increasing complexity, and value to job seekers being in the recycling composting and energy or feedstocks production sectors and closer to manufacturing. Overall and considering other industry assessments we believe the new net jobs added would be between **72,000 and 175,000** resulting from this analysis (72,000 being the 175,000 less 103,000 already in the sector).

To animate and explain the real-world examples of the above contributions to a Circular Economy considering the materials and energy components two cases studies are highlighted in Figure 6.12 overpage.

A total of circa **£32 billion** and **72,000 jobs** (conservatively) would result from the move to a Circular Economy that is a significant part of GDP depending on the speed of actualisation.

Note on data sources:
Drawing together the earlier results of the analysis of infrastructure needs with this analysis of Circular Economy value, there are some discrepancies in the precise tonnage figures used, but promisingly the figures are broadly in line with expectations considering different data sources are compiled which have different scopes and are inherently cutting data in different ways. The 72mt considered in this analysis comprises 23mt household waste, 27mt commercial waste and 22mt industrial wastes (ashes) which is consistent with the 50mt household and commercial wastes considered earlier plus the 22mt arising from energy waste flows.

Whilst the data used is resulting from the infrastructure study as well as ONS sources, it is relevant to the English jurisdiction, however, the GDP (GVA) contribution would be into the UK GDP coffers.

DIARY CREST - a story of circulating biomass

The Dairy Crest biomass energy plant is one of the largest wood pellet combustion installations in its industry sector, using sustainably sourced pellets made from used or life-expired waste wood. Dairy Crest is the UK's leading chilled dairy foods company. At their Davidstow site, they manufacture a range of dairy products including milk, cheese and butter – many of which are household names. In order to make the 55,000 tonnes of cheese they produce every year; they need 100,000 tonnes of steam for the pasteurisation and drying process. This was traditionally generated by burning fossil fuel.

They commissioned a solution that would reduce their carbon emissions and make their factory more energy efficient. The answer was a new biomass steam plant fuelled by waste wood pellets. These wood pellets were produced from life-expired wood that had been thrown away by the construction and manufacturing companies as it no longer had any use. As a country the UK produce a large amount of waste wood. Every year 10 million tonnes of wood is disposed of in the UK with only 1 million tonnes of it being recycled (2014). The rest is sent to landfill. There was a clear opportunity to put some of this waste wood to good use.

After wood is collected from commercial and domestic sources, it is sorted into grades and checked to ensure it meets sustainability requirements. Then it is chipped, shredded and any contaminants –like nails or staples – are removed and recycled. The wood is then dried and made into pellets. As a result, Dairy Crest's carbon emissions at the site were reduced by 60%. The energy savings made also mean they will see a return on their investment early in the plant's life. By using life-expired wood, they have reduced the burden on landfill and are turning this into a valuable fuel source.

Due to the project's success, the plant has won three awards: The Lord Ezra Award, The Energy Awards – Best Renewable Energy Project and the region's Best Biomass Project.

BAG TO BAG - how plastic saved the earth

Working alongside local authorities, a closed-loop environmental solution for recycling used plastic bags into refuse sacks was implemented. In England alone, over 8 billion plastic carrier bags are used each year. A large percentage end up in landfill sites where they take a long time to decompose, or can be found littering our towns, cities, coasts and countryside.

Although England is due to follow in the footsteps of Ireland, Wales and Scotland when it introduces its mandatory charge for single use plastic bags in 2015, the problem is still a big one.

The idea was to give plastic bags a new life by turning them into refuse sacks. Bags were collected at scale from retailers and at Materials Recovery Facilities (MRFs) then transported to a remanufacturing partner. The bags are then washed, processed, turned into pellets and then made into bin bags. The waste bags relate virgin plastic feedstock. The recycled bags are then delivered to the local authority where the used shopping bags were first used, disposed and collected - providing a Circular Economy.

Figure 6.12 CASE STUDIES of circular approaches to business

Chapter 7. The Role of Policy in Driving System Changes for a Circular Economy

7.1 Introduction

TV coverage, namely the *Blue Planet* series (BBC1), widespread media coverage of plastics in the oceans, public movements such as Extinction Rebellion who published their work "*This is not a drill*" (Extinction Rebellion, 2020) and the Greta Thunberg 'movement' (Thunberg, 2019) pushed forward an environmental agenda in 2019 and early 2020. At the same time local events such as increased prevalence of flooding events (Yorkshire, Humber, East and West Midlands, 2019-2020), and the societal costs imposed, reinforced the very real prospect that there would be large impacts on the economy from a decline in biodiversity and impacts from climate change. This all combined into a perfect storm of public sentiment, a sentiment which drove political action in the UK governments around plastics and waste more generally.

The Confederation of British Industries (UK) labelled the 2020s as the '*decade of delivery'* which amongst other things would lead to the political and business support for new regulations for the environment (CBI, 2019). COVID19 hit the world in late 2019 and stalled proceedings for the next 12 months. In January 2021 the World Economic Forum theme for 2021 was heralded as the Great Reset, with 3 requirements, a "stakeholder economy", more "resilient, equitable, and sustainable" approaches, based on Environmental, Social, and Governance (ESG) metrics, and more green public infrastructure projects (WEF, 2021). In a post COVID19 world it appears policy will still have a role in extending the traditional resource based 'limits of growth' and potentially more far reaching than before in reshaping society and capitalism (Meadows, 2004). The post COVID landscape the UK Government is persisting with its net zero 2050 policy, and the same waste policy wedded to a Circular Economy.

7.2 Methodology

The subject matter of raw materials, wastes, and the recycling sector, as well as the existing policy landscape was studied in order to review impacts over the past 20 years and to date. Moving to a Circular Economy is a significant sustainability transition (Makard, 2012), and one that lends itself to long established cradle to cradle business management ideas which have not yet been fully deployed (McDonough, 2002).

The availability of raw materials is a fundamental prerequisite for economic growth. Per capita income and consumption has been the strongest historical driver of growth in material use (OECD, 2011). Overall, the global economy expanded more than threefold since 1970, population almost doubled but global material extraction tripled (Schandl, et al. 2016). Global human population is predicted to exceed 9 billion by 2050 (United Nations, 2015), coupled with strong economic growth occurring in developing nations. As per-capita income increases in these countries, all things being equal, the demand for raw materials will surpass the planet's boundary limits. Three billion new middle-class consumers anticipated by 2030 will add to humanity's rapidly growing consumption of resources needed for electronics, urban development, farming, and military (Kharas, 2017). In the traditional modern industrialised economy, natural resources are mined and extracted, turned into products in manufacturing systems driven by heavy industrial growth and resource-intensive infrastructure and finally discarded after consumption or use.

While emerging scenarios and calculations demonstrate that benefits delivered from resource efficiency alone will not address the demands of this ever-growing production and consumption for raw materials and energy, these scenarios also dictate the need to re-assess the potential of our consumption in the context of sustainable resource management (Voulvoulis, 2014). Addressing resource scarcity requires reducing the extraction and use of resources and an absolute decoupling of growth from the use of natural resources – a systemic change. Improving resource use through better design requirements, and through waste legislation that ensures upward movement in the waste hierarchy (thereby fostering waste prevention, reuse, preparation for reuse and recycling), could bring substantial net savings to businesses, public authorities, and consumers (European Parliament, 2015).

The business case for a transition to a Circular Economy is compelling both in terms of economic outputs and jobs, but this is not always enough for such a transition to take place (Ellen MacArthur Foundation, 2015). There is vast evidence that shows the need of policy and regulations to enable this transition and to help economies move away from a polluting economic trajectory and advance to a 'clean' one (Dechezlepretre and Sato, 2014). Many Circular Economy opportunities have a sound underlying profitability, but there are often non-financial barriers limiting further scale-up or holding back development pace. Policymakers can play an important role in helping businesses overcome these barriers. Regulation has played a pivotal role in driving circular material use and this has been proved globally many times.

Governments should encourage investment in Circular Economy innovation and its take-up, and, against the background of the reform of the financial system, address barriers to mobilise more private financing for resource efficiency. This paper looks further into resource taxes for this, focusing on their potential to kick start the Circular Economy.

7.3 The Circular Economy

The current "take-make-dispose" approach (Figure 7.1) results in systematic waste arisings; in the fast-moving consumer goods sector alone, about 80% of the USD3.2 trillion material value is lost irrecoverably each year. Decoupling material use and environmental impacts from economic growth is a strategy that will be essential for ensuring future human well-being based on much lower material throughput. Many regions and countries have embarked on strategies to substantially increase the material efficiency of their economies and to reduce overall levels of material use (Schandl et al., 2016).

The technological potential for decoupling is large and the economic benefits are substantial. There are many cost-effective ways for decoupling in the short and medium terms and in the long-term decoupling will generate much higher economic returns than business as usual (Schandl et al., 2016). Meeting the needs of a growing world population with a finite resource base on a planet that is already under stress, comes down to the economy's ability to grow while resource use is declining.

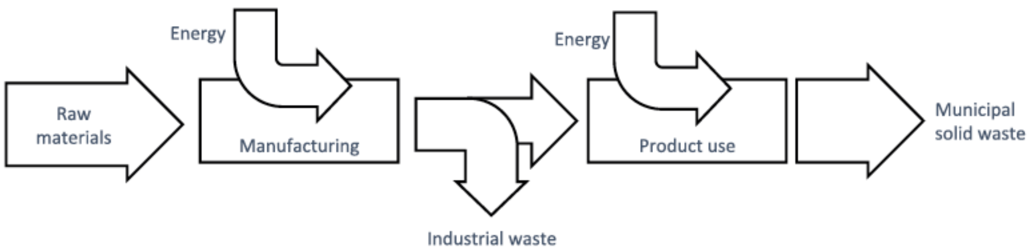


Figure 7.1 The Take-Make-Dispose economy

This shift to a Circular Economy is not just necessary but also incredibly complex. It requires a transition to industrial economy that, by design or intention, is restorative and eliminates losses (Voulvoulis, 2016). To move towards a Circular Economy (Figure 7.1) means moving away from our current linear economy (make-use-dispose) towards one where our products, and the materials they contain, are valued differently, creating a more robust economy in the process.

Circular Economy approaches include 'design out' waste and typically involve innovation throughout the value chain, rather than relying solely on solutions at the end of life of a product (European Commission, 2014).

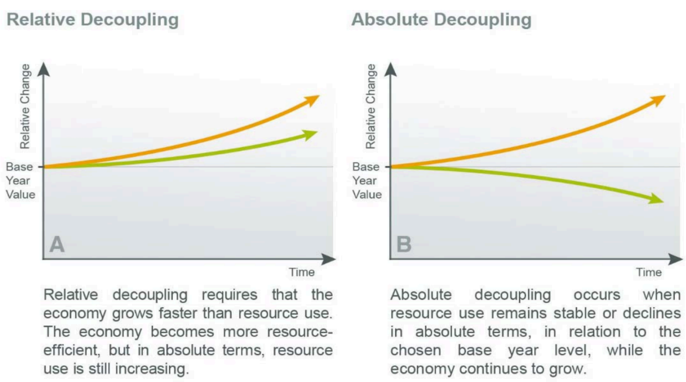


Figure 7.2 Decoupling economic activity from resource use enables economic growth while resource use is declining (European Environment Agency, 2015)

A transition to a Circular Economy aims at delivering dematerialisation (the absolute or relative reduction in the quantity of materials used and/or the quantity of waste produced in the generation of economic output). Ultimate decoupling could be achieved through the stages shown in Figure 7.3.

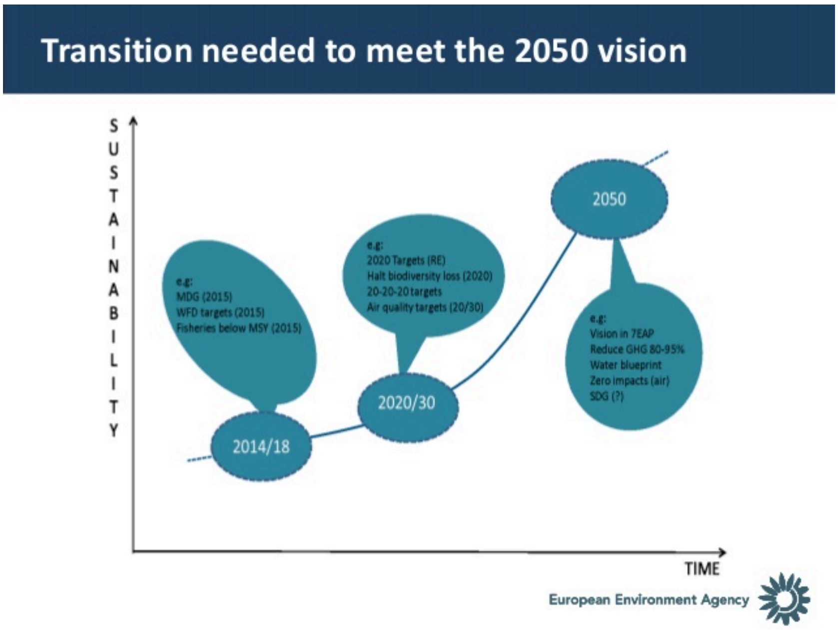


Figure 7.3 Stages to be achieved in a Circular Economy in order to decouple economic growth and resource use (Reichel, 2013)

7.4 The Role of Policy

Environmental policy is designed to tackle market failures by controlling pollution, regulating resource use and protecting and managing the natural environment. It aims to achieve a more efficient use of resources in the economy, maintaining the environmental assets which people value and which support a healthy economy and society, while reducing the costs to citizens and businesses of environmentally damaging activities (Mossalanejad, 2011). Without government intervention, there is no market incentive for firms and households to take into account environmental damage, since its impact is spread across many people and has little or no direct cost to the polluter (Rosiek, 2015). Therefore, protection of the environment generally requires collective action, usually led by government. In the past, environmental policy was typically dominated by “command-and-control” regulations (OECD, 2011).

These approaches were generally prescriptive and highly targeted – e.g., banning or limiting particular substances or requiring certain industries to use specific technologies. Over recent decades, interest has grown in using market-based instruments such as taxes and tradable emission permits (OECD, 2011).

There are a number of reasons for the increasing use of environmental taxes. From an economic efficiency point of view the main aim of fiscal taxes is to raise sufficient revenues without distorting economic activities too much. In practice, this implies that goods for which demand is relatively price inelastic should be taxed higher than goods whose uses are more sensitive to own-price changes. Quite often natural resources fall into the former category of goods. Environmental taxes have many important advantages, such as environmental effectiveness, economic efficiency, the ability to raise public revenue, and transparency (OECD, 2011). Also, environmental taxes have been successfully used to address a wide range of issues including waste disposal, water pollution and air emissions.

Regardless of the policy area, the design of environmental taxes and political economy considerations in their implementation are crucial determinants of their overall success. Taxes directly address market failure by "pricing in" environmental costs. They directly address the market failures that cause markets to ignore environmental impacts. A well designed environmental tax increases the price of a good or activity to reflect the cost of the environmental harm that it imposes on others. The cost of the harm to others – an "externality" – is thereby internalised into market prices. Thus it is ensured that consumers and firms take these costs into account in their decisions (OECD, 2011).

7.5 The Case for Recycling

Radetzki reported that the demand for natural resources and virgin materials tends to be inelastic, especially in the short-run. Studies indicate that the demand for metals and minerals is relatively inelastic (Radetzki et al., 2008), and that is increases or decreases to pricing does not massively impact demand. Soderholm went on to explain, this is partly because: (a) few substitutes to the resource exist; and (b) the processing of natural resources often is very capital intensive (e.g., metal smelting or pulp and paper production) and substitution to other inputs may therefore be costly and take a considerable amount of time (Söderholm, 2011). In addition, Soderholm asserted that the demand for natural resources is typically a **derived demand**, i.e. people rarely demand natural resources directly but instead they demand a very large number of consumer goods that are produced with the help of these resources (Söderholm, 2011).

Prices are a human convention which serve the purpose of sorting preferences. For example, waste markets, like any other market follow price signals. If the cheapest option is to landfill or burning waste it should not surprise anyone that recycling doesn't take off. For instance, in the EU, in countries such as Bulgaria, Portugal or Slovakia the average cost of landfill is below 20€ per ton which is a bad incentive to bother separating waste to recycle it (Zero Waste Europe, 2012). But this is not only about waste; it is also about the material cycles. Simple economics of supply and demand can't fully capture the value of demand for recyclables. When compared with their virgin counterparts, recycled products provide a number of intangible but increasingly crucial business benefits. From a marketing perspective, use of recycled products or investment by industry in new technologies that use recycled feedstocks will help win new customers and retain old ones. In addition, reassessing procurement policies to determine if there are subtle prejudices against recycled products calls into question more general quality standards and buying practices that may cost more than management had assumed. Investment in recycled products also means more competition and will inevitably force design innovations and new technologies that can further lower production costs. Therefore, decoupling the economy and its material needs must be understood as a double decoupling, the two components of which being inoperative if they are implemented separately.

Only the combination of the two makes a significant impact on the problem of resources:

(i) fundamental decoupling, namely to restrain the growth of total consumption of raw material (virgin or recycled)

(ii) A relative decoupling to reduce, through recycling and reuse, the share of primary resources (virgin) in the total production of raw material.

If resources are cheap the incentive to run a throw-away society is higher, if materials are more expensive the incentive go in the direction to build a Circular Economy. The usual thinking regarding economic incentives is that taxes should be placed on the scarce resources in order to limit their use whereas the abundant resource can remain untaxed (Baker, 2017). During the last century labour has been scarce whereas resources have been considered abundant and this is why traditionally the former has been taxed and the latter hasn’t (Zero Waste Europe, 2012). The current economic crisis in Europe shows that we are doing things wrong; as the unemployment statistics show labour is abundant -yet heavily taxed- whereas resources are not taxed albeit growing increasingly scarce.

7.6 Is it Time to Shift Taxation from Labour to Resources?

If resources were to be valued wrapping in their total cost (including externality to the environment), there would likely be an explosion in the reuse and repair market since the cost of materials would force built-in reparability, reusability, durability and recyclability in most products (Zero Waste Europe, 2012). It will also make the Extended Producer Responsibility concept a lot more relevant because producers will be highly interested in getting the materials back and closing material and energy cycles. Waste is increasingly becoming a sign of inefficiency that can no longer be sustained. The growing scarcity of materials and fuels is calling for a taxation shift from labour to materials. It would generate employment, potentially increase revenues for the state and surely help redesign the economy and phase-out waste.

7.7 Taxes on Virgin Natural Resources

Taxes on natural resources may be used as a way of encouraging the substitution of secondary and recycled materials for virgin materials (Söderholm, 2011). In general virgin materials are often associated with more negative externalities than recycled materials. One commonly cited reason for this is that the processing of secondary materials tends to be less energy intensive (Söderholm, 2011). In addition, recycling is one way of avoiding the disposal of solid waste. Taxes on virgin materials will change the relative price between virgin and recycled materials, and in this way influence waste disposal behaviour (Söderholm, 2011).

Theoretically charges on waste disposal would be the optimal policy in this case, but, as discussed above, the transaction costs involved in controlling such non-point source emissions may make second-best policies more attractive (Söderholm , 2011). Normally there are few producers of a chemical compound compared to the number of actors downstream in the supply chain, i.e. manufacturers of products using the chemical. Similarly, there are fewer of these intermediate producers than there are of the thousands of diverse end-user consumers. In addition, in several studies it is also argued that direct charges on waste disposal can be ineffective because of the risk of illegal disposal (Dinan, 1993; Fullerton and Kinnaman, 1995). Other measures that are easier to implement and that still have desired impacts on the environment can therefore be motivated. For the above reasons, the use of virgin material taxes can be an efficient method to encourage the use of recycled materials (and ultimately reduce waste and emissions) (Pearce and Turner, 1993; Conrad, 1999; Miedema, 1983). For instance, Conrad (1999) argues that a tax on virgin materials is a better instrument than a tax on waste, since in the former case the environmental aspects are integrated at the beginning of the production process. The results of his theoretical analysis show that the incentive to recycle and reduce waste is lower under a marginal increase in waste fees than under a marginal increase in a tax on virgin material. Nevertheless, other studies (Dinan, 1993; Fullerton and Wu, 1998; Palmer and Walls, 1999) argue that a tax on virgin material can only correct the external costs resulting from extracting or harvesting virgin materials, but not external costs resulting from waste disposal. These authors show that no single tax can generate the optimum level of both downstream and upstream waste disposal and that multiple policy instruments are necessary to fully internalise the externalities involved.

Similarly, subsidising recycling has limitations as well. While it is typically argued that the use of recycled materials generally is more environmentally benign than virgin material use, this really needs to be assessed in each case. Recycling also consumes resources, and could therefore not be seen upon as a fundamental policy goal in itself (Baumol, 1977; Berglund and Söderholm, 2003).

Most notably, if a natural resource tax encourages substitution away from a virgin material to some alternative raw material (recycled or not), this shift in use will imply a set of general equilibrium impacts whose net environmental impacts are a priori ambiguous. The environmental attributes of the replacement material may be less appealing (and potentially not well internalised by existing policy instruments). Similarly, the overall material intensity of the economy may not decrease in the presence of selected taxes on virgin natural resources.

Palmer and Walls (1999) argue that a combination of a tax on intermediate goods (or natural resources) and recycling subsidy would provide the appropriate incentives. This approach, they argue, has many virtues: *"Since the tax discourages production, it acts to reduce waste. And if the tax is assessed per pound of intermediate material produced, it gives producers of those intermediate goods the incentive to produce lighter-weight products. This further reduces the amount of material entering the waste stream. Moreover, the subsidy for recycling encourages the use of secondary materials in production by reducing their cost relative to virgin materials".* The system they proposed is very similar to a deposit-refund system in which the deposit acts like a tax on the virgin material, while consumers who recycle get the refund back (Söderholm, 2009). Some previous studies present empirical evidence in support of the above theoretical conclusion.

Palmer and Walls (1999) compare and evaluate three different waste management policies:
(a) deposit/refunds;
(b) advance disposal fees (equivalent to a virgin materials tax); and (c) recycling subsidies. From the empirical literature they collect demand and supply elasticities for aluminium, glass, paper, plastic and steel, and employ these in a simple simulation model to analyse the cost of reducing disposal of municipal solid waste.

The conclusion is that a deposit/refund scheme is more cost-effective than the two other policies. Still, when also taking administrative costs into account this conclusion may change in favour of the advance disposal fee. A similar approach is adopted by Sigman (Sigman, 1995) who compared four different policies aimed at achieving reductions in the disposal of lead: virgin material taxes, deposit/refund schemes, recycling subsidies and a recycled content standard. Focusing on the cost effectiveness of each of these policies, and using empirical estimates of own-price supply and demand elasticities for virgin and secondary lead as model inputs, virgin materials tax and the deposit/refund policies were preferred since they both encouraged the recovery of lead and discourage its consumption. All the above demonstrate the principles behind the need for the appropriate pricing of resources, one that is inclusive of all environmental costs. While some of the ideas presented here might be considered out-dated compared to the ways markets function today, it is the principles behind them and what they are trying to achieve that count. Tax breaks, for example, for those taking action in reuse and redesign of resources, could be an alternative way to incentivise businesses, using a more current tool, if designed to achieve the desired result as discussed above. This has been done for instance in Sweden where the government has introduced tax breaks on repairs to everything from bicycles to washing machines (Orange, 2016). Similarly, the UK Government has recently introduced schemes that businesses can apply for, to pay less tax, by demonstrating that they are operating more efficiently and producing waste that is less damaging (UK Government, 2017).

A business tax on use of virgin resources is an incentive for businesses to look towards more sustainable technologies, renewable energies and resource security (Frerot, 2015). For example, alongside encouraging businesses to produce less waste and pollution, this incentive will increase material flow. This could also take the form of a carbon tax that would encourage more renewable energy, offer greater energy security and more security for businesses to be sustainable and grow in the future, while funding the necessary infrastructure needs. Some initial industry estimates indicate that this could be achieved for a carbon tax around €30 to €40 per tonne of CO_2 (Veolia, 2015), but would have to be comprehensible, while also being ambitious in each application, and in line with the principles discussed above. Such schemes designed from a systems perspective have the potential to make the transition to a Circular Economy possible at scale and more effective.

7.8 Findings from the Policy Landscape

A transition towards a sustainable and Circular Economy should combine ambitious environmental goals with strong social requirements, including the promotion of decent work and healthy and safe working conditions (i.e. ensuring that workers are not exposed to harmful substances in the workplace); and establish a more coherent legal framework for sustainable production and consumption. These require both legislative measures and economic incentives, the internalisation of external costs and further funding of research and innovation, as well as social and lifestyle changes; points out that a variety of instruments are needed at various policy levels, taking account of subsidiarity.

There is clearly a need for more appropriate pricing of virgin materials and natural resources that is inclusive of all environmental costs. The carrying capacity of the natural environment is an un-priced input to resource production, and it is increasingly accepted that resource users should be made to pay for the environmental impacts they cause. While several methods for the monetary valuation of environmental impacts have been developed (Damigos, 2006), the internalisation of environmental costs have yet to be fully mainstreamed in practice (Dalal-Clayton and Bass, 2009). By influencing the use of resources, environmental policy has the potential to affect the way in which economic activity develops. It can encourage more efficient use of energy and materials and the development of new, cleaner products and services while discouraging activities that are environmentally damaging. This in turn encourages product and process innovation and influences the allocation of labour, capital, land and raw materials, either through direct regulation or through pricing mechanisms.

When properly evaluated, recycling and reuse can provide a viable opportunity to augment traditional resource supplies, at the same time reducing the need for waste disposal (Iranpour et al.,1999). As a result, resource reuse can help to close the loop between supply and waste disposal, providing a sustainable alternative to mining and consuming virgin stocks. Policies that allow for environmental externalities to be better accounted for in decision and policymaking in relation to materials and resources, can also encourage the development of new products and services designed primarily to enhance the environment. This integration of environmental considerations into wider economic activity has many benefits and can be achieved though many different ways. For instance, voluntary agreements could be an alternative for the industry, as these commitments between authorities and target groups set out environmental objectives based on voluntary participation and absence of sanctions (Skjærseth, 2000). The key message is that achieving more from less, by closing resource loops, is paramount, given the twofold need of protecting the environment and recognising the importance of natural capital, while at the same time enhancing economic prosperity and improving living standards of developing countries and the world's poor.

7.9 The Resources & Waste Strategy - a System Change for Producers

After several years in the making and following a long hiatus in waste management policy, for more than 5 years DEFRA launched a new strategy for waste and resources in 2018 (DEFRA, 2018) which was both wide ranging, and progressive in delivering options for system change. This strategy included amongst other things eco-design, reform of the packaging regulations and extension into a more comprehensive Extended Producer Responsibility (EPR) regime, a deposit return scheme, harmonisation of collection and labelling and proposals for fiscal measures to incentive recycling content in new products, as well as obligatory food waste collection. As well as proposing these measures the interconnections have been considered and calculations made as to the levels of reuse, recycling and recovery that can be achieved by its implementation and that was circa 60-70% recycling levels. A particular challenge for DEFRA in implementing such a policy is the complex interaction of stakeholders, citizens, business, local authorities all with competing roles, requiring some careful though as to how to incentivise and co-design the schemes (Mckelvey, 2002).

7.10 Methodology for systematic review of key pillars of policy arising from the strategy

The first part of this chapter is concerned with the policy and regulation in place or anticipated in England, but is relevant across the UK where significant alignment is anticipated for the devolved administrations. The second part considers the likely technological change in the next 30 years and possible impacts on that policy.

Central to the DEFRA policy is implementation of an Extended Producer Responsibility (EPR) scheme for packaging with the intent of later rolling this out to wider material groups, such as Electronic Waste, Furniture etc.

There are two important features of EPR policy:

1. the shifting of responsibility (physically and/or economically; fully or partially) upstream to the producer and away from municipalities; and

2. to provide incentives to producers to incorporate environmental considerations in the design of their products (Government of Western Australia, 2005).

The DEFRA scheme involves switching both financial and regulatory responsibility for downstream packaging post consumption from local authorities to producers, where in all likelihood they will transfer that cos directly to consumers. The idea stems from the fact in the current system local authorities pay for dealing with recyclable or residual packaging wastes arising at the doorstep and this cost would be transferred directly to the producers (manufacturers and retailers), thus implementing a **"pay as you buy"** approach to the costs of recycling and disposal of packaging. This could in turn be rolled out to further products to ensure that when materials are consumed the full life cycle of cost is included in the purchase cost, rather than a significant proportion being addressed by general taxation. The impact of this would be to allow business to optimise these costs, reducing them where possible, designing more items to be recyclable - since that is cheaper in this proposed system and effectively internalising some environmental externalities. This is something that local authorities are not equipped to do. The DEFRA EPR does directly incentive financially, for the first time, some kind of consideration for downstream treatment and circularity, since a modulated fee is also proposed which charges more for non-recyclable and less for recyclable materials. Currently we estimate local authorities pay circa £256m per year for managing municipally arising packaging (OECD, 2008; LGA 2015), whilst the manufacturers and retailers of those materials pay circa £73m per year into the packaging levy scheme (NAO, 2018), commonly known as PRN - packaging recovery notes, arising from the packaging regulations. Figure 37 below attempts to estimate the costs not born by the producers, some £200m per annum. Therefore, this scheme would move circa £200m of cost annually into the FMCG (fast moving consumer goods) sectors along the supply chain from manufacturer to retailer. Notionally public taxation could be reduced by that same amount since local authorities would no longer bear this cost, and therefore environmental costs of packaging consumption would move from general taxation to “pay as you buy”, arguably a more equitable approach, and with the prospect of optimisation via better design. The question asked in this section is why new environmental policy which may lead to costly regulation be an opportunity for sustainable businesses, and why would they not position themselves against such new mandates.

7.11 England recycling performance

It is not easy to compare the England to other countries around the world for packaging and the recycling performance since each country measures and reports in slightly different ways, however, our research indicates that 45-50% is the real rate of recycling of packaging for most countries which have implemented separate collection (Eurometaux, 2016). Current recycling levels in England are reproduced here in Figure 5 *(reproduced from Chapter 2 above)*. These measurement methods are currently being harmonised under the EU Circular Economy package, and we believe England will come out as one of the Eurozone's top performers based on the method of calculation. The real question is how we move from this position and shoot from the current 44% into the desired 70% recycling zone. Current recycling levels in England are reproduced here in Figure 7.4.

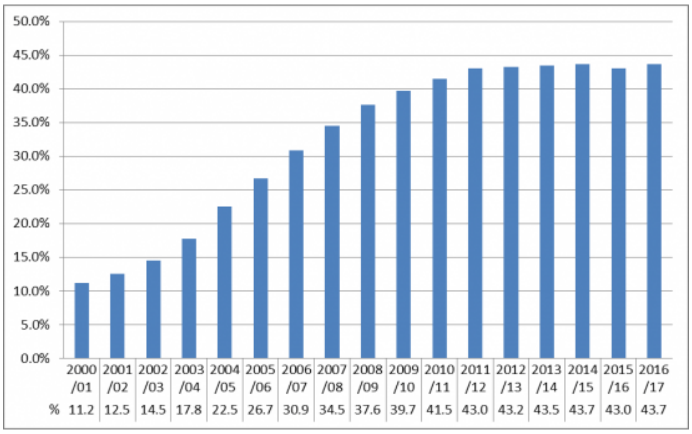


Figure 7.4 Household waste recycling rate, 2000/01 to 2013/14 (DEFRA, 2013a)

By way of example, in Germany they consider what goes into a recycling facility is recycling, and in England they consider what comes out of a recycling facility as recycling (Eurometaux, 2016). In fact the limiting factor on performance is the make-up and design of packaging which broadly speaking is the same the world over (Fletcher, 2018).

For plastics packaging there are broadly 3 categories, *bottles* which make up a 3rd and for which we recover 60% via doorstep collection (Statista, 2020) and can reach 90% with a DRS scheme; *pots tubs and trays* which make up another 3rd and for which about 50% are recyclable - however - labelling makes it very difficult for householders to determine which are and which are not; and *films*, almost all of which are non-recycle except bags (note: films can be separately collected and then shredded into road use applications but this is not a long term solution). (WRAP, n.d.).

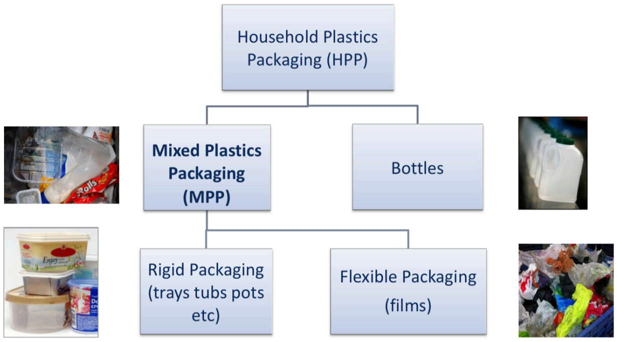


Figure 7.5 Main types of plastic in packaging (WRAP, n.d.)

For metals most are recyclable and will be recycled either by source separation or from post energy recovery separation the former being a better solution.

For paper and other cellulose fibres (e.g., cardboard), again most is recyclable, but we have to take care on the quality and plastic films that are often bound to the paper to protect it from moisture when it is used as food packaging. For glass, bottle glass is entirely recyclable.

An additional complication is much packaging is a combination of the above for example Tetrapak*, which has no current recycling solution. Ultimately the responsibility of the packaging design will fall at the feet of the producers.

*For Tetrapak the benefit is that it uses less resources in the first place, yet it is not recyclable, demonstrating one of the weigh-offs in environmental choice.

7.12 What does business want?

It wants to be successful (defined by its financial profits) in the short but also the long term, to have certainty and to have fair competition (WBCSD, 2010). The Climate Crisis, Plastics in the Ocean, air pollution, and the inefficient use of physical and energetic resources, such as packaging, food, and waste heat are all clear and present matters to grapple with in the post COVID19 environment. Their is also a growing part of the population, the next generation, millennials and generation Z who do not trust big business and we must demonstrate that business is a force for good in society (Deloitte, 2020). In the past corporate development of what are in effect ecological solutions has fallen on barren ground due to the perception of the objective as purely capitalist (Cohen, 2006) and eco-innovation must work on how it is perceived if it is to gain more mainstream support.

We propose that the UK resources and waste strategy allows business to take a lead on a level playing field. For example, most businesses have launched and announced ambitious plans to reduce carbon impacts and even address biodiversity (both analogs for wider environmental matters), to reduce packaging waste and be more responsible in contributing towards the UK net zero-carbon 2050 requirement. Previously the early sustainability adopters have been penalised with higher costs and therefore gain only niche market penetration, but with a level playing field all companies including the largest brands will be able to realise their sustainable ambitions, and relatively will be rewarded for it. The new RWS strategy is a game-changer in terms of overall system incentives. Formulated in 2018, it is a well-documented, consulted and thought through set of proposals which would ensure system change driving financial incentives for reuse, refill, better material choice, and which would put the efficiency of packaging in the hands of the industry producing it. At its core it prices in the waste disposal or recycling part of the supply chain at the point of purchase and by doing so reveals the true cost of our lifestyles.

Many blue chip/FTSE100 businesses have launched and announced ambitious plans to reduce carbon impacts, reduce packaging waste, be more responsible with their externalities (unpriced impacts), but few have real competitively viable plans to do so. Environmental and social promises are economically difficult to deliver in the face of competitors who do not comply with the same standards - there is no level playing field for sustainability. Some consumers will pay extra for better environmental performance, but the majority will not, and so regulatory levelling is needed. A list of businesses committing to climate change net zero targets publicly in Q1 2020 was more than 100 large enterprises, with dates ranging from 2030 to 2050. It is questionable as to whether the true ability, method to deliver, and costs have been calculated and worked up in any granular detail across these portfolios and indeed whether the technology exists to deliver on the commitments, however, it clearly demonstrates a desire to respond to net zero regulation. A total of 103 firms had already announced plans to reduce net carbon emissions to zero by 2050 or in many cases before 2050, some as early as 2030. It is unlikely they had all detailed plans with respect to the mechanisms of costs for delivery of these targets, but it does demonstrate a strong ambition in face of information we know about global impacts of carbon.

Table 7.6 Announcements of net zero dates February 2020 (Burchett, 2020)

Total identified 103 at end of 2019, See Appendix 5 for full list and dates.

SECTOR	No of firms disclosing NetZero 2050 or before
Retail	10
Manufacturers	22
Local authorities	29
Aviation	7
Oil & Gas	4
Building / construction	8
Water	4
Other	19
TOTAL	103

7.13 Conclusions: The main elements of the Resources & Waste Strategy

6 key findings were observed from the DEFRA strategy that expected to have important consequences for producers and citizens (consumers), see Figure 37;

(i) An Extended Producer Responsibility mandate,
(ii) A Deposit Return Scheme,
(iii) A Tax on using non-recyclable plastic (enforced via treasury, HMRC, UK Government, 2019),
(iv) Harmonised municipal recyclables collection, and,
(v) Packaging Product labelling.
(vi) An obligation on local authorities to collect food waste separately*

*Unclear if that means with green waste in some circumstances

Other policy aspects of the document consider eco-design, sustainability, and the Circular Economy however, they do not indicate any mechanisms for incentivising or legislating for those aspired positions and therefore we focus on the obligatory and regulated elements of the policy.

Each of the 6 elements of the policy and their implications are discussed here;

(i) Incentivising the right choices - EPR - Extended Producer Responsibility

We already have in place a packaging tax in the UK (Packaging regulations) that has delivered circa 50% recycling of packaging materials. That has been successful, and cost controlled, whilst the target to recycle has been matched with an equal amount of infrastructure.

Recently China closed its doors to UK recycled plastics meaning the target exceeded the recycling capacity and that has surged temporarily the “PRN” packaging tax costs (plastic PRNs rose from circa £50 per tonne to £370 per tonne (in late 2019), (Letsrecycle, 2019).

This has started to return to normal in 2020, but it highlighted shortfalls in the scheme and opportunities to improve it. Under this scheme the manufacturer/consumer is directly paying for **only around 20%** of the disposal or recycling cost of packaging when they buy something (see Figure 7.7 estimations). The remainder is funded via **general taxation** and exercised by the local authority.

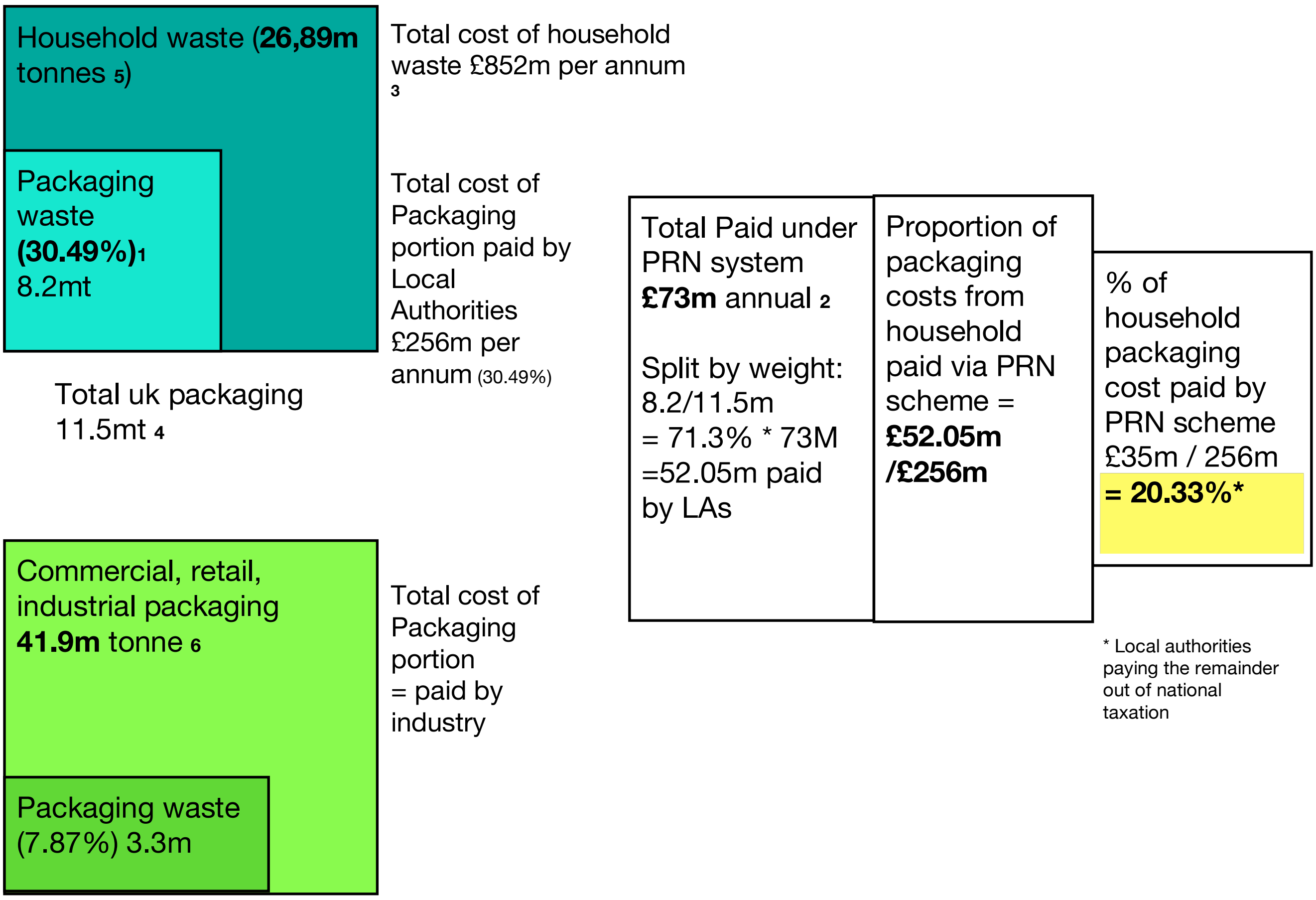


Figure 7.7 Estimation of the proportion the PRN contributes to packaging costs

Estimation References

1. Amount of packaging waste in household waste <33%, we took the assumption that it is **30%**, (OECD, 2009)
2. In 2017, 7002 companies paid a total of **£73m** towards the cost of recycling packaging (NAO, 2018).
3. Councils spend **£852m** per year on waste collection (LGA, 2015).
4. **11.5 million** tonnes of packaging waste in the UK in 2016 (EDIE, 2018)
5. Total amount of UK Household Waste 2017, **26.89m** tonnes (DEFRA, 2020a)
6. Total amount of UK Commercial and Industrial Waste 2017, **41.1m** tonnes (DEFRA, 2020a)

The new proposals are to push the full cost to the manufacturer/consumer directly on a packaging item - we would pay for the end of life when we buy something. This principle can then be rolled out to all products in due time, including WEEE, furniture, clothing etc. This creates competition between manufacturers to reduce the overall lifecycle cost for consumers via sustainable product design

(Bocken, 2016), something which is not present today. The costs which have been hidden from producers (the recycling, disposal part) is being shifted back to them which will incentive the most efficient package design, material choice, consumer sale process (which could even be refill).

The impact of re-apportioning the costs to the private sector are estimated in Figure 7.8.

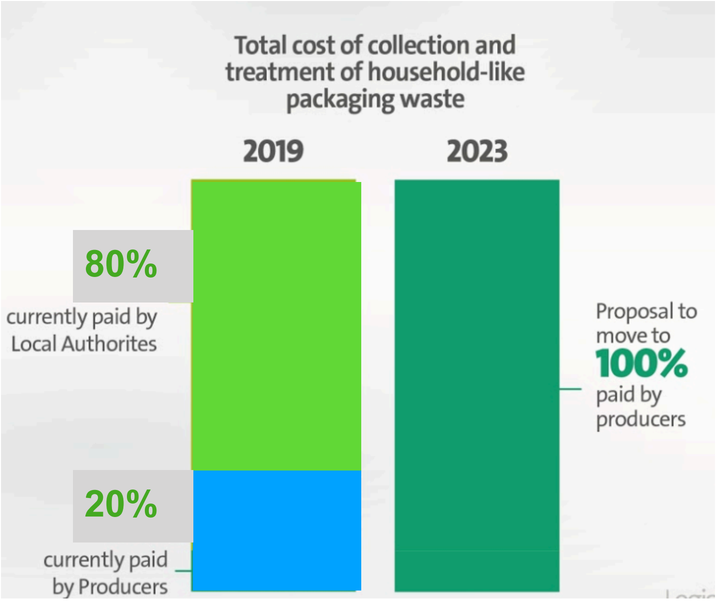


Figure 7.8 Re-apportioning costs to the private sector - a shift in incentives

(ii) The Deposit Return Scheme (DRS)

Deposit return schemes existed in the UK back in the 1970s which glass bottles often having a 10p per bottle return value. This worked well in short supply chains where products did not travel large distances, but with modern supply chains this became ineffective requiring the transport of air-filled containers long distances. At the same time the proliferation of plastic bottles and containers means we have a lot of single use materials in circulation. Today, 72% of bottles are recovered through doorstep recycling systems in the UK (Statista, 2020), after at least 15 years of messaging to consumers and homeowners and significant improvement is unlikely, particularly since this arises largely 'on the go' outside the home. We know from many overseas DRS schemes that 90%-98% bottle recovery is possible under a well-designed scheme. The case for the improved recovery of bottles from a financial deposit assigned to it seems high. This advantage is countered by the fact that the UK has deployed an extensive home collection system and any DRS would likely scavenge from that system depriving the home recyclable containers of plastic bottles and metal cans, one of the higher value items, thus rendering the basket value of a container lower, a value that offsets the collection cost for local authorities.

Despite all this, if the aforementioned EPR is effectively installed local authorities will not be paying for recyclable collection anyway, and therefore the costs of either home collection or DRS recovery would fall with the supply chain, and the only remaining question is how to design the two systems together to reduce overall cost. The UK waste sector, represented by the Environmental Services Association, suggest that an 'on the go' focus for DRS would mop up the majority of lost containers, leaving the majority to still be collected in household recycling schemes, and that this could be more or less implemented on a container size basis, since the majority of large containers are from the home and small from on the go.

(iii) A tax to incentive recycled content in plastics

The primary reason waste infrastructure was developed in the UK and why we were able to move away from landfill was the landfill tax. A blunt instrument which had targeted and highly effective impact on providing a business case for alternatives.

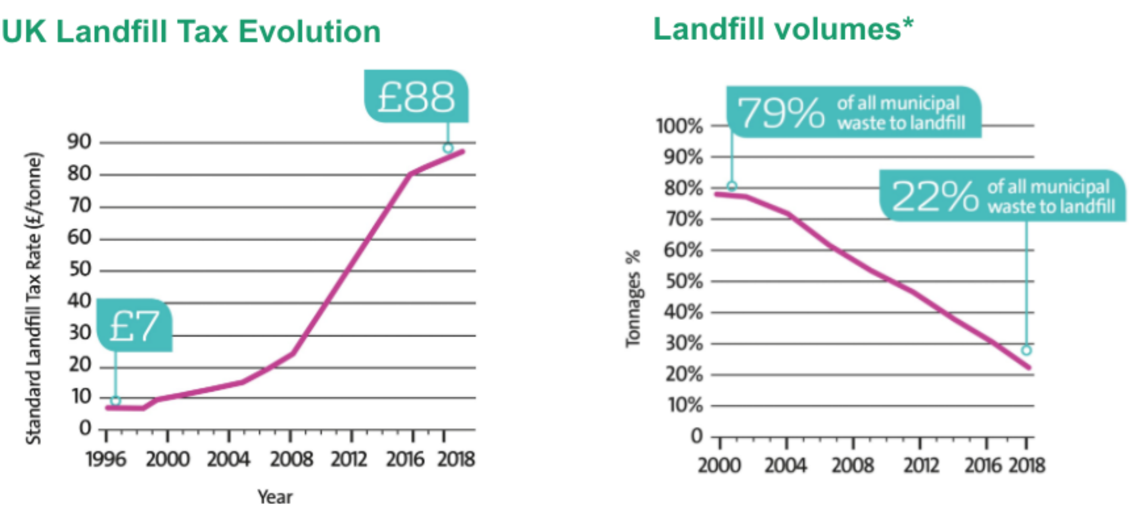


Figure 7.9 Reduction in landfill as tax increases and infrastructure is delivered (Veolia, 2018)

Other factors such as the legal requirement for household recycling to be provided and targets for local authorities also assisted this change but the landfill tax escalator implementation was the prime mover for the UK moving from 11% to 45% recycling levels over a 20-year period. This clear fiscal measure demonstrates that we need financial incentives to move cities to a new paradigm of landfill diversion. The escalating feature of the landfill tax made it politically attractive since most large companies were already citing they would move away from landfill, therefore they would never be exposed to significant landfill tax if this were the case. Local authorities were also able to undertake complex public procurements for infrastructure to replace landfill and the escalator gave them time, as well as a solid business case for industry. Most of these long-term contracts relied on minimum tonnages into new infrastructure guaranteed so subsequent governments would not easily be able to remove the tax and revert to landfill since it would not save anything, leading to a long term locked in environmental benefit (Kirkman, 2018).

As well as regulatory policy we think that fiscal policy also has a key role to play in moving towards a circular approach to the economy, so further analysis was considered, focussed on plastics which were a contemporary example where public and political debate was underway. Therefore, blunt economic drivers are considered important indicators and flags to business. As the landfill tax was the enduring delivery model for diversion from landfill we explore here how a plastics tax, and subsequent taxes on raw materials, might provide the switch to secondary materials that today is not scaled in all parts of the economy, notably for plastics.

A consultation on a potential for tax on non-recycled plastics packaging by HMRC received some 160,000 responses, an order of magnitude more than would be expected from a tax office. This research focussed on calculating the cost to the average consumer from the proposed tax regime to ensure lower income families would not be unduly impacted from a direct packaging tax. The range of costs, taking into account a likely and possible reduction in consumption revealed the costs could be as low as 6-22p per week. Other consumer research on behalf of Veolia by You.gov (Yougov,,2019) also indicated that consumers would be ready to pay higher than these levels to ensure plastic packaging did not reach our oceans.

The Treasury have been exploring a plastics tax for nearly 12 months since the initial consultation. Here, we consider the case of the proposed plastic packaging tax in the UK that will apply to all plastic packaging with less than 30% recycled content which is manufactured in the UK, as well as unfilled packaging imported into the country. We evaluate the cost of this tax, based on the price difference between recycled and virgin plastic, for all plastic packaging to reach the target of a minimum of 30% recycled content.

Assuming the tax cost is transferred to households by packaging producers and retailers, the average impact of plastic packaging tax would be in the range of 16p per week per household (or 7p per week considering projected levels of recycled content in packaging) for all plastic packaging to reach the target. The tax will provide assurance to the recycling value chain and stimulate new investment in domestic recycling infrastructure, as well as an incentive for the packaging sector to look towards green product design and resource security. In the traditional modern industrialised economy, natural resources are mined and extracted, turned into products in manufacturing systems driven by heavy industrial growth and resource-intensive infrastructure and finally discarded after consumption or use.

This “take-make-dispose” approach (Figure 7.1 above) results in pollution and waste and puts resource security at risk. Meeting the needs of a growing world population with a finite resource base on a planet that is already under stress from overconsumption will come down to an economy’s ability to grow while resource use is declining.

Emerging scenarios and calculations demonstrate that the benefits delivered from resource efficiency alone will not address the demands of an ever-growing production and consumption of raw materials and energy. These scenarios dictate the need to decouple economic growth from resource consumption (Voulvoulis et al., 2013; Voulvoulis, 2018). The technological potential for decoupling is large and the business case for a transition to a Circular Economy is compelling, both in terms of economic outputs and environmental improvements (Schandl et al., 2016).

However, despite most Circular Economy opportunities having a sound underlying profitability, there are often barriers limiting further scale-up and preventing momentum (Kirkman and Voulvoulis, 2017). Policymakers can play an important role in helping businesses overcome these barriers (Voulvoulis, 2015). For example, environmental taxes directly address market failure by “pricing in” environmental costs. A well-designed tax can increase the price of a product or activity to reflect the cost of the environmental harm that it imposes on others. The cost of the harm to others – an “externality” – is thereby internalised into market prices. Thus, it is ensured that consumers and firms take these costs into account in their decisions (OECD, 2011).

Plastics are inexpensive, lightweight and durable materials, which can readily be moulded into a variety of products that find use in a wide range of applications. However, their production, usage and disposal generate several environmental problems. Around 4% of world oil and gas production, a non-renewable resource, is used as feedstock for plastics and a further 3–4% is expended to provide energy for their manufacture (Hopewell et al., 2009) As is widely known substantial quantities of end-of-life plastics are accumulating in the oceans and as debris in the natural environment, resulting in both environmental damage and waste management issues (Geyer et al., 2017).

While recycling is one of the most important actions currently available to reduce these impacts, providing opportunities to reduce oil usage, carbon dioxide emissions and the quantities of waste requiring disposal, the more than 1.5m tonnes of plastic packaging used in consumer products in the UK each year are mostly made from virgin rather than recycled plastic. Plastic packaging accounted for 44% of plastic used in 2017 in the UK and 67% of the plastic waste produced (2.26M tonnes). Given the failure of the market to incorporate the environmental and end-of-life cost burdens into the price of products, commodity prices continuing to stay low and with the ratio of plastic packaging in waste continuing to grow, there is a need to ensure recycling remains both economically and environmentally sustainable. Current policy measures such as the landfill tax, the producer responsibility regime and recycling targets, have to some extent supported the secondary plastics market, but have not produced a stable enough environment to attract the investment needed to develop the market and generate sustained demand or deliver optimum environmental performance.

The challenge of recycling plastics

Plastics are derived from by-products of petroleum refining and natural gas processing. Therefore, when oil prices dip, the price of plastic resin follows. The price of plastics is volatile – not only because it depends heavily on the price of oil, but also because it's affected by other market conditions, such as capacity constraints and stockpiling by users (Seliger, 2007). Over the past five years, the price of plastic has varied from £850 to £1300 per tonne. These variations have the potential to materially affect the bottom line and directly affect the competitiveness of recycled plastics (Stindt, 2014). In fact, oil prices are currently so low that it's cheaper for manufacturers to buy virgin plastic than it is for them to buy recycled plastic feedstock, despite its lower environmental impacts.

The introduction of "Operation Green Fence" and "National Sword" has lead to China only importing uncontaminated and high-quality plastics, which has increased the price of recycled plastic at a time when the price of crude oil makes them even less competitive (Alademi, 2020). Several recycling companies had already collapsed after being squeezed between a slump in global oil prices and a supermarket price war leading to the price of reprocessed plastic in the open market being between £300 and £500 per tonne more expensive than virgin plastic (Taxscan, 2019).

Demand for recyclables is driven by raw material procurement decisions made by product and packaging suppliers and their customers. While using recycled content allows producers to meet corporate social responsibility goals, including greenhouse gas reduction targets, the key variable that determines the amount of secondary material used in production is price.

When oil prices are moderate to high, secondary materials are attractive to producers but if the price of energy or raw materials is low, the attractiveness of secondary material inputs diminishes, with businesses going for virgin. It is for this reason that voluntary initiatives among product manufacturers, although laudable and very important, cannot be the sole path towards the greater use of recycled materials. Significant variations in the price of new plastic over time also discourage businesses from committing to using recycled plastic in the long term.

The approach in this research was to calculate the required tax envelope that might influence materials choice when producing plastic packaging. With the knowledge that the Italian proposal is

0.45Eurocent/kg or 450Euro per tonne (Taxscan, 2019), we wanted to determine for an average packaging item what level of tax would ensure that use of recycled content could be financially justified by packaging producers and retailers.

The UK is currently considering the introduction of recycled content targets to support the use of secondary plastic in domestic production and manufacturing processes and a future plastic packaging tax as a flat rate tax on packaging to support this. Under the proposals, the plastic packaging tax will apply to all plastic packaging with less than 30% recycled content which is manufactured in the UK, as well as unfilled packaging imported into the country.

Considering that the main reason for not using recycled plastic is that virgin plastic costs less, the proposed tax would have to compensate for their price difference to make recycled plastic competitive. With the price difference between recycled and virgin plastic currently estimated around £500 per tonne (Taxscan, 2019), the minimum tax level needed to make costs to industry similar between using 100% virgin plastic packaging and packaging with a minimum 30% recycled plastic content comes to £150 per tonne (0.015 pence per gram).

If the tax cost *(£230 million – see Appendix 6)* was transferred by the packaging producers and retailers to UK households, the average impact of the plastic packaging tax would be 16p per week per household. However, this cost is expected to be even lower, considering that 55% of packaging would meet the 30% recycled plastic content stipulation even without any tax, according to Ernst & Young’s analysis for the British Plastics Federation. Ernst & Young's analysis, which was shared with the BPF at a meeting in mid-April, finds that the proposed tax would increase the proportion of packaging using at least 30% recycled plastic from a quarter in 2017 to three quarters of all packaging on the market in 2022 (Ernst & Young, report for the BPF, 2019)**.**

In this case, transferred to households, the average impact of the plastic packaging tax would be 7p per week per household for all packaging in the UK to meet the target (see Appendix 5).

However, it is unlikely that companies, rather than increase the inclusion of non-virgin materials in their products, would choose not to act and just pass on the cost to consumers. To do so would be an unwise move, as competitors who do jump in with both feet will be offering consumers a better product at a similar or lower price in comparison. In fact, evidence points to the opposite, with many leading brands, retailers, and packaging companies already committing towards 30% average recycled content across all plastic packaging (See Table 21).

Ultimately, the problem of plastics is not so much one of waste, but one of production. The solution to a world drowning in plastic refuse requires questioning the need for plastics and reducing their manufacturing in the first place. Increasing the recycled content of plastics exposes the current rhetoric: Blame not the production, for what is produced is of vital importance to the world (especially those in the developing world), but call for everyone to come together in addressing the problem of the waste (Wilkins, 2018). Recyclers did not create the plastic waste crisis, it is the prolific, ever-increasing production of plastics that needs to be addressed. Voluntary industry initiatives are often a common delay tactic for industries wishing to avoid binding regulations.

On the contrary, increasing the levels of recycled content in plastic packaging can reduce both the need for manufacturing plastics and the amount of plastic wastes produced. The future plastic tax will be a key part of the solution as it is expected to enable an additional two million tonnes of plastic packaging to be recycled in the UK and to fulfil 71 per cent of UK manufacturing's raw material demand (Peake et al., 2018). It should also drive the UK Circular Economy by creating several thousands of jobs in the recycling industries.

Table 7.10 Voluntary achievements in advance of looming policy

- In January 2018 **Ecover** launched a new 100% recycled plastic (PCR), recyclable, washing-up liquid bottle. The bottle is made from transparent, 100% recycled PET and mostly comes from used soft drink or water bottles. The rest of Ecover bottles are made from 25% recycled plastic (either PET or HDPE) and 75% plant plastic, which is made from renewable sugarcane.
- In October 2018 **Ecover** trialled recycled plastic in its caps for the first time. Introducing 50% post-consumer recycled polypropylene plastic in 200,000 of its caps in Europe in October 2018. Most caps are made from virgin polypropylene plastic. By starting to use recycled polypropylene, Ecover wants to help create an economic demand for recycling it.
- All **Innocent** bottles contain a minimum of 30% recycled plastic and their new smoothie bottle contains 50% recycled plastic and 15% plant plastic. This is their next major step towards having a completely renewable bottle (made only of recycled and plant plastic) by 2022.
- **Charpak** produces clear and black recycled PET packaging which contains 50% post-consumer waste and up to 40% post industrial waste.
- In 2017, **Procter & Gamble** launched the Fairy Ocean Plastic bottle made 100% from post-consumer recycled plastic and ocean plastic. Over 320,000 Fairy Ocean Plastic bottles were made in this material.
- **Highland Spring** has launched a trial bottle made from 100% recycled plastic.
- **Aldi** have saved 139 tonnes of virgin plastic per year by using 95% recycled plastic in their pasta pots.
- **Tesco** flavoured water bottles have been reduced in weight and now have a 25% recycled content (rising to 51% soon). Over 540 tonnes of plastic per annum have been removed.

Most large brands have committed to its use and an escalator would not impact firms sticking to those public commitments. Currently the consultation starts the tax at £200/metric tonne for the 30% threshold of recycled content, leading to an effective £666/tonne impact versus virgin plastics value (Kirkman, 2019). This contrasts to the current very low price of oil which will have knock on downward pressure on finished virgin grades. There is scope to escalate the tax to encourage progressive usage. Figure 40 summarises our calculation and which suggests a cost of 6-22p per week for the average consumer based on food packaging if you also take into account reduced use.

Currently some pharma and medical applications are prevented from using food grade recycled content due to food regulations, and there is no available food grade PP on the market. We would expect these taxation pressures to instigate regulatory and technical innovation to allow use in all applications and for all polymers.

Figure 7.11 The tax and the consumer costs for packaging

Incentivising the right behaviour over time with slowly escalating taxes on externalities allows time to change behaviour, allows time for innovation and allows people to choose not to pay any tax at all if they switch.

(iv) Harmonisation - of collection

There are 352 local authorities in the UK who have been empowered to deploy their own collection containers, schedules, and rules for recycling across the country. Whilst there is a high level of uniformity, there are notable differences between councils, and this causes some confusion and prevents a national campaign advertising how to recycle in the UK most effectively. The likely way forward will be three national schemes accommodating urban, semi urban, and rural needs since housing density and space is a factor. The other principal harmonisation would be to list the materials that are to be collected and mandate that across the UK, removing the current differences where some local authorities collect pots, tubs, and trays, Tetrapaks, and food waste and some do not. A more limited number of schemes will allow better benchmarking, communications, and simplicity to a complex system. WRAP proposed a three-option system which could fit the UK demographics, summarised in Figure 7.12.

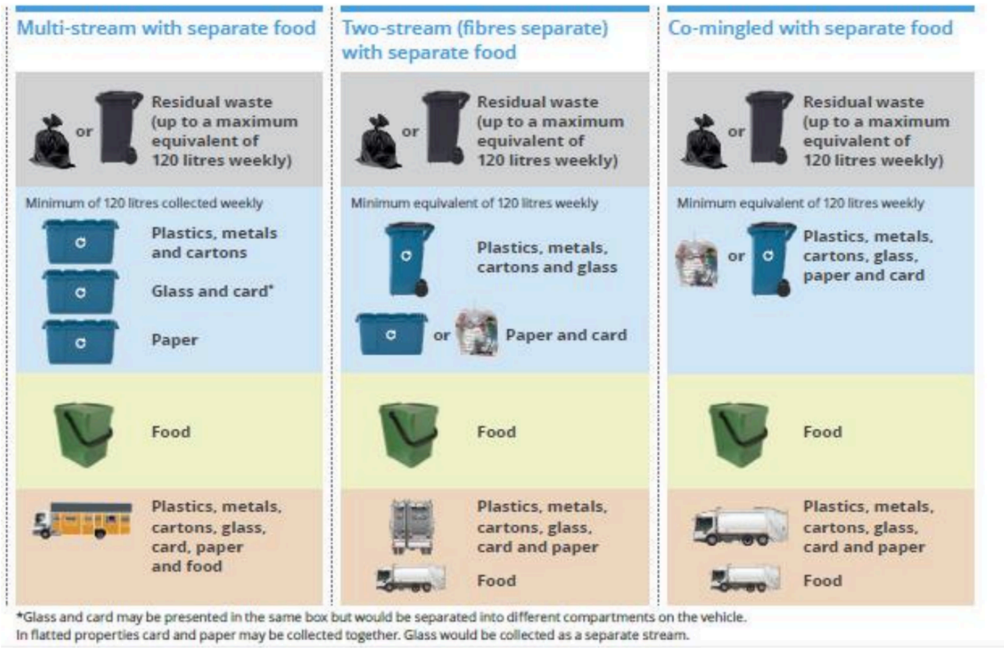


Figure 7.12 Potential harmonised schemes from WRAP (WRAP, 2017).

(v) Harmonisation of labelling

In fact, the collection container and methodology are not the main factors in confusing the consumer, but the complexity of the packaging items themselves are a strong factor (OPRL, 2019). On pack labelling is not uniform, and there are more than 50 types of visual label currently used. A few of the labels indicating different recyclability are reproduced in Diagram 7.13.

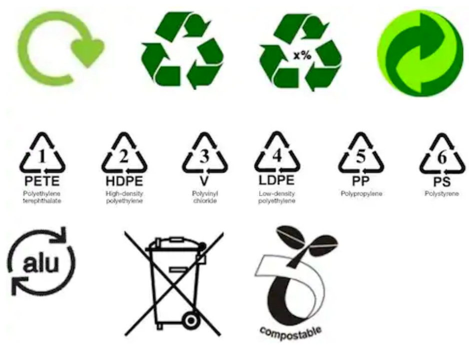


Figure 7.13. Multitude of labels on UK packaging

(https://www.telegraph.co.uk/news/2019/07/03/bring-laws-force-companies-make-recycling-labels-simpler-mps/)

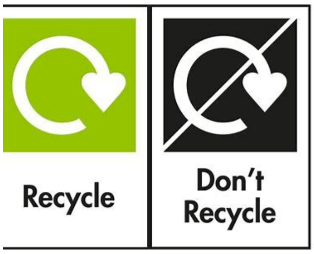


Figure 7.14. OPRL binary label (recycle or not), (OPRL, 2019)

OPRL (on pack recycling label) scheme provides for a binary system, see Figure 7.14, based on clear rules about collection, sorting and recyclability which may evolve into a nationally mandated scheme.

(vi) Food waste collection

DEFRA policy still anticipates that food waste will be collected and funded by local authorities. There is clear evidence that separate collection of the biogenic, biodegradable organics fraction of municipal waste, namely food and green waste, and treatment via composting or Anaerobic Digestion is environmental beneficial. The GHG associated with the 9.5mt of food waste in the UK is around 25mt of CO2 equivalent – which is equal to 10 million cars on the road (WRAP, 2020). Undoubtedly not all this food waste can be effectively avoided, since we cannot eat banana skins, chicken bones and tea-bags, and after reduction at source (e.g. reduction of useful food that householders discard), separate collection facilities in the form of FOGO (food and organics), green only or food only does provide consistent thinking with the waste hierarchy. Consideration of the demographic, geography and density is important (since flats don't have gardens and gardeners can use food waste as compost feed), but all in all the roll out of food and green waste collection, treatment and recovery is desirable. Local authorities are concerned about cost of these schemes since, particularly for food, the quantities per household are small and methods of collection difficult (e.g. odorous, wet). The widespread application of this policy is yet to be tested at scale in the UK, but has had extensive success in Scandinavia, with food waste reduced by some 25% in 5 years in Denmark (Rabobank, 2019).

This policy is important due to its high value environmental impact, but also since it removes wet waste from the streams enabling better recycling of dry wastes. However, discussions with local authorities suggest they are nervous about the costs and the impacts on their budgets from the introduction of collection of small volumes of waste. This policy needs more development to determine where it would best be enforced since some households do not generate green waste and some dwellings do not easily facilitate collection of food waste (multi person dwellings such as apartment blocks).

7.14 Systems Change

System change is always mooted as the need to ensure eco-design, refill, reuse and better upstream and downstream optimisation of human impacts. Together we consider that these RWS policies are impactful, work well together, and will deliver a fundamental system change, whilst not necessarily increasing cost excessively, since the main aspect is a shift of cost from one payer to another. The set of proposals brings together an EPR and a Plastic Tax that moves towards this position of switching behaviour. Packaging will become more expensive (or rather its true cost will be included in its purchase price), that packaging which is less recyclable will be more expensive, and packaging with no recycled content will be more expensive - all proposed to be implemented over a period of time to allow switching to alternatives and so as not to impact unduly low-income families.

7.15 Alternatives and Additional Approaches

Bans on some types of packaging have been proposed as alternatives, for example banning non recyclable materials. Bans can result in unintended consequences, banning plastic bags could lead to cotton, paper or reusable bags being substituted which have higher impact. For this reason, we believe that a carbon tax, albeit notoriously difficult to implement, is required, in order to also level out that factor in decision making.

7.16 Withdrawal from the Environment or a Step Forward

In the midst of the COVID lockdown Q1 2020 we have seen a reduction or partial postponement of key environmental movements;

- The Environment Bill is on hold (2019)
- The Resources and Waste strategy sits below the Environment Bill
- In England, the government has temporarily suspended the plastic carrier bag tax
- The Government is delaying the ban on plastic straws, stirrers and cotton buds
- Scotland has delayed the introduction of its deposit return scheme

During the first months of 2021 we saw the consultations recommence and particularly of importance the strongest components of the new policy, that of EPR, to start progressing.

In the next few years one question may be do we learn from COVID19 and respond with a renewed passion to stimulate growth from environmental improvements or do we revert to a low environmental threshold and focus on capitalist growth alone.

Chapter 8. The role of public engagement in the Circular Economy transition - Plastic packaging as a case study

8.1 Introduction

The building of Circular Economy infrastructure, in line with environmental policy, faces a large variety of social acceptance issues (Higgs, 2006). Appraisal of the impact of siting the facilities is faced with assessing the desirability of the policies, or in many cases in the UK the lack of clear policies or indeed established strategies/vision for the future (Wolsink and Devilee, 2009). The reasoning is that such infrastructure is considered to serve the (proclaimed) public interests, whereas the potential impacts or risks are concentrated at a smaller scale, for example in local communities (Wolsink, 2010). Such risks threaten environmental quality; and a frequent type of environmental conflict arises when the proclaimed public good lies within the domain of environmental policy and sustainability (Higgs, 2006). Public perception plays a critical role in waste management decision making, affecting both what systems (infrastructure) can be put in place, and at the same time if, and how, successful implementation is possible.

In this section, therefore, the link between public communication and waste management infrastructure delivery has been investigated The need for waste management infrastructure is reviewed and how its delivery in the UK has evolved is used as an example of the role of public perception in the planning and delivering of waste facilities. Since it is often on the basis of environmental concerns that the public raises objections to the very infrastructure that is needed to improve environmental quality (Petts, 2004), the role of scientific evidence and the communication of science as a potential source of these concerns is also addressed. Convincing the public that their waste cannot all disappear, nor all be recycled, and that a range of technical processes are required is complex to communicate. To further explore this, this chapter considers the example of plastics packaging, an emotive public topic, to evaluate the relationship between public perception and scientific evidence. The likely real-world impacts of different packaging strategies are considered to offer insights on how to communicate the science to the public.

8.2 Public perception in the planning and delivering of facilities

The progress in delivering infrastructure across the UK over the past 30 years is a good example of the role of public perception in the planning and delivering of waste facilities: The infamous 'Winter of Discontent' during 1978/79 in the UK is remembered for images of uncollected piles of refuse in the streets of major cities associated with a loss of government control (Davies, 2007). Until the late 1980s/1990s the UK was more or less dependent on landfill, with only a small part of the wastes being collected by private entrepreneurs (known as 'rag and bone' men) who would collect economically valuable wastes such as glass or metal (Ostman, 2008). This eventually led to a policy of privatisation and a service formally owned and provided by local government (Ball et al., 2006). UK municipal waste management became one provided by large multinational companies. The Local

Government Act 1988, the Environmental Protection Act 1990, and the Local Government Act 1999 (covering Best Value) enabled the market to evolve using companies to invest in, develop and operate waste management infrastructure. The annual production of in excess of 300m tonnes of materials defined as waste in the UK (ERM, 2006), together with some 30m tonnes of domestic waste (largely biodegradable and methane producing), created a pressing need for investment in such infrastructure that formed part of this new market in the late 1980s/1990s.

The UK changed direction in the early 1990's when it became clear that landfilling was politically unacceptable and that better methods for the treatment of waste needed to be developed (Brown et al., 2017). The EU legislation, the Waste Incineration Directive, the local authorities outsourcing waste collection and treatment to meet the landfill directive, subsequently enacted by the landfill tax escalator, combined to make this happen (Martin, 2003, Brown et al., 2017). As a result, and despite some failures, England has managed to quadruple its recycling rate since 2000 (Figure 7.4, Chapter 7) achieving a rate of 43.2% in 2012/13 (DEFRA, 2014).

The landfill tax was instrumental in moving wastes away from landfill and into alternative treatment and recovery processes. The tax has increased from a starting price of £7 per tonne in 1996, when it was first introduced, to £80 per tonne in 2014 (DEFRA, 2011b). The latter figure increases to £100/Euro110 per tonne, if the operator charges of £20/Euro30 per tonne are also taken into consideration. At this cost almost all alternatives are attractive and the limiting factor becomes the number of facilities and infrastructure that is available to treat the wastes.

The UK's need for waste treatment infrastructure itself has been the subject of keen debate, with a number of studies conducted to determine whether a capacity gap exists (DEFRA, 2013a,b; Ricardo AEA, 2013; Kirkman et al, 2014). Whilst the UK Department of Environment, Food and Rural Affairs (DEFRA) estimates that there is sufficient capacity in the pipeline for the UK to meet the Landfill Directive cap on biodegradable municipal waste (BMW) to landfill in 2020, their analysis does not take into account the treatment of commercial, industrial and other wastes or the appropriate treatment required based on the composition of the waste collected (DEFRA, 2013a). But putting methodological concerns aside, the whole debate on infrastructure needs reduces the need for an integrated waste management strategy to the need to simply meet targets to avoid fines from the EU (Kirkman et al, 2014). Waste management strategy and infrastructure provision should aim to deliver sustainability benefits rather than providing the means to simply meet regulatory requirements. As a result, export of processed waste, currently the cheapest option, is preferred to investing in innovation and change that delivers environmentally sustainable treatment options, materials and energy recovery, while at the same time reduction of waste. At the same time the UK is falling behind; for instance, recycling technology for paper processing in China, whilst variable, is often more state of the art than the UK equivalent, allowing not only higher returns but also better recovery rates and lower energy consumption (Bouton et al., 2010).

Two well recognised examples of successful waste management infrastructure delivery and, for comparison, two where proposed schemes were rejected (Table 8.2) further demonstrate the need for infrastructure, as currently up to 2 million tonnes of residual waste per annum is being exported from the UK to continental Europe (DEFRA, 2011). The lack of national strategy on waste, dearth of financial resources and fierce opposition by local protest groups, sometimes founded on misperceptions and made worse by failures to adequately communicate waste policy and benefits to key stakeholders and the public, were some of the reasons for this (Petts, 2004).

Still, at least 100 major facilities are required in London alone, as increasing London's waste processing capacity has been identified as a major mayoral priority (Veolia, 2012). In the London Plan 2015, boroughs and waste authorities are asked "to identify sites which are potentially suitable for a variety of technologies, depending on the particular site's opportunities and constraints, and assess how many facilities and what type of waste processing facilities/technologies will be required locally to meet their apportionments" (GLA, 2016), and yet obtaining planning permission with the right technology in the right place is becoming more and more difficult. The role of public perception has been central to such developments, with some proposals fiercely fought against by local protest groups because of health and financial concerns (Cabinet Office, 2002). Such health concerns are based on the idea that modern waste infrastructure would pose a health or environmental risk to those living in the vicinity. This is despite overwhelming evidence and confirmation of safety from environmental impact studies and government agencies responsible for health (Steg and Vlek, 2009). The Health Protection Agency confirms that "well managed incinerators make only a small contribution to local concentration of air pollutants" (HPA, 2010), and the UK Environment Agency position statement further confirms that this is a suitable method of waste treatment. Both DEFRA (DEFRA, 2013c), and additionally the EU Environment Directorate also endorses this process, particularly within the Waste Incineration Directive that authorises the activity (EU 2000/76/EC).

The financial concerns are usually expressed in the form of condemnation of excessive profits by commercial organisations, despite the PFI process being highly competitive, with cost often as the key differentiator: that is, lowest price wins. Some pressure groups are advocating exporting solid recovered fuel known as Refuse-Derived Fuel (RDF) to Europe where facilities do have capacity, as an alternative to developing further infrastructure in the UK (Eunomia, 2011). It is suggested that this would allow the UK to develop its recycling and composting up to around 70% (Eunomia, 2011).

This disregards the fact that the RDF currently exported could allow recyclables to be extracted economically, which obviously is currently not taking place. Similarly, the possibility of the introduction of industry treatment standards for RDF, which might reduce the amounts of RDF exported (DEFRA, 2014), are not considered in the forecasting of waste treatment infrastructure needs. By exporting this material, the UK is not only incurring an economic cost, it is also exporting several 100,000 tonnes of biomass contained within the material whilst importing biomass for energy from the US and Canada (JNCC, 2011). Exporting this material rather than building UK infrastructure also has the impact of preventing the roll out of a District Heating network in the UK. In 2009, 40% of Polish households used district heating, most of them in urban areas (Statystyczny, 2012).

The feeling against incineration remains vehement even where it has developed extensively and has produced promising results, such as in Germany (Hee and Quicker, 2013). Additionally, where planning processes have led to the growth of novel technologies such as gasification/pyrolysis (Arena, 2012) and currently in 2015 a large number of advanced thermal treatment (ATT) technologies are being developed. However, many industry operators are pessimistic about their functionality, and they are often considered as purely experimental (Arena, 2012). The feeling against incineration remains vehement even where it has developed extensively and has produced promising results, such as in Germany (Hee and Quicker, 2013).

Additionally, other viable waste management processes have led to the growth of novel technologies such as gasification/pyrolysis (Arena, 2012) and currently in 2015 a large number of advanced thermal treatment (ATT) technologies are being developed. However, many industry operators are pessimistic about their functionality, and they are often considered as purely experimental (Arena, 2012).

Table 8.2 Two examples of successful waste management infrastructure and two where proposed schemes were rejected in the UK

South East London combined heat and power (SELCHP) development

Conceived in the late 1980s, this was one of the first of a new generation of developments (Parau and Joss, 2003). This project proposed to service three London councils' (Lewisham, Southwark, and Greenwich) waste streams, and required construction of an energy recovery facility for the non-recyclable fractions of waste. This almost completely avoided the need for landfill. The aim was to provide electricity to the national grid and eventually district heating (Wheatley and Hedgecock, 1993). The scheme was finally operational in 1994, and went on to be a benchmark case for delivering infrastructure (Parau and Joss, 2003). In 2015 the district heating aspect of the facility has just been realised and stands testament to the fact that these schemes have long digestion times; a hallmark of nationally important infrastructure (Parau and Joss, 2003).

Hampshire ambitious waste infrastructure plan of the late 1990s

An exemplary case of how to develop integrated infrastructure rapidly and to optimize utilisation of the resources arising in the wastes (Petts, 2004). An ambitious waste infrastructure plan was conceived in Hampshire in the late 1990s (Hampshire County Council, 1989). The infrastructure vision required planning permission for 2 recyclables sorting centres, 3 composting sites and 3 incinerators with energy recovery. This plan was delivered combining a network of household waste recycling centres with all forms of waste recovery and treatment to provide a robust and optimised system (Petts, 2000). Very quickly the county moved from around 10% to almost 40% recycling and composting and around 90% landfill diversion in 2011/12 (Petts, 2004).

Locally approved Hertfordshire

A foresighted plan where residual wastes would have any remaining recyclates removed with the residual material used as a fuel to generate electricity, utilising a recognised safe and low carbon technology, would save the local authority around £450m over the project life compared to its current disposal route (Petts, 2004). The planning was locally approved, and yet despite the growth of localism in politics it was called in by the Secretary of State for a planning enquiry (Petts, 2004). The outcome was that the planning decision was reversed by the Secretary of State and the planning denied, PFI credits cancelled and the scheme thrown into jeopardy. A revised plan will be conceived but in the meantime many 100,000s of tonnes of waste will be landfilled bearing financial and environmental costs to the community (Fischer et al., 2011).

Proposed Norfolk recovery incinerator rejection & PFI credits cancelation

Leading to a failure in delivering the local waste management plan (Sunderasan, 2015). Despite having been granted planning permission in June 2012 and an Environment Agency permit in July of that year, the plans for the £500-million Power & Recycling Centre in Saddlebow, Kings Lynn, were called in by the Secretary of State in August 2012 after he found the project concerned 'matters that are of substantial regional and national controversy'. Norfolk County Council agreed to terminate this on April 2014 to protect itself from incurring future costs (Norfolk Country Council, 2014). Still it had to pay the developers £33.7 million (£20.3 million of capped compensation, as well as public inquiry costs of £1.6 million, and costs relating to the ending of the 'hedging arrangement' of £11.8 million). Local stakeholders have credited this as a success, however, the wastes continue to either be landfilled or exported overseas.

8.3 The role of public communication

Understanding the role of public communication is critical to Circular Economy infrastructure delivery. A standardised consultation process has emerged since the Hampshire type project was successful, and this has been repeated in most locations since then, demonstrating some successes and some failures in developing robust schemes (Petts, 2004). For example, several outcomes have arisen from the consultation and public engagement approach adopted to deliver infrastructure in the UK (CBI, 2014).

There is a recurring issue of the public believing that “they do not generate waste”, that all waste is recycled or that technologies such as mechanical biological treatment and gasification are the main current trends (Kirkman, 2017). There also appears to be a large information gap around what happens to waste and recyclable materials once they have been collected. Research in London reveals that a significant perceptual barrier is the suggestion that the Council does not actually recycle all the materials collected (Cabinet Office, 2002). This lack of awareness leads to waste being considered “out of sight, out of mind” (Petts, 2004), and creates the idea that waste minimization is not necessary. On the other side the target of increasing recycling, regardless of actual benefits is perceived as a priority, despite the actual waste composition having an optimum point, beyond which it becomes counterproductive (DEFRA, 2011). This presents new challenges in conveying information on the waste management ‘hierarchy’ (Cabinet Office, 2002).

Energy recovery facilities, or incinerators, have been the most obvious candidates for protest although in fact, similar opposition has occurred with recycling, composting or anaerobic digestion facilities during the planning process (Davies, 2003). In nearly all cases the local opposition has been contentious (UKWIN, 2011), despite these plans presenting a local solution to waste arisings. Success has been dependent on selection of sites with viable planning proposals that are largely driven by local political-will and government support, generating a largely political decision (Petts, 2004). It does appear that the public is rejecting the science and the professional advice from independent authorities, thus choosing to propose their own financial and technical solutions where they may not be best equipped to do so (Chandrappa and Brown, 2012). Could this be one of the fundamental causes behind the public discontent with waste management infrastructure?

In an increasingly complex world with technology and its application out pacing the ability of the majority to understand the details, the main question is how can governments, organisations and companies communicate in order to improve social acceptability of what they propose. The UK has a lot of latent issues which are not being solved; for example, today landfills provide a significant proportion of the renewable energy produced in the UK (circa 3%) but this is declining as we landfill less (Connor, 2003). Still obtaining permissions to replace the landfill stock with alternative treatment capacity has been met with opposition. Despite this, a recent survey of attitudes to infrastructure in Great Britain (Copper, 2015) revealed that 87 per cent of the public support infrastructure investment, and 85 per cent want to see world-leading or solid improvements to existing infrastructure. The report found that almost 9 out of 10 people in Britain want to see investment in new infrastructure e but many also want more of a say in how it's planned and delivered. Interestingly, only six per cent of British people thought there is a 'very well co-ordinated' national or local plan. Many people felt that infrastructure projects happen 'to them', not 'for them' and they do not see any local or national coordination (Copper, 2015).

8.4 Plastic waste as a case study

Only 2% of British people consider plastic, compared to other materials used in packaging, to contribute the least greenhouse gases to the environment from its production, use, and post use treatment (Kirkman, 2020). Whilst in absolute numbers it is a fact the least impactful. Plastics do have a large carbon impact - accounting for 3.8% of global greenhouse gases emissions - but it is wrong to assume that alternative packaging materials would perform better, and it is important to consider the carbon benefits that arise from plastics use (Kirkman, 2020).

When considering the production and manufacturing of the main alternatives to plastic for a 500ml bottle, other packaging types (fibre, glass, steel and aluminium) emit more greenhouse gases than plastic bottles, with glass bottles being the highest emitter overall. By way of example, if all plastic bottles used globally were made from glass instead, the additional carbon emissions would be equivalent to powering around 22 large coal-fired power plants.

This is equivalent to the electricity consumed by a third of the UK. Life-cycle assessment (LCA) is a useful tool which should be more widely used to evaluate environmental impacts of packaging alternatives over their life-time, from the extraction of raw material to the disposal or recycling of packaging at the end of its life. Undertaking LCAs to compare the environmental performance of alternative materials for different packaging applications is essential if we want to take into account the environmental impacts associated with the whole life-cycle of packaging (mining, manufacturing process, logistics, usage and end-of-life route).

Results can vary significantly from one study to another, depending on key parameters and assumptions. For example, the risk of producing more food waste because of the packaging design and shelf life is not always considered in LCAs while this can have a large impact on the packaging carbon contribution. In this study, a total of 73 publications on LCAs comparing different types of packaging were identified and reviewed *(see list in Appendix 8).*

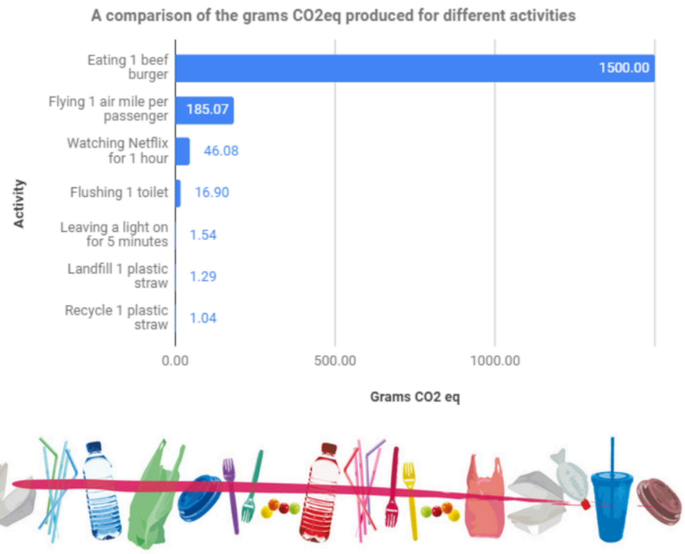


Figure 8.3 relative impact of consumption examples with associated carbon impacts (Kyle, 2019).

Figure 8.3 indicates that eating one beef burger has much higher consequences to the environment in terms of carbon emissions that disposal of a plastic straw, with one burger equal to around 1,500 straws and yet the public has much higher concern over straws and indeed the UK government aims to ban them (DEFRA, 2020b).

By assessing many different studies we can draw some general conclusions about the range of results and what the majority of analysis determined. Findings indicate that in the applications it is used, most of the time, plastic packaging performs better than its alternatives, and mainly due to its very lightweight properties. Transport distance and method, sources of electricity generation, packaging shape and weight, all significantly influence the LCA results and should be considered on a case by case basis. It is also important to consider the full life cycle of the material, such as, for plastic the prospecting and mining stages. The waste management route in place to treat packaging at its end of life, is also shown to be a critical factor explaining variations of LCA results for the same packaging. Recycling always wins over virgin production on all environmental indicators. For plastics, there seems to be consensus that recycling saves between 30% and 80% of the carbon emissions that virgin plastic processing and manufacturing generate.

If all plastic were recycled this could result in mean annual savings of 30 to 150 million tonnes of CO2, equivalent to stopping between 8 and 40 coal-fired power plants globally. The findings of this study demonstrate that if we really want to tackle the environmental issues we face with plastics today then removing, reducing, reusing or recycling the plastic packaging placed on the market is the way forward. This approach is more certain and reaps better results than waiting and hoping for solutions not yet commercialised or switching to alternative available materials respectively. Considering that only around 9% of plastics are currently being recycled worldwide, there is a lot that can be done to improve things. We can see that where the right policy drivers are in place, this is already happening, with regulatory statutes that themselves deliver fiscal actions on business. In concert with the widespread application of renewable energy and demand-management strategies, increasing the recycling of plastics have the potential for both curbing the growing life-cycle GHG emissions from plastics, and also preventing them from entering the marine environment.

Plastic production, use, and disposal all emit significant amounts of greenhouse gases, but the situation is complex and one would be wrong to assume that reducing plastic use or switching to alternative materials would automatically result in curbing emissions. In a paper published in 2019 in the journal Nature Climate Change (Zheng and Suh, 2019), the global assessment of the life cycle of greenhouse gas emissions from all plastics was presented. The overwhelming majority of plastic resins come from petroleum, which requires extraction and distillation. Then the resins are formed into products and transported to market. All of these processes emit greenhouse gases, either directly or via the energy required to undertake them. The carbon footprint of plastics continues after their end of life, since landfilling, incinerating, recycling and composting (for certain plastics) all release carbon dioxide either directly or via the energy and consumables used to undertake the treatment (in the case of landfill for example). Emissions from plastics in 2015 were equivalent to nearly 1.8 billion metric tonnes of CO2, (Zheng and Suh, 2019)). Across their lifecycle, plastics account for 3.8% of global greenhouse gas emissions (Olivier and Schure, 2017). Plastics production has risen from 2 million tonnes per annum in 1950 to 381 million tonnes per annum in 2015, with an estimated 9% of plastic discarded since 1950 considered to have been recycled (Geyer, 2017). Rising plastic production will exacerbate both problems with pollution and climate change. Production is set to increase. If current trend continues, by 2050, it is estimated that total plastics ever produced will reach 34,000 million tonnes (Amienyo, 2013). By then, if the production and recycling systems for plastics do not change, the accumulation of greenhouse gas emissions from plastic could reach 15% of the amount of global carbon emissions permissible to keep temperature rise under 1.5°C (Zero Waste Europe, 2018). With around 8 million tonnes of plastic ending up in the oceans every year, and 3,000 pieces of plastic litter found in every square kilometre of seawater, this not only represents a significant hazard to marine species and human health, but considerable wastage of resources and inefficiency (Leung et al, 2019). Looking at the entire life cycle of fossil fuel-based plastics today, nearly two thirds of its greenhouse gas emissions are produced in the early stages from fossil fuel extractions to the production of resin, while converting resin to pipes, bottles, bags and other products generates just under one third of its emissions, with the remainder coming from the disposal phase (Centre for International Environmental Law, 2017). This indicates there are high carbon benefits of recycling plastics, avoiding those 61% of greenhouse gases emissions from the extraction and resin production process (Brandt and Pilz, 2011), discussed further throughout this Chapter. Despite the large impact of plastics on the environment, their application for packaging offers some environmental benefits (Bright Blue, 2018). Reducing its usage or switching to different materials may have unintended negative consequences.

8.5 The benefits of plastic

Plastic is a versatile material that can easily be made thin and lightweight. It is durable and provides protection from contaminants and the elements. It reduces food waste by preserving food and increasing its shelf life. It protects food against pests, pathogens and humidity. Plastic packaging is more flexible and lighter than alternatives such as glass and card, which reduces transportation costs and the carbon emissions that come with them.

Without packaging, food is more likely to get damaged and become unusable. Since food waste contributes to climate change, water and energy consumption, deforestation and biodiversity loss, every effort we make to mitigate those effects makes a big difference, and plastic packaging helps make that possible. Plastic packaging is useful for keeping products fresh and insulated. Removing plastic entirely from our food supply may not be the best solution when it comes to protecting the environment and conserving valuable resources. Plastic packaging is used in the food supply chain because it supports the safe distribution of food over long distances and minimises food waste by keeping food fresh for longer. A lot of food is air freighted, so prolonging its shelf life has important benefits for the environment. Plastic minimises food waste and conserves all valuable resources involved from farm to shelf. A 2016 review of studies on food waste found that 88m tonnes of food is wasted every year in the EU – that's 173kg per person and equals about 20% of food produced (Dora and Lacovidou, 2019). Minimising this wastage is crucial for environmental protection, as well as food security. Several factors must be considered when determining how useful plastic packaging is in the food supply chain, as it has the potential to preserve food and prevent its wastage.

For example, the use of just 1.5g of plastic film for wrapping a cucumber can extend its shelf life from three days to 14 days and selling grapes in plastic bags or trays has reduced in-store wastage of grapes by 20% (Dora and Lacovidou, 2019). Recent estimates from Zero Waste Scotland suggest that the carbon footprint of food waste generated can be higher than that of plastic, with 456,000 tonnes of food waste produced in Scottish households contributing to around 1.9m tonnes of CO_2, three times higher than that of the 224,000 tonnes of plastic waste generated, (BBC, 2019).

8.6 The carbon impact of plastic bottles compared to other material type containers

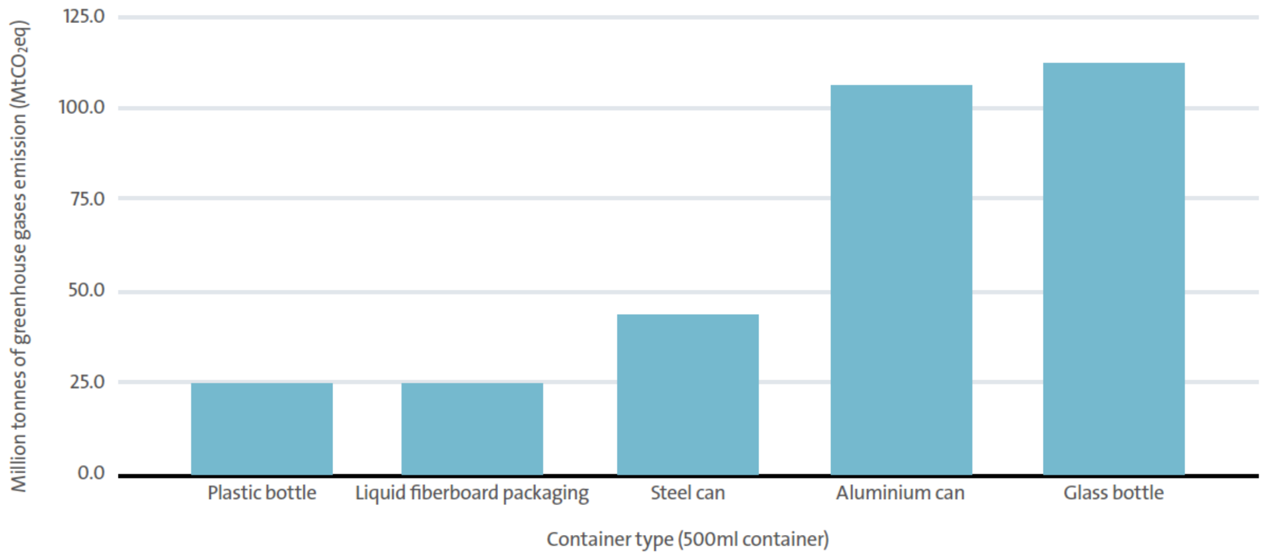
All food and drink packaging, whether plastic or another material, has an environmental impact. There is a lot of emphasis on plastic waste and pollution, but other impacts such as carbon emissions must also be considered when determining which materials are most suitable for different packaging applications. When considering reductions in the use of plastics, it is therefore important to consider the carbon footprint of things that could replace plastic — materials such as paper, aluminium, or glass. It is also worth noting that aluminium cans and carton containers, despite often being explicitly depicted as alternatives to plastic bottles, still contain considerable amounts of plastic.

Aluminium cans often have a complex plastic closure weighing around 4g (nearly half the weight of a single use plastic bottle); glass containers usually include a relatively heavy plastic lid – 14g (meaning they weigh more than a lightweight plastic water bottle); and multilayer cartons usually include nearly 10g of plastic (roughly the weight of a plastic water bottle) (Green Alliance, 2019).

In addition, virtually all metal cans used for food and beverage products are also lined on the inside with a coating that uses Bisphenol A (BPA) as a base protective material, while most plastic bottles are made from polyethylene terephthalate (PET) plastic, which does not contain BPA. To illustrate the difference of carbon impacts from the production of bottles from plastics and alternative materials, we calculated carbon emissions that would have been incurred in 2016 if every 500ml PET bottle produced worldwide was replaced by alternative material. The results are shown in Table 8.4 and Figure 8.5 below.

Note: Emissions have been calculated using the 2019 Conversion Factors from DEFRA that covers the extraction, primary processing, manufacturing, and transporting materials to the point of sale (DEFRA, 2019).

Table 8.4 Calculating greenhouse gases emissions for producing all 500ml containers in 2016 from alternative materials



Container type (500ml bottle or can)	Composition	Weight per bottle (grams)	Tonnes in 2016 (485 billion bottles)	Tonnes CO_2-e per tonne of 500ml bottles/cans produced*	Million tonnes of CO_2 in 2016 from production if all plastic bottles were replaced by this format and material*
Plastic bottle (baseline)	Plastic (PET)	12.7	6,159,500	4.053	25.0
Liquid fiberboard packaging	Plastics (50% PET closure and 50% PE layer)	8	3,880,000	3.585	25.5 (+0.5)
	Aluminium	1	485,000	12.874	
	Carton	13	6,305,000	0.844	
Steel can	Steel	30	14,550,000	3.004	43.7 (+18.7)
Aluminium can	Plastics (PE layer)	4	1,940,000	3.116	105.9 (+80.9)
	Aluminium	16	7,760,000	12.874	
Glass bottle	Glass	259	125,615,000	0.895	112.4 (+87.4)

Figure 8.5 Greenhouse gases emissions for producing all 500ml containers in 2016 from alternative materials

Carbon emissions from the production of plastic bottles are lower than all other materials equivalent: glass, aluminium and steel in particular, glass bottle being the worst alternative from a carbon perspective. If all plastic bottles used globally were made from glass instead, the additional carbon emissions (87.4mtonnes of CO2eq annually) would be equivalent to powering 22 coal-fired plants (EPA, 2020). Although plastic bottles perform similarly to liquid fibreboard packaging in terms of carbon impact during the production process, they are much easier to recycle and thus should have a lower carbon impact if we were considering their end of life. The necessity to capture all environmental impacts of a packaging full life (including its end of life), and to capture the complexity of each specific packaging design produced in a specific supply chain and disposed in a specific waste management system, advocates to use a more detailed life cycle approach to assess the environmental impact of one particular packaging. Note: It is important to note that there will be examples when alternative materials still make sense, for example the widely cited reusable milk glass bottles case where it is evident that emissions can be lower when the farm is local, bottles are filled and distributed by electric milk floats (running on low carbon electricity) in a locality close to the milk distribution centre, and are then cleaned and reused (not forgiving the detergent and water required for the cleaning) (WRAP, 2010).

Therefore, every case must be assessed in its own merits, since there will be examples of Liquid Fibre Board, Metals and Glass presenting better packaging solutions on a carbon basis (DEFRA, 2019).

8.7 The science: Life Cycle Assessment (LCA)

Life cycle thinking is increasingly seen as a key concept for ensuring the sustainability of resources production and consumption. Over the years, life cycle assessment has been used extensively to assess products from “cradle to grave” - from extraction of resources to end of life management. The assessment has been formalised by the International Standard Organisation (ISO) (Geneva, Switzerland). LCA is based on an iterative process with four steps, i.e., goal and scope definition, inventory analysis, impact assessment, and interpretation.

In January 2018, when the European Commission adopted the European Strategy for Plastics in a Circular Economy, they proposed a vision in which alternative materials and feedstocks should only be developed and used where evidence clearly shows that they are more sustainable compared to the non-renewable alternatives (European Commission, 2018). In particular, they promoted specified specific actions aiming at better understanding the life-cycle impacts of alternative feedstock for plastics production. LCA provides a quantified methodology to assess the environmental performance of goods and processes. The cradle-to-gate LCA study usually starts with raw material extraction and ends with the final products leaving the factory gate (Madival et al, 2009).

A cradle-to-grave study starts with raw material extraction and ends with the disposal of product in landfill, incineration or recycling. A cradle-to-cradle study starts with the same process and considers not only the final disposal but also the energy recovery from incineration or the raw material replacement due to recycling of the studied products (Madival et al, 2009).

In the assessment, the burdens imposed on the environment by plastic packaging is ascertained by accounting for the resources and energy (inputs) consumed at each stage of the system and the resulting pollutants and wastes (outputs) emitted. Unlike issues such as energy, water, and material use, which can be measured during the production process, "impact of plastic litter on the environment" is not easy to express in figures. Plastic crumbles into smaller and smaller pieces that enter the food chain, resulting in unknown effects on our health.

Despite the increasing concerns regarding the impacts of plastic in the marine environment, including the long-term impacts associated with their durability under marine conditions of cold and dark which inhibit degradation, there is a stark lack of literature on the LCA end-of-life impact in the marine environment. Woods et al. (2016) examined the use of LCA for marine ecological impacts, and singled out key stressors such as ocean acidification, over exploitation and invasive species in order to examine approaches to quantifying their effects on the biodiversity of the marine environment (Woods et al, 2016).

However, for marine plastic debris they concluded that no methods have yet been proposed to quantify the effect of plastic waste on biodiversity at any scale greater than the individual organism. The Medellin Declaration in 2017 has addressed this need but it remains unmet (Sonnemann et al, 2017).

Keeping this limitation in mind, LCA still remains the best existing assessment tool to compare the environmental impact of packaging alternatives. In the following section, we review existing LCA studies on plastic packaging and its alternatives and discuss the main factors driving its environmental impact

8.8 Methodology for comparing packaging alternatives - review of life cycle assessments

A total of 73 LCAs were identified, and information on LCA procedures including scope and boundary, functional units and analysed life cycle impacts were reviewed and are summarised here. Most LCA undertaken for various plastic uses show plastic performing better than the alternatives from a carbon perspective.

Even if, ounce for ounce, some kinds of plastic have a higher carbon footprint than other kinds of packaging, less quantity is used reducing overall impact, as plastic is light. Plastic performs better most of the time (for example heavier-duty plastics, such as low-density polyethylene or woven polypropylene bags, do have a bigger climate and energy impact than paper, but they're more durable and you get more use out of them).

Several studies have shown many materials used as alternatives to plastic in packaging, such as cotton, glass, metal, or bioplastics, to have significantly higher CO2 impact or water usage compared to plastic packaging.

On average over current food packaging, replacing plastic packaging with alternatives, would increase the weight of the packaging by 3.6 times, the energy use by 2.2 times, and the carbon dioxide emissions by 2.7% but these can vary significantly for different cases (Hansard, 2019).

Some examples are highlighted in Figure 8.6 overpage.

Plastic versus glass

Humbert et al. (2009) showed that plastics perform better than glass packaging in terms of production and waste treatment processes based on global warming scores. The steam consumption with ultra-high temperature processed used in plastic packaging systems is lower that those used in producing glass packaging. Although Accorsi et al. (2015) showed than PET bottling lines comprising many automated working stations is more energy consuming compared to glass bottling lines, they also showed it is more efficient when dealing with input materials. Plastic packaging is lighter, and this leads to a significant reduction in packaging transportation. Glass packaging performs worse for impact categories such as primary energy demand, abiotic depletion, acidification potential, human toxicity potential, terrestrial toxicity potential and photochemical oxidant creation potential (Accorsi, 2015). A 2L PET soft drink packaging in the same study was shown to perform best across most of the impact categories.

Plastic versus aluminium

According to EIA studies on beverage packaging, plastic bottles perform better than aluminium cans. Amienyo et al (2013) pointed out that aluminium can production causes higher global warning potential than PET bottle production. Due to high emissions of PAH and hydrogen fluoride during aluminium can production, the human and marine toxicity are disproportionately higher for aluminium cans than PET bottles compared with their market share in the Amienyo study. Pasqualino et al. (2011) as well as Simon et al. (2016) had similar findings with the aluminium cans intensive thermal production performing worse for the environment. Plastic product saved 57% more energy and 61% more GHGs emissions compared to alternatives in these respective studies.

Plastic versus paper

Comparing plastic to paper bags, the global warming potential of paper bag production was shown to be much higher due to the need for fertiliser during the tree farming and plantation phases (Brandt et al, 2011). Moreover, cardboard production, as a common stage of paper packaging production, has significant water depletion potential. Paper packaging production is also responsible for greater ecosystem quality damage due to the land use required for wood pulp as a paperboard production input.

Figure 8.6 Comparing packaging alternatives from various sources

8.9 Important factors impacting a packaging LCA

While LCAs are widely used to inform discussions on packaging, the inherent complexity in capturing the environmental impacts of packaging means that results will vary based on the details of the methodology used. For example, food waste can or not be taken into account in a food packaging LCA via shelf-life extension or via other drivers linked to the packaging design (e.g. trimming and multipack). The shape of the packaging container also influences the overall environmental performance of the system since the amount of resin used per container varies in different shapes. The stackable container consumes more resin for enabling distribution without any crates, resulting in high greenhouse gases emission and energy consumption associated with the production process.

Containers with different plastic materials also have various scores in impact categories due to the container mass. PET strawberry packaging with higher container weight is worse for the environment compared with similar PLA or PS packaging (Humbert et al, 2009).

Though some LCA studies claimed that transport-induced environmental impacts are much smaller than the environmental impacts of packaging production (Amienyo et al, 2010) most pieces of literature have considered transportation within the life cycle impacts. The results of the country-scale LCA study in the United States also suggest that railway transportation has a better environmental performance than the truck one (Madival et al, 2009). Different weight of packaging material types also influences the transporting related impacts. The heavier the packaging type is, the higher impact is generated within the transportation phase (Pasqualino, 2011). Another LCA study on olive oil packaging suggested that the preferable packaging changed with distribution distance. Glass bottles were more suitable for local transportation while tinplate cans were chosen for long-distance distribution. Besides, a reduction in the average distance travelled to market can improve the overall environmental performances of heavier packaging containers (Cleary, 2013)**.** In summary, transport-efficient packaging depends on several factors including food ingredient, type and amount of used packaging materials, and more importantly, travel distance between producer and retail as well as transportation mode (Katrin, 2016).

Technological advances and changes can also alter LCA results, as materials improve over time. Over the past years the gram weight of the 16.9 ounce “single serve” bottled water container has dropped by 32.6% (Forcinio, n.d.). The average PET bottled water container weighed 18.9 grams in 2000 and by 2008, the average amount of PET resin in each bottle has declined to 12.7 grams (Forcinio, n.d.). The amount of aluminium and steel used to produce cans has also been reduced by around 50% in the past 40 years: a 500ml aluminium can now weighs around 16 grams, while a steel can weighs around 30 grams (Metal Packaging Europe, 2020). Transport costs are a function of weight, so this further reduces outgoings and also CO2 emissions. Another important factor in the LCAs is the source of electricity and the type of energy supplied during the whole product life which can dramatically influence the total environmental impacts (Khoo et al, 2010).

8.10 Importance of recycling

Finally, considering the waste management capabilities of locations/countries where waste is collected at the end of its life is essential to have a full and accurate LCA. Many environmental impacts, such as environmental leakage and chemical migration, are not captured well by LCA when real-life waste scenarios are not considered. Changing waste management practices for food waste, including increasing redistribution, or separate collection of organic waste for composting and anaerobic digestion, for example has the potential to reduce the impact of waste and LCAs could be used to explore the waste reduction potential of these activities.

Some LCAs maintain the assumption that all products are collected, recycled, and reused in the end-of-life phase. The reality, however, is not that simple; and often depends on recycling rate in a particular study/country/city. End of life scenario has a great impact on the LCA results and on what can be done to reduce impacts, as currently 79% of plastic worldwide ends up in landfills or the environment (Maga et al, 2019). Similarly, in some studies (Accorsi et al, 2015), where plastics perform better, it is assumed that the PET material recycling systems are operated with a high share of high-grade recycled PET in a closed loop. Assuming a high proportion of recycled PET in bottle production might not be a realistic assumption in some countries on one hand, on the other it shows the importance of closed loop recycling in improving the environmental performance of plastics. Amienyo et al. (2013) showed that increasing recycling rate to 60% of PET bottles would save approximately half of the emissions, equivalent to 445,000 tonnes of CO_2 eq. every year in that study (Amienyo et al, 2013).

Recycling wins over virgin production on all environmental measurements, especially when it comes to carbon emissions. Estimates vary with the type of recycling process used, but researchers agree that recycling and remanufacturing plastic saves between 30% and 80% of the carbon emissions that original processing and manufacturing produces. That could mean annual savings of 30 to 150 million tons of CO_2, given our previous calculations of carbon emissions from plastics production. An LCA study showed that the environmental impact of PET bottle-to-fibre recycling compared to virgin PET fibre and other commodity fibre products, i.e. cotton, viscose, PP (polypropylene) and PLA (polylactic acid) offer important environmental benefits (Zhen and Suh, 2019). Depending on the allocation methods applied for open-loop-recycling, non-renewable energy use savings of 40–85% and global warming potential savings of 25–75% can be achieved (Zhen and Suh, 2019). Recycled PET fibres produced by mechanical recycling performed better than virgin PET in at least eight out of a total of nine categories used in the study, with recycled fibres produced from chemical recycling performing better in six to seven out of nine categories compared to virgin PET fibres.

8.11 Conclusions

According to a recent YouGov poll (YouGov, 2019), only 2% of British people consider plastic, compared to other materials used in packaging, to contribute the least greenhouse gases to the environment from its production, use, and post use. The survey findings prompted a better understanding of the issues amongst the wider public to help them make “informed” decisions.

Indeed, as reviewed in this work, in terms of carbon emissions, plastic is often the packaging material that is least damaging to the environment from a whole life cycle perspective, particularly when used in closed loop recycling, and most alternative packaging are actually not plastic free.

It should not be dismissed that plastics have a large and unacceptable impact on the marine environment and potentially impacts to human and ecosystem health that are not yet well understood and which cannot be easily expressed in figures and incorporated into life-cycle assessments. This complicates the choice made between carbon emissions versus marine pollution, environmental and health impacts in terms of deciding what to choose for packaging.

However, we believe this dilemma must be pragmatically managed. Environmental bodies and industry are already supporting the view that climate is one of the most serious threats to the ocean, certainly in the long term, which indirectly restricts most of the options for replacing plastics. On the other hand, global demand for plastics is expected to increase by some 22% over the next five years, with GHG emissions from plastics reaching 15% of the global carbon budget by 2050 (Zheng and Suh, 2019). This anticipated growth of plastic production is of real concern, but we need to recognise that production is growing in response to increasing global demand for lightweight automotive parts, building insulation, and product packaging—all of which will play an important role in reducing greenhouse gas emissions and helping people live more sustainably around the world. We must be mindful to not fix a problem by removing one of the solutions.

What is clear is that we need to reduce plastics production while ensuring that any alternatives do not contribute more to climate change, and this is where recycling comes in. The emissions reductions from eliminating the need for new plastic outweigh the slightly higher emissions that come from processing wastes to recover plastics. The findings of this study indicate that if we really want to tackle the environmental issues we face with plastics today, removing, reducing, reusing or recycling the plastic packaging placed on the market is an important part of the way forward, and a better option to replacing it with current alternative materials or waiting and hoping for solutions not yet available. Considering that only around 9% of plastics are currently being recycled worldwide, there is a lot that can be done to improve on this. We can see that when the right policy drivers are in place, this is happening already, with regulatory statutes that themselves deliver fiscal actions on business. For England, the various measures planned in the Waste and Resources Strategy planned by DEFRA, such as the extended producer responsibility scheme, the deposit return scheme and the harmonisation of waste collection associated with a clear labelling system, as well as HM Treasury proposals for a plastic packaging tax are all good steps for creating a fully functioning circular and sustainable system for packaging. Increasing the levels of recycled content in plastic packaging can reduce both the need for manufacturing plastics and the amount of plastic wastes produced (Voulvoulis, 2019). As recycled plastic is more expensive than virgin plastic, the future plastic packaging tax announced by the UK government will be a key initiative to drive the market, increasing the recycling infrastructure and ultimately improving plastics recycling rate. Widespread application of renewable energy, recycling and demand-management strategies in concert, have the potential to curb the growing life cycle GHG emissions from plastics. Recycling can also play a key role in stopping plastics entering the marine environment, as once collected the chances of plastic waste entering the environment are reduced or at least there is clear accountability in what ultimately happens to plastic waste.

8.12 Implications for public communication

The front cover of National Geographic in March 2015 and the associated article by Joel Achenbach describes the current *Age of Disbelief*, suggesting that in the contemporary environment large numbers of citizens reject the evidence that scientists painstakingly compile (Achenbach, 2015). In an age where technology is arguably at the forefront of human development, where science, engineering and innovation are driving the economies of the world, people are less engaged than ever in the science and the facts around how the world works, and what will impact all of us based on our actions.

Although the IPCC (IPPC, 2013) reports that climate change is mainly caused by human activity, less than 50% of non-scientists have the same view (Fischer et al., 2011). The concept of reengineering business models of consumption and developing a more 'Circular Economy' presents a solution and yet the majority of UK consumers are not aware of what this term means (CIWM, 2014).

Petts (Petts, 2004) suggests that there is a requirement for a decision support framework utilising multi-criteria decision-making with full public participation. They also suggested that current decision tools are weak and not integrated (Petts, 2000). This is supported in the experience of consolidating tools such as financial models (outline business cases), environmental assessment tools such as WRATE (Waste and Resources Assessment Tool for the Environment), health risk assessments within the context of an environmental impact assessment, and the multiple considerations for public engagement processes. In some earlier work the author also advocates the application of community advisory committees and citizen juries in waste decisions (Petts, 2001). It is expected that better provision of the right information on multi criteria assessment by independent bodies, which are adequately qualified, might provide better communication. Still, the hypothesis that public awareness alone will lead to better engagement and social acceptability is unsupported.

Almost all public policy issues have scientific or technological implications. Everybody, therefore, needs some understanding of science, its accomplishments and its limitations. Scientific literacy is a prerequisite for citizens to make informed decisions and be informed consumers (globalisation of society and economies requires one to understand science and technology). Many personal decisions would be helped by some understanding of the underlying science e not just the facts but also the method and its limitations as well as an appreciation of the practical and social implications (Lutz, 1985). This would help with public communication and could help promoting public engagement and participation.

For example, despite recent UK Government commitments to encourage public participation in environmental decision making, most exercises conducted have been largely confined to ‘traditional’ modes of participation such as the dissemination of information and in encouraging feedback on proposals through, for example, questionnaires or surveys (Higgs, 2006). A public engagement system that better facilitates the reinvention of society’s issues, backed by good science may be what is required.

On the other hand, the policy domain of waste is internationally well known for its environmental conflicts (e.g. Gallagher et al., 2008; Elliott and McClure, 2009). A recent report by Sir John Armitt into how to rebuild the country’s crumbling transport, energy, telecoms and water infrastructure, calls for the establishment of a new National Infrastructure Commission charged with evaluating the UK’s needs 25-30 years out (Armitt, 2013). It is reported that about 10% of the UK’s current energy generation stock at risk of closure as coal- and oil-fired power stations become uneconomical under new emission restrictions, and the water industry highly underinvested with 5 year investment terms leading to low capital expenditure but resulting in high operating costs and non-optimal total cost. It raised the risk of waste infrastructure being added to this list of infrastructure failures. By contrast, the government has been advised by DEFRA that European targets will be met with no further policy or investment required in waste management. During a period of extreme fiscal discipline, the government would rather hear that we have enough infrastructure. Still, when the EC proposed 2030 objectives for review, with phasing out landfill waste dumping and a 30% cut in food waste by 2025, and recycling targets of 70% for municipal waste, 90% for paper, 60% for plastics, 80% for wood and 90% for ferrous metal, aluminium and glass for 2030, the UK Government opposed such binding targets to cut waste and improve recycling. On the contrary, using the ranges of inputs that they believe to be realistic, the proportion of forecasting simulations for meeting the target was found to be very high and financial support for a number of planned waste treatment projects has been withdrawn as a result. To make things worse, the associated impact on public perception is expected to damage further the evolution of new schemes. Significant risk and investment is passed onto the private sector, left vulnerable to any consequences of power or material price fluctuations

(Sunderasan, 2015). With the exception of some residual schemes in construction and some novel technologies, which are unlikely to deliver, waste infrastructure development in the UK has ground to a halt.

The link to public perception is clear. Negative public perception of biomass is generally based on a lack of information and is fixed on environmental concerns about timber cutting, fear of noxious smoke, noise, traffic, disinterest in handling solid fuel, and concerns about system reliability, performance, and maintenance (Cabinet Office, 2002; BTEC, 2015). This perception often comes from an antiquated understanding of technology and does not account for the tremendous progress made in system design, efficiency, and emission reduction (BTEC, 2015).

Moving forward, an open dialogue with all stakeholders is necessary for disseminating factual information. The dialogue must include an active role in listening and responding appropriately to voiced concerns, particularly those that are founded in misperceptions, and willingness to compromise. This failure to adequately communicate to the key stakeholders and the producers of the wastes is leading to non-optimal final outcomes with millions of pounds spent on failed PFI contracts (Petts, 2004). Political cycles tend to be on a 5 year basis, and therefore infrastructure needs tend to suffer from this short-termism (Petts, 2004).

Whilst it is not the only way to address the packaging conundrum, we can - at least in part - recycle our way out of this problem. Building a sustainable system for packaging and all the products we use every day is achievable, but only if we accept to continue using plastic when it is the most carbon efficient option, supporting any material choice with scientific facts and not led by popular beliefs. Still, heightened public awareness of the growing and unsustainable plastics production provides policy makers with a unique mandate for change and businesses with opportunities for using packaging that can be easily recycled and reused. Making the transition to a sustainable Circular Economy is an important goal for society, yet, the complexity and interdependencies of such an undertaking mean that ecosystem-wide orchestration is necessary. Strong regulations and policies have a clear role to play in supporting recycling if we are ever to reach as a society a truly circular sustainable state

Chapter 9. Overall Discussion (Future Trends and Recommendations)

9.1 Introduction

This discussion is structured in two parts. The first part to ensure that the research delivered across the thesis is realistic and that the findings remain up to date with developments in this fast-changing sector, we first considered what impacts will or could **rapid technological change** have from the wider environment (digitisation, home working etc.) or within the waste field (e.g. gasification, energy) and with respect to the impact on efficacy of policy frameworks and tools.

In the second part, the findings from each of the studied topics in the thesis have been assembled and discussed, drawing together the key findings of the research, to make recommendations that take into account policy options, incentives and tools, communication matters, and technology impacts over time to geographies or authorities with an ambition to implement a Circular Economy in their region are made.

9.2 Technology trends that may impact policy tools

In order not to miss any significant technological, social or economic trend in the global market a wide set of views was required from subject matter experts and industry players. The objective here was to understand potential future market scenarios and to ensure the current policy proposals and direction of travel were consistent with those futures, since technology has a key role to play in policy evolution (Chertow, 2001). For example, would it be unwise to develop a Circular Economy if we considered that wastes would not exist in the future, and what do we think the technological trends might be.

9.3 Future technology scenarios

Forecasting technological development is inherently difficult due to uncertainty around the rate of scientific discovery in any given field. We took the approach of bringing together the leaders in technical development within their industrial and municipal fields, largely the practitioners who are within the economy and responsible for the development, representing Manufacturing, Food, Pharmaceutical, Energy/Estates and Local Authority sectors.

The research took the form of questionnaire, interview, and workshop in order to elicit trends and indicators of future scenarios and to ascertain any common elements which may impact long term policies which may be put in place today. The objective of this work was to conduct live discussions with practitioners to elicit their views on where they were taking their organisations into the future, since regardless of actual future direction, their current thinking and actions would shape current policy success.

Three principal workshops were held with groups from municipal/public sector and industrial backgrounds, as well as an energy workshop which emerged as a common trend form the initial two. The target set by the groups was to imagine 2050 for their field. Policy trends were considered, topic areas were posed against each trend, and the most pertinent or repeated comments were recorded after consensus was reached on the most important indicators. Three reports were also produced summarising findings for both a Municipal, Industrial and Energy focus.

Global megatrends were identified common to both sectoral threads, municipal and industrial, one respondent noting "There is a convergence of forces energising the economy, technological innovation, connected humans and a pressure on resource availability that together are driving responsible businesses to include environmental factors as a catalyst for their growth". The studies indicated that from climate change to autonomous vehicles, the challenges we will face in the next 35 years will stem from two key megatrends: **population growth** and **advancing technology.** Together these will mean more people connecting in new ways, leading to an acceleration of ideas and innovation. 34% of the European population are estimated to be aged 60 years or over in 2050 (United Nations, 2006). The specific transversal trend of Energy security, supply and resilience was identified particularly since its climate change contribution is significant and a further study was conducted with a similar approach to workshops of experts in order to elicit the value of energy and specifically the role waste may play. The report was named *Keeping the lights in: Operating without fossil fuels*, Veolia UK, (Amouyal, 2019). The results of the three workshops and interviews are summarised in **Appendix 10** with the main Trends listed and topic areas recorded.

9.4 Municipal Trends

The summary of the points raised under the Municipal Technology banner, main trends identified and limbs of each trend (topics) is summarised here

Municipal Technology
TREND #1 - Population Growth
Topic: Resource Efficiency
Topic: Smarter waste to use space
Topic: Changes in healthcare
TREND #2 - New Technology
Topic: New skills / jobs for workforce
Topic: Smarter solutions
Topic: Role of Cities
Topic: Nanobot sorting (recycling)
Topic: Intelligent packaging
Topic: Underground waste collection

Table 9.1 Municipal Technology trends

9.5 Municipal Discussion

Undoubtedly, the behaviours we develop as society will play a key role in policy success. Any tourist staying in a hotel in Scandinavia will see recycling bins in their room. The local fast food restaurant will have three bins for food, plastics and paper and if you don't use the recycling on-the-go bins correctly, people stop and stare at you until you fix it. In short, at least in Scandinavia, the social battle seems to have been won. This level of awareness and cultural acceptability has yet to percolate into the UK and other European countries or further across the globe. We are certainly well on our way and the convergence of social, economic and environmental probity is taking a foothold. There was a time when the majority looked at recycling with great scepticism, wondering whether these highly valuable resources might be secretly going to landfill, worrying about exports to China, or debating the health impacts of waste management.

However, views and behaviours seem to be changing amongst the general population and the media. Even under the new dynamic of austerity – and perhaps because of it.

Using the technological know-how we have today, combined with the seeds of innovation and pioneering technology to improve our future cities, we can make progress. We believe this will enhance and protect the natural world around us, leading to a better social environment for future generations. We expect the home of the future to be underpinned by green building materials, protected water and material sources, low carbon energy supplies and a zero-waste strategy. Not from cradle to grave - which implies a disposal point - but via a circular approach.

Packaging as we know it today, literally, has a limited shelf life. We expect advanced chemical processes, depolymerisation and molecular dissolution to create more complex packaging and intelligent materials that can be de-manufactured or re-engineered after each use.

Technology to sort materials is already growing exponentially, with infrared, spectroscopy, robotics automation and sensing technology leading the way. Processes long used in automotive manufacturing are being adopted more readily each year. This will make recycling easier than not recycling because it takes people's choices out of the equation.

We are likely to see sustainability hard wired into our society. Advanced biotechnology will thrive and new materials such as plastics made from sewage sludge will provide the future security of supply for consumer products. We expect a complete circular approach with no wastes generated. As in nature, each waste will be the feedstock for the next system. Centralised traditional manufacturing will decline and be displaced by 3D printing, the 'replicators' from science fiction becoming a reality for the next generation.

We also expect to see waterless cleaning as standard in many fields, such as washing of clothing and home furnishings. Material and water resources will be reused many times and the closed cycle will become the norm. The carbon era will have come and gone. For energy we will seek solar, wind and wave and biofuels amongst the new energy resources.

To make this future story into a reality we believe three things need to change. Firstly, **attitudes** – the public must begin to accept that treatment, and in the future, manufacturing plants may be on their doorsteps or at the end of their street. As we move into the Circular Economy these materials will no longer be seen as waste, but more as a valuable commodity. However, things will only change when attitudes towards them improve.

Secondly, **planning** must be streamlined. Government must recognise that building green infrastructure is key and must be pushed forward and not held back by bureaucracy. If we work closer with communities to engage them and provide the benefits of jobs, investment back into the local economy, as well as reducing carbon dioxide emissions, the full potential will be realised to create a sustainable city.

Finally, **businesses** must engage in the Circular Economy. As they create new products on to the market, it must be recognised that virgin materials should be dramatically reduced if not eradicated. They must work with manufacturers of green products to provide the public with only sustainable options and best practice. We have the waste materials so let's mine them for the resource.

9.6 Industrial Trends

The Industrial Trends were focussed on Manufacturing, Pharmaceutical, and Food sectors, a function of the experts available, but also representing a large part of UK asset base and GDP.

Table 9.2 Industrial Technology trends

MANUFACTURING Industry

Industrial Technology

MANUFACTURING

TREND #1 - Hyper efficient business models
- Topic: Adaptable production lines
- Topic: Selling benefits, not products
- Topic: Assets in the seas

TREND #2 - Next generation materials
- Topic: Technological alternatives
- Topic: Biological materials
- Topic: Manufacturing wastes as a tradable asset

TREND #3 - Rise of Robotics
- Topic: New era of efficiency
- Topic: Connected thinking
- Topic: Onshoring

PHARMACEUTICAL Industry

Industrial Technology

PHARMACEUTICAL

TREND #1 - New Dynamics
Topic: Collaboration and convergence
Topic: Shift the value

Topic: Mining metals (from waste)
Topic: Localised production

TREND #2 - Personalised health
Topic: Data driving customisation

TREND #3 - Biofutures
Topic: An evolving opportunity

FOOD Industry

Industrial Technology

FOOD

TREND #1 - Food but not as we know it
Topic: Cultured meat (grown form petri dish)

TREND #2 - Emotional investment
Topic: Deeper consumer connections
Topic: Technology and bespoke nutrition

9.7 Manufacturing, Pharmaceutical, Food Discussion

The visions of the future relied heavily on technology change based on extrapolation of the existing research fields, such as automation, robotics, digital as well as new technology in pharma and industrial applications.

It was notable that the theme throughout implied that waste would be streamlined into material flows, presenting separation and logistical challenges but relying on new materials and ways of handling those materials post use which could render them immediately and more readily useable again either as a material or a fuel.

The work appeared to be consistent with the policy direction and incentives discussed in this thesis and we do not expect technology to present a particular barrier to

We believe the miniaturisation of waste treatment systems will reduce centralised plants to facilities, processing rubbish onsite. Smaller businesses could see shared facilities installed and managed by Veolia. Combined with rapid advances in extraction from waste, this could help all businesses achieve a 100% recovery rate.

We're already extracting and selling fertiliser, road salt, paint thinners, glass, fibre, road building materials, plastic polymers for car bumpers, and oils from waste. We're also looking at how we can recover materials like precious metals on a commercial scale and turn sludge into plastics. This means businesses will be able to trade these products on the open market through our existing waste management brokerage teams.

Pharmaceutical and chemical

By 2050, we see the pharmaceutical and chemical industries facing increasing regulation around how they use and dispose of resources. Waste companies are already working within these industries to design efficiency into products from a concept stage – rather than just treating the generated waste at the end. Waste companies are extracting glucose from organic waste to be used as feedstock for production. This reduces costs by avoiding the need to grow and harvest crops. In the future, our role may evolve to help keep the country healthy. With recent advances in sensor technology, it's possible that local health authorities may work with waste companies to monitor municipal water supplies to detect early signs of contamination and disease. This data could be used to ensure preventative treatments are available by keeping pharmaceutical companies one step ahead of illness. The pharmaceutical industry will ensure better quality healthcare and the chemical industry will become a key enabler of emission reductions, with both industries enabling wider positive change across other sectors**.** **£805** million worth of hidden value in the pharmaceutical and chemical industry in their unutilised resources. To take advantage of this within a Circular Economy context we need to revolutionise the way we source, produce and consume food to feed a growing population.

By 2050, we see cost pressures and concerns around food production leading to major changes across the food and beverage sector. Water and energy will be central to this debate.

We are already trialling a process to unlock the commercial potential of biomass ash, by turning this into a phosphate-rich fertiliser. If successful, the remains of one whisky batch could eventually help to grow the crops that make the next.

By 2050, we see new technology playing a significant part in helping both businesses and communities keep energy prices to a minimum. Biomass combustion technology, anaerobic digestion processes and water recovery systems cannot only produce enough energy to power the factory, but thousands of local homes as well.

£464 million worth of hidden value in unutilised resources within the food and beverage industry.

9.8 Energy – a ubiquitous impact

Energy was a common thread in discussions - In both municipal and industrial groups - concerning future industrial and municipal trends. Arguably energy is pervasive across all aspects of environmental threat, since with unlimited energy we can recycle anything and clean anything, it is a limiting factor. Also, it is a very near and present danger in terms of its changing impact on policy. In this section we discussed with the industry experts the changing face of energy provision to their sectors and conducted a literature review of current thinking.

At a later stage in the research period we considered it was useful to undertake supporting research into the role of decentralised energy, energy efficiency and the move away from fossil fuels, and the role energy has in supporting the UK economy, with respect to the contribution waste can play in providing renewable energy.

This report sets out to discover whether we are being realistic about our future energy demands and if renewables can fill the gap. It's also about planning for radical change. The potential risks are no secret and seem to be permeating business consciousness - but solutions are in shorter supply. A national debate about planning for the future of UK energy capacity would seem to be a step in the right direction.

The future of our energy supply is in the balance and addressing it will require profound changes from UK businesses. This is not exaggeration – a recent paper from the respected House of Commons Library addressed the challenge of a low-carbon energy gap in the 2030s, setting out profound implications for us all. And there are many other reports with a similar message (Commons Library, 2019).

The importance and relevance of tackling these issues is rising up the business agenda but there is a long way to go. Companies relying on critical energy supplies to meet production schedules and maintain operational performance increasingly need to answer one crucial question: Can we afford to take our energy supplies for granted? The answer is 'no'. The infrastructure for generating energy in the UK is under increasing pressure and there is a consensus over the reasons why.

With the ending of all coal-fired generation by 2025 and uncertainty over future nuclear plants, we must look at smart ways to optimise, secure and store existing sources of energy. Energy security is one of five key pillars of the UK's integrated national energy and climate plan. The others are energy efficiency; decarbonisation; an internal energy market; and research, innovation and competitiveness (UK Government 2019).

We believe an 'energy crisis' is likely. We don't mean fuel rationing, power cuts and the like, but we do mean dwindling supplies, price increases, strain on the National Grid and lack of investment in infrastructure.

9.9 Findings from energy impacts assessment

Discussions with the industrial and municipal sectors highlighted energy as a common impact and six policy directions were proposed.

Businesses should embrace all five topics listed above to maintain just 'business as usual'. Industry, hospitals, education, water supply, shops and public buildings all depend on a constant, reliable power supply. Without it, the consequences could be catastrophic. How shortfalls will be managed and what investment is required to guarantee the energy security of our businesses are essential questions for the boardroom and the answers can't wait until tomorrow.

(1) Energy efficiency measures

From smart monitoring to energy performance contracts, integrated energy management measures span construction, operations and day-to-day maintenance – all backed by 24/7 support. Energy-saving opportunities can be identified with auditing capabilities and specialist expertise. These feature real-time performance reporting to improve both sustainability and the environmental footprint while achieving the required compliance.

(2) Battery storage

Battery storage works by charging when the cost of power is low and providing power to a site during peak times, including Triad avoidance where businesses reduce the power they draw from the transmission system over winter in order to avoid the three highest peaks. This power can either supplement the existing energy provision, avoiding peak power prices, or take the site off-Grid. A battery can also serve as an Uninterruptible Power Supply (UPS), instantaneously providing energy if there is a power cut. This gives advantages over traditional back-up generators and is more carbon friendly. Revenue can also be generated by selling surplus power back to the Grid and participating in National Grid Balancing Services.

(3) Power balancing

Power Balancing is based on using a virtual platform allowing consumers to respond instantly to market trends and National Grid needs, to save consumption or when consumption occurs and therefore cost. Users can turn down or turn off nonessential assets during peak Grid demand while capitalising on excess Grid energy at peak times. Smart management of a diversified portfolio means assets are achieving new revenue streams while remote controls and software access the most profitable services.

(4) Combined heat & power

By capturing the heat generated as part of the electricity generation process and delivering this in a decentralised way close to the sites they serve, Combined Heat and Power (CHP) offers an effective option. CHP technology gives consistent and stable electricity and heat supply, reduction in energy costs and a reduction in carbon, all of which are typical key performance indicators for a business. *There is a policy overlap with waste to energy here in that using residual wastes as an energy source is of sufficient scale to be interesting to local communities whilst being small enough to fit into residential areas and offer a decentralised partly renewable energy source for the long term.*

(5) Biomass

A source of renewable energy, biomass can also refer to waste when it is of biological origin from agriculture, forestry, fisheries and aquaculture, as well as biodegradable industrial and municipal waste. Carbon neutral (short rotation carbon), it can be transformed into biogas or solid fuel to produce energy, reducing dependence on fossil fuels and helping to secure the energy supply. *Again, this presents an overlap between waste and energy policy.*

(6) Private wire (behind the meter) networks

Through district heating and private wire networks (which negate the use of the main power grid for standard supplies and consumption), the impact of the price of energy on operational costs can be reduced, security of supply can also be under direct control in areas of intermittent black or brown outs, sometimes at the expense of some planned downtime, however resilience can be provided by batteries. Almost uniquely the waste to energy sector is sized and operationally equipped to develop both district heating and private wire networks, usually a result of existing Energy Recovery Facilities. Favourable government schemes, including the Heat Networks Investment Project (HNIP), the Renewable Heat Incentive (RHI) and licence-exempt supplies boost the economic potential of such projects. *Again, this presents an overlap between waste and energy policy.*

For these 6 areas we suggest to policy makers that they create incentives within waste and energy policy for firms to pursue the practices, since there will be a win-win in terms of economy and environment.

9.10 General Findings - Future trends

What emerged is a lack of awareness, concern and, crucially, urgency in addressing the impending energy crisis. UK demand on the National Grid is growing exponentially. The UK Government has declared an environmental and climate change state of emergency and accepted the Committee on Climate Change's call for the UK to be a net zero emission economy by 2050. So how can we deliver these challenging carbon targets whilst keeping the lights on? Technologies for producing power from low carbon and renewable sources already exist. We need a leap of faith from business. For that to happen, three key partners are required:

Government

We need Government to remove uncertainty for businesses with a clear road map providing confidence that renewables are worthwhile investments. Valuable support schemes such as Feed-In-Tariffs, LECs and Triads have all been scrapped in recent years so the market is nervous.

Businesses that invest in efficiency, renewable or low carbon energy solutions such as CHP or district heating must be supported. Heat is still the largest contributor of carbon emissions and so we should not just be focussed on power if we are to future-proof the UK.
The Industrial Energy Transformation Fund (IETF), with a UK-wide budget of £315m until 2024, will support businesses with high energy use to transition to a low carbon future. But this is only a small element of what is needed to deliver zero net carbon in 2050.

Business

Companies that care about price certainty and the resilience of their operations should invest before any crisis occurs. They must take the right steps to run as efficiently and as reliably as possible by investing in their own sources of power. Less reliance on an overloaded Grid will ensure security of supply.

Specialists (Energy & Waste sector partnerships)

Specialists will make these off-grid decentralised networks a reality, from concept through construction and into operation. The waste sector, where it deals with residual waste for energy) is designing a future based on local micro-Grids that can function in complete isolation from the Grid. The sector has a suite of tools and solutions to meet the most particular of client needs – on any scale.

It is clear from the researched views, questions and conversations that industry still has some way to go to understand the implications of an energy crisis and why they must do more to guarantee a secure energy supply. There is a clear desire to offset price rises and a need for innovative solutions, with the government and business investment at the heart of any initiatives.

So, the question remains can policy and incentives act quickly enough to avert an energy crisis? There appears to be a dual benefit of treating non-recyclable waste, and as a by-product creating energy which is partly biomass and therefore partly renewable (Government statistics count it as renewable) in order to serve local communities and businesses.

9.11 Policy implications of technology

Given the technology visions and indications from industry experts responsible for the development of the innovation and with the research budgets in their grasp the question remains, where does the Circular Economy end up under these changes and will policy inspiring a Circular Economy outlive these futures.

It appears that the CE is almost fundamental to a lot of the futures envisaged by the experts, which all tend to have a design better approach embedded in the idea. By 2050, we see the cost of energy and water becoming a significant burden for expanding UK manufacturing. Businesses will need to think smartly about how they generate, use and recover these resources.
Digital smart monitoring centres already monitor heat, electricity and gas usage in real time. Central control centres remotely adjust systems to ensure constant optimisation. Customers can also be identified, prioritised and notified when improvements could be paid for by cost efficiencies.

Where does this technological brainstorming tie into the Circular Economy? Well the industrial and municipal experts seem to agree that the future is significantly different with technological shift expanding rapidly in robotics, digital, food and industrial applications. There is simply only enough resources to fulfil a growing population with all this development if we conserve and reuse resources.

Whilst there were indications that manufacturing would be more led by designing out waste, the idea that bespoke and targeted manufacturing would bring about a wider variability and potentially colluded with new materials, we do not conclude that wastes will disappear. However, it is reasonable to assume that the combination of new design, manufacturing, and operational practices, pressure on resource availability with population growth as well as new materials themselves, that different circular loops of material will evolve (batteries, solar panels, wind turbines are already emerging as new streams). The principles of product stewardship and other producer responsibility incentives seem to remain robust under these conditions and if anything, the potential futures indicate a greater need for a Circular Economy, probably one which has evolved to become as bespoke as the manufacturing that proceeds it.

The future scenarios all result in more robust data capture, tracking and visibility tools being enabled by digital transformations of the sectors, which is line with the anticipated data needs of EPR, DRS and producer responsibility proposals.

Future scenarios tend to suggest increased visibility of producers wastes arisings and where things end up, and therefore endorse additional responsibility being attached to these wastes.

9.12 Discussion of overall findings and recommendations

The discussion is perceived through the lens of the key contributions to science and analytics if a Circular Economy, the field that this work intended to consider.

9.12.1 Infrastructure needs

Better methods can be deployed to determine infrastructure needs both at a national level whilst allowing for regionally and compositionally relevant technology choices to be made.

It was determined that DEFRA waste calculations were misleading to industry, and that the analysis neglected to accommodate some of the underlying drivers to capacity needs, namely geographical mismatch, and composition of waste types. Ultimately DEFRA proposed no further infrastructure requirements, and yet subsequent analysis by Tolvik (Tolvik 2019 a/b) showed a proliferation of further facilities, and still in 2020 a capacity gap.

In combination with continued landfilling more facilities are needed, demonstrating that analysis of infrastructure capacity should take into account geography, waste analysis, waste transport and movement, and that the market appetite for new facilities is a good yardstick for future needs (since debt providers rarely improperly size this type of infrastructure development).

In order to successfully plan for waste treatment infrastructure a number of parameters have been identified as important:

1. **Types and quantities of waste materials**. Obtaining compositional information may be essential for a proper analysis. Integrated consideration of commercial/industrial, household waste and potentially agricultural wastes is needed in order to see what wastes could be combined in single streams and appropriately treated. Moreover, waste management planning should be integrated with energy strategies in order to maximise regional/national benefits delivered by the waste management facilities, and so that such facilities can contribute to achieving binding EU renewable energy targets. This may mean prioritising energy recovery over recycling particularly where further recycling is very costly and/or the environmental benefit is limited.

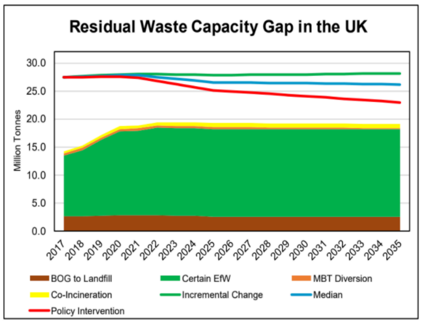
2. **Location of waste arisings,** including information on how waste is contained and how frequently it is collected.
3. **Type and location of existing waste treatment facilities** and other reprocessing facilities or end markets that could make use of the produced outputs (recyclates, energy etc).
4. **Sustainability assessment of alternative management options** (e.g. distance of waste transportation and related impacts, local social and environmental impacts).

The framing of the question associated with future infrastructure requirements needs to be technology specific, appropriate to different waste streams and accept that waste cannot generally be transported from one end of the UK to the other without long term consequences.

The assumptions made in the DEFRA forecast and the limitations of the overall approach restrict the potential of its findings to support decisions. The aggregation of waste composition and treatment capacity nationally may disguise regional variations and lead to the assumption that one region's surplus can meet another region's deficit. This study highlights that even in cases where this refers to similar materials or similar technologies, aggregations of which could be appropriate, the cost and practical implications of long-distance haulage should be further investigated before decisions are taken. In other words, waste doesn't travel well.

Municipal waste is a complex stream of many different materials that cannot be considered as one single stream. By using data on waste composition and grouping technologies by input, this study provides more detailed information about waste materials and their treatment needs, empowering local authorities to make the best use of existing infrastructure as well as determining the demand for additional facilities. The use of the DEFRA findings to justify significant reductions in funding for new waste infrastructure is problematic particularly where decisions were taken without an assessment of the performance of existing capacity or the viability of planned/proposed capacity.

Subsequent actual data and developments demonstrate that simple capacity calculations are not enough to determine the way towards a Circular Economy. The outcome of the DEFRA policy direction to stop further infrastructure funding is that export has continued and diversion from landfill has been retarded with still around 9 million tonnes going to landfill. Figure 9.3 demonstrates that since the DEFRA predictions the capacity gap has remained and significant capacity continues to be delivered and planned.



Scenario	2020	2025	2030	2035
Incremental Change	9.2	8.6	8.7	9.0
Median	9.1	7.3	7.2	7.0
Policy Intervention	8.8	5.9	4.9	3.8

Figure 9.3 Residual waste capacity gap (reproduced with permission, Tolvik 2019b)

Whilst the policy of deferring new facilities has avoided PFI funding requirements (perhaps one of the actual objectives), nevertheless private finance initiatives have now prevailed in developing additional facilities which continue to develop to take up the slack between landfill and recycling respective needs and technical possibilities (DEFRA, 2010a). One technicality we may consider in DEFRAs favour is that the original analysis did anchor some weight on the idea that only biodegradable waste was of interest, linked to the EU targets and a requirement to be legally compliant with the Waste Landfill Directive. However, we consider that our assumptions, results and conclusions remain valid (since even if we only consider biodegradable waste the capacity is still required), and whole more so given the overarching need to provide a Circular Economy and environmental management of all wastes.

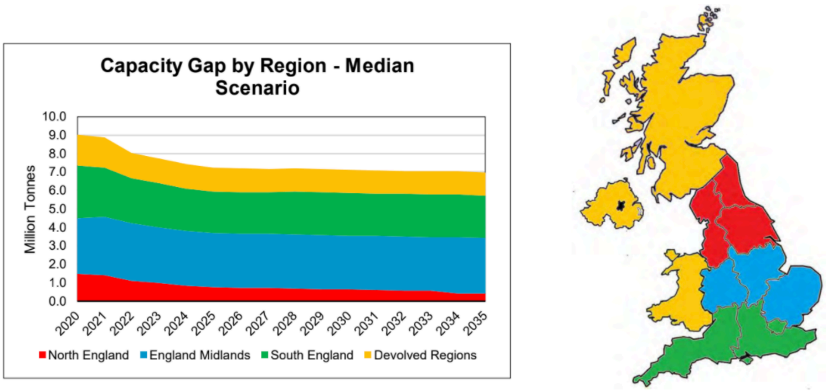


Figure 9.4 Capacity gap by region (reproduced with permission, Tolvik, 2019b)

Figure 9.4 shows the capacity gap by region and it is evident that there are large regional differences with more capacity in the north for Energy from waste than in the South. Figure 9.5 goes on to explain the waste types that are relevant to the analysis, again reinforcing the compositional analysis which we undertook in our research and the importance of this approach in understanding regional needs for capacity. Figure 9.6 goes on to show regionally the overall impact.

Mt	2017	2025	2035
Bulky Residual LACW	1.1	0.8	0.7
Outage of EfW	0.9	1.3	1.3
Geographically remote	0.5	0.5	0.5
Total "BOG"	**2.6**	**2.6**	**2.6**
% of Municipal Waste	*4.6%*	*4.3%*	*4.0%*

Figure 9.5 Regional capacity growth expectations (reproduced with permission, Tolvik, 2019b)

Mt	2025	2030	2035
North England	0.7	0.6	0.4
England Midlands	2.9	2.9	3.0
South England	2.2	2.3	2.3
Devolved Regions	1.3	1.3	1.3
UK Total	**7.3**	**7.2**	**7.0**

Figure 9.6. Regional capacity growth expectations (reproduced with permission, Tolvik, 2019b).

As discussed at the introduction to this infrastructure sizing objective the core research was conducted in 2014, some 6 years ago, this allows 1 investment cycle for new facilities (3 years to plan, 3 years to build) and in that time the capacity gap has remained.

The subsequent Tolvik studies have reinforced the compositional and regional elements of the study, indicating some value to the alternative analysis method, or at least demonstrating the DEFRA analysis flaws from evidence of remaining capacity gaps. Arguably infrastructure was still constructed with private equity and debt, rather than public monies, however, the implications for the timeline were significant with planning delays on several projects (see Table 8.2, page 94). When developing waste management solutions there may be a case for a phased approach to policy. Initially in the absence of any significant recycling and reuse infrastructure blunt instruments such as a collection requirement on authorities, a landfill tax, and packaging recycling subsidies do work and can allow significant investment and interest from the investment community, latterly and in later stages of development, perhaps once the 50% threshold of easy to do recycling has taken place a more systemic approach involving deep extended producer responsibility, deposit return and harmonisation as well as tax on virgin commodities can bring about system change allowing business to settle on the best economic outcome. Of course, combining all these elements in tandem, can work, albeit burdensome to implement simultaneously

It appears that DEFRA set out to show that enough biodegradable waste would be diverted from landfill and that additional PFI funding would not be needed. The analysis therefore did not take into account all the available materials, quantities and locations of those waste resources that could be diverted from landfill and otherwise be usefully reused (with lower environmental impact) and only answered a narrowly designed question about EU landfill directive compliance. Whilst this was stated in the report, the headline result was largely misinterpreted by investors, policy makers, decision makers and citizens to mean that no further infrastructure was usefully required, casting doubt on the need for recycling and recovery facilities, something that was already contentious from a planning perspective. Since many more project developments are required than actual infrastructure required, due to a relatively low success rate, this approach of DEFRA did not assist the rapid deployment of infrastructure. However, The Tolvik studies show that market analysts (and financiers) better predicted the market need and indeed proceeded with the infrastructure development in any case which is still persisting today.

9.12.2 Valuation of the Circular Economy

Valuation of the Circular Economy to UK GDP and Jobs elicits a significant contribution as well as an incentive and encouragement for policy makers.

Based on the vectors approached the quantified findings constitute a contribution from the Circular Economy towards GDP and employment of **£32 billion and between 72,000 and 175,000 jobs**, with particular opportunities in the plastic sector, making for a compelling business case for change.

The importance of this figure which is most likely an underestimate based on EMF and PWC (references) research and datapoints is significant at around 1% of GDP, given GDP growth is normally at 2% this is providing a significant intervention to the system.

The opportunity is clear for business to benefit from designing products to take into account a second and third life and better supply chain pricing as the quality of secondary recycled materials becomes business critical. By promoting greater resource efficiency, we can help manufacturers protect their own supply chains and stimulate a growth in the
market for recovered materials.

9.12.3 Past, Present, and Future Government Policy

A review of the historical government policies leading to the initial moves away from landfill, and their limitations, as well as the current and future policies in play indicates the additional policy is required to improve recycling beyond 45-50%.

The initial success in changing the system came about from setting a landfill tax, a recycling collection obligation on local authorities and targets for recycling which require separate collection. When implemented at scale (Nationally) in all local authorities this system can allow the circular approach to flourish. Local authority areas are separately tendered to offer the service to one contractor since the resources required to separate and collect any given tonnage of material can be reduced to an optimal cost in that way when it is collected by one operator at every household or business, whereas if multiple collectors are collecting at the same places there is wastage.

This is the case in Ireland where household waste is collected by private companies and multiple vehicles can go down the same street doubling or trebling the impacts from vehicles and fuel use. This explains the reason commercial waste is more difficult to divert to alternatives from landfill - and particularly to recycling - since the uniform application of a harmonised collection is not in place. Figure 7 demonstrates what has happened due to the landfill tax, by far the greatest contributor to landfill diversion, the alternatives, only possible when segregation of waste type talks place, have flourished due to their cost dipping below landfill. The System is commercially weighted to divert, where alternative facilities exist, the tipping point being around 2009 in the UK. This then attracts investors to build more infrastructure to deliver more diversion for the options which are more cost effective for the market, such as AD, ERF, sorting and composting.

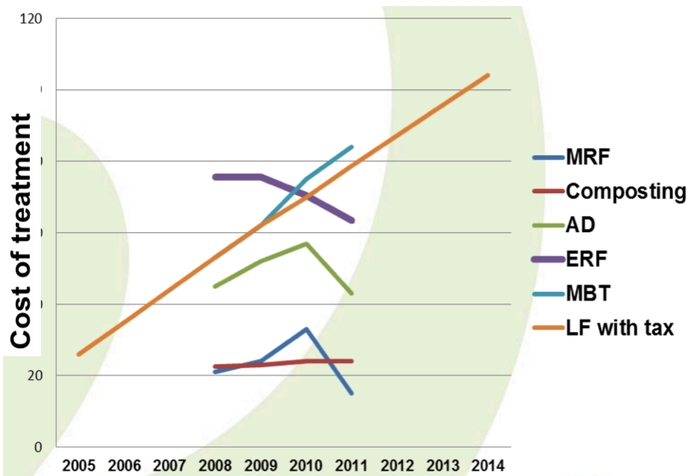


Figure 9.7 The cost of alternatives falling below the rising cost of landfill (£/tonne versus time) (Kyle, 2018).

All this development in line with the waste hierarchy appears to peak at around 50% recycling, across Europe, taking into account nuances in reporting principles for recycling and diversion, and England plateauing at 44% recycling and composting. The limiting factor starts to be material composition and what is actually recyclable or compostable which is more a feature of design than post use management. This indicates that some additional policy is required to reach above the 50% diversion rate, and looking to Europe, Germany and Scandinavia, Extended Producer Responsibility, for example deposit return schemes, appear to have an impact.

9.12.4 Contribution to public communications thinking

A more supported contribution from the public can be achieved through shared problem solving and novel methods of two-way communication.

Problem solving and decision making are often interchanged as concepts but differ significantly, notably with problem solving including a higher degree of unknown outcomes, whereas decision making more often being a selection between known choices (Huitt, 1992). Determining waste policy often happens at a state or authority level and is then explained to householders rather than any real dialogue at the discovery phase. This missed opportunity - to get the public engaged from the start – could well be the key to better acceptance of infrastructure needs.

Participation can be an empowering process for citizens to handle challenges and influence decisions that will impact their lives. This leads to joint decision making about what should be achieved and how, increasing problem ownership and thus the chances of both proposition acceptance and implementation success.

Without engaging the public in such an interactive and participatory way, aiming for people not to simply accept but to understand and appreciate the need for infrastructure, there is a risk that we will not develop the right infrastructure, in the right place, at the right time.

The need to engage the public and enable it to play an active and constructive role in the selection of appropriate facilities and construction decisions is clear (CEAA, 2008). In order to build world class infrastructure, the public's support must be canvassed, but this process needs to go further than simply making the case that what is proposed is relevant to them. Public perception needs to be taken into account early in the decision-making process. Informed local debate is an essential first step to building high quality national infrastructure that takes public participation beyond the consultation stage (Figure 9.8).

Making a better public case for infrastructure can help reduce opposition to local infrastructure projects and big projects that are often in part funded through UK tax receipts (Steg and Vlek, 2009). Research has shown that those left to make the case for infrastructure to local communities are the least trusted to do so, so it is perhaps not surprising that an already sceptical public is often unmoved by their arguments for change (CBI, 2014). Gaining public support for new infrastructure will require a consistent message and a neutral, credible voice that can outline independent evidence about the challenges faced and the possible solutions open to the UK (CBI, 2014).

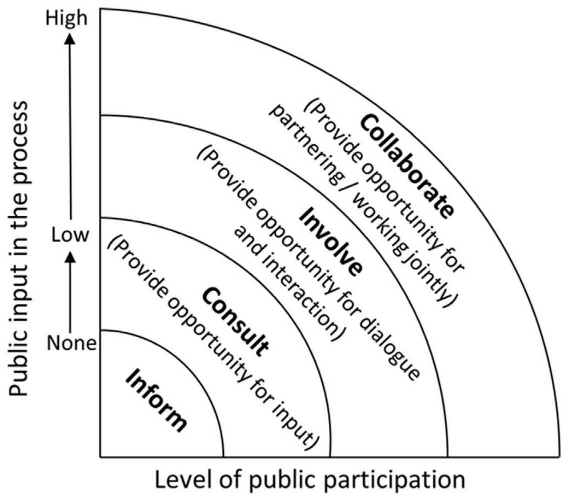


Figure 9.8 Types of engagement as a function of public input in the process and level of public participation (CEAA, 2008)**.**

Modern techniques for community and public communication suggest that we can do more or we can use alternative techniques to assist the decision making of the important stakeholders in society, rather than continuing to dictate the solution dogmatically, which only serves to put up the barriers. As described by the deficit model (Seethaler 2019) it is not just more information that will elicit better results, it is a change to the method of engaging itself. There appears to be a pressing need for people not simply to accept but to understand and appreciate the need for infrastructure; the nature of infrastructure investments and development; the costs and benefits; and the technological aspects if we are to continue to develop and sustainably, and the sis a global problem (Clark, 2005). Individuals' and groups' abilities to understand problems and make decisions are recognised as important skills that the recent transition to the information age has further highlighted as necessary. It seems to be important to be able to more clearly link empirical work from life cycle thinking and filter that via the media, to the public mind, to establish more science based views on complex subjects which would provide policy makers with the ability to deliver the right infrastructure.

9.12.5 Future technology trends that may impact policy thinking

Policy is likely to be successful in its proposed form given the technological trends envisaged.

Whilst there were indications that manufacturing would be more led by designing out waste, the idea that bespoke and targeted manufacturing would bring about a wider variability and potentially colluded with new materials, we do not conclude that wastes will disappear. However, it is reasonable to assume that the combination of new design, manufacturing, and operational practices, pressure on resource availability with population growth as well as new materials themselves, that different circular loops of material will evolve (batteries, solar panels, wind turbines are already emerging as new streams).

The principles of product stewardship and EPR policies as well as other producer responsibility incentives such as Deposit Return Schemes seem to remain robust under these conditions and if anything the potential futures indicate a greater need for a Circular Economy, probably one which has evolved to become as bespoke as the manufacturing that proceeds it.

The Role of Energy (and Waste)

It is clear from the researched views, questions and conversations that industry still has some way to go to understand the implications of an energy crisis and why they must do more to guarantee a secure energy supply. There is a clear desire to offset price rises and a need for innovative solutions, with the government and business investment at the heart of any initiatives.

So, the question remains can policy and incentives act quickly enough to avert an energy crisis? There appears to be a dual benefit of treating non-recyclable waste, and as a by-product creating energy which is partly biomass and therefore partly renewable (Government statistics count it as renewable) in order to serve local communities and businesses. This position is supported by the DEFRA and is official government policy (DEFRA, 2013c).

Communicating Science

What is clear is that we need to reduce plastics production while ensuring that any alternatives do not contribute more to climate change, and this is where recycling comes in. The emissions reductions from eliminating the need for new plastic outweigh the slightly higher emissions that come from processing wastes to recover plastics. The findings of this study indicate that if we really want to tackle the environmental issues we face with plastics today, removing, reducing, reusing or recycling the plastic packaging placed on the market is an important part of the way forward, and a better option to replacing it with current alternative materials or waiting and hoping for solutions not yet available.

Considering that only around 9% of plastics are currently being recycled worldwide, there is a lot that can be done to improve on this. We can see that when the right policy drivers are in place, this is happening already, with regulatory statutes that themselves deliver fiscal actions on business. For England, the various measures planned in the Waste and Resources Strategy planned by DEFRA, such as the extended producer responsibility scheme, the deposit return scheme and the harmonisation of waste collection associated with a clear labelling system, as well as HM Treasury proposals for a plastic packaging tax are all good steps for creating a fully functioning circular and sustainable system for packaging. Increasing the levels of recycled content in plastic packaging can reduce both the need for manufacturing plastics and the amount of plastic wastes produced.

As recycled plastic is more expensive than virgin plastic, the future plastic packaging tax announced by the UK government will be a key initiative to drive the market, increasing the recycling infrastructure and ultimately improving plastics recycling rate. Widespread application of renewable energy, recycling and demand-management strategies in concert, have the potential to curb the growing life-cycle GHG emissions from plastics. Recycling can also play a key role in stopping plastics entering the marine environment, as once collected the chances of plastic waste entering the environment are reduced or at least there is clear accountability in what ultimately happens to plastic waste.

9.12.6 Forecasting likely impacts of incentives and regulatory tools

Likely impacts of proposed incentives and regulatory tools are described here which may suggest policy options that would assist other geographies.

A transition towards a sustainable and Circular Economy should combine ambitious environmental goals with strong social requirements, including the promotion of decent work and healthy and safe working conditions (i.e. ensuring that workers are not exposed to harmful substances in the workplace); and establish a more coherent legal framework for sustainable production and consumption. These require both legislative measures and economic incentives, the internalisation of external costs and further funding of research and innovation, as well as social and lifestyle changes; points out that a variety of instruments are needed at various policy levels, taking account of subsidiarity.

There is clearly a need for more appropriate pricing of virgin materials and natural resources that is inclusive of all environmental costs. The carrying capacity of the natural environment is an un-priced input to resource production, and it is increasingly accepted that resource users should be made to pay for the environmental impacts they cause. While several methods for the monetary valuation of environmental impacts have been developed (Damigos, 2006), the internalisation of environmental costs has yet to be fully mainstreamed in practice (Dalal-Clayton and Bass, 2009). By influencing the use of resources, environmental policy has the potential to affect the way in which economic activity develops. It can encourage more efficient use of energy and materials and the development of new, cleaner products and services while discouraging activities that are environmentally damaging. This in turn encourages product and process innovation and influences the allocation of labour, capital, land and raw materials, either through direct regulation or through pricing mechanisms.

When properly evaluated, recycling and reuse can provide a viable opportunity to augment traditional resource supplies, at the same time reducing the need for waste disposal (Iranpour et al.,1999). As a result, resource reuse can help to close the loop between supply and waste disposal, providing a sustainable alternative to mining and consuming virgin stocks. Policies that allow for environmental externalities to be better accounted for in decision and policymaking in relation to materials and resources, can also encourage the development of new products and services designed primarily to enhance the environment. This integration of environmental considerations into wider economic activity has many benefits and can be achieved though many different ways. For instance, voluntary agreements could be an alternative for the industry, as these commitments between authorities and target groups set out environmental objectives based on voluntary participation and absence of sanctions (Skjærseth, 2000). The key message is that achieving more from less, by closing resource loops, is paramount, given the twofold need of protecting the environment and recognising the importance of natural capital, while at the same time enhancing economic prosperity and improving living standards of developing countries and the world's poor.

9.13 Resources & Waste Strategy

System change is always mooted as the need to ensure eco-design, refill, reuse and better upstream and downstream optimisation of human impacts. Together we consider that these RWS policies are impactful, work well together, and will deliver a fundamental system change, whilst not necessarily increasing cost excessively, since the main aspect is a shift of cost from one payer to another.

The set of proposals brings together an EPR and a Plastic Tax that jointly move towards this position of switching behaviour. Packaging will become more expensive (or rather its true cost will be included in its purchase price), that packaging which is less recyclable will be more expensive, and packaging with no recycled content will be more expensive - all proposed to be implemented over a period of time to allow switching to alternatives and so as not to impact unduly low income families.

9.14 A Plastics Tax

Ultimately, the problem of plastics is not so much one of waste, but one of production. The solution to a world drowning in plastic refuse requires questioning the need for plastics and reducing their manufacturing in the first place. Increasing the recycled content of plastics exposes the current rhetoric: Blame not the production, for what is produced is of vital importance to the world (especially those in the developing world), but call for everyone to come together in addressing the problem of the waste (Wilkins, 2018). Recyclers did not create the plastic waste crisis, it is the prolific, ever-increasing production of plastics that needs to be addressed. Voluntary industry initiatives are often a common delay tactic for industries wishing to avoid binding regulations.

On the contrary, increasing the levels of recycled content in plastic packaging can reduce both the need for manufacturing plastics and the amount of plastic wastes produced. The future plastic tax will be a key part of the solution as it is expected to enable an additional two million tonnes of plastic packaging to be recycled in the UK and to fulfil 71 per cent of UK manufacturing's raw material demand (Peake et al., 2018). It should also drive the UK Circular Economy by creating several thousands of jobs in the recycling industries.

Chapter 10. Conclusions

10.1 Infrastructure

Over the past 20 years, since at least 2000 the Circular Economy principle has led the way over and above previous emphasis on landfill diversion and recycling alone, with organisations like the Ellen McArthur Foundation promoting politically a stronger system change approach to production and waste developments, despite this idea having been around since at least the 1970s (Commoner, 1971).. Latterly the European Union has brought forward the Circular Economy package, which has real targets to install producer responsibility and recycling levels not before achieved (above 65%). This will require the redesign of goods, packaging and services by industry and commerce and in the aftermath of the 2019 global health pandemic (COVID19) has transformed into a Green Recovery stimulus package which is re-enforcing these various moves.

Following a 10-year hiatus on policy and new legislation across the administrations of the UK surrounding waste management, and after successful landfill taxes, a criticised but ultimately well performing packaging tax, WEEE, battery and recycling incentive schemes, the 2020s sees a new Waste Strategy being forged. Currently (2021) in final consultations, the impacts are expected to land in 2022-23 (accounting for COVID19 delays). Public outcry emanating from television broadcasts such as Blue Planet (BBC, 2001) which highlighted widespread ecological impact form plastics particularly in the oceans, has brought about the ability for voluntary groups to bring together manufacturers and brands with biting targets such as those under the Plastics Packaging Pact (EMF, WRAP), where 60% of plastic placed on market is represented by the producers who have committed to 100% recyclability by 2025. No doubt the Pandemic will give some excuse for delay, however, public pressure on the subject is unlikely to go away. Unsubstantiated claims regarding the failures of the PRN (packaging recovery note) packaging tax scheme and the damage that waste export has with respect to waste ending up in the environment are having lasting impacts on new policy formation. The new resources and waste strategy proposals are thus far reaching since they shift the cost of - initially packaging waste – from local authority direct taxation to product sale and thus directly as a consumer cost – this could bring about significant system change. Certainly, we believe that *Anderson* et al was right in that the role of recycling must not be underestimated in bringing about significant change (Andersen, 2007).
What we might call a *'pay as you buy'* system structure has the potential to be rolled out across sectors and cover more than just packaging wastes.

The research presented in this thesis further supports system change, This has been achieved by firstly understanding the infrastructure needs (Objective 1, Chapter 5), that is how to best assess and determine what is needed where and for what waste; the value created from a Circular Economy

(Objective 2, Chapter 6), the historical policies needed for systems change (Objective 3, Chapter 7); the approach to be adopted in front of the public (Objective 4, Chapter 8); the technological trends that may impact those policies (Objective 5, covered in the discussion Chapter 9) and overall recommendations (Objective 6), which are tackled in Chapter 9 and this section (Conclusions).

The infrastructure study – central to this work – concluded that;

- DEFRA's forecast of capacity gap appears to be rather misleading, addressing only a narrow question
- Method limitations suggest caution when interpreting results
- We should not aggregate material streams
- There should not be cuts to funding without a strategy in place - Post study data supports the original hypothesis, and a capacity gap remains, despite additional infrastructure delivered.

This analysis indicated that England was in fact close to the DEFRA targets, which emanated from EU law, but that there was still at least 11.2 million tonnes of residual and potentially recoverable solid waste going to landfill every year which could generate value as a resource through recycling as a material or recovery as a fuel, aggregate or organic material (compost, fertiliser). This indicates that whilst some more infrastructure has been developed there remains recoverable waste going to landfill. Further to the 11 million tonnes of residual municipal waste it is estimated that England generated 41.1 million tonnes of commercial and industrial (C&I) waste in 2016, of which 33.1 million tonnes (around four fifths) was generated in England (DEFRA, 2020a), much of which is also suited to treatment. The Armitt review (Armitt, 2013) recommended the establishment of the National Infrastructure committee which itself was established and in 2018 concluded that infrastructure was required for waste suggesting that Recycling targets of 65% for all waste, 75% for plastic packaging by 2030; Clearer labelling for recyclable or not recyclable packaging; Restricting use of hard to recycle plastics by 2025; and Separate food waste collection by 2025 (NIC, 2018), all items included in the Resources and Waste Strategy (UK Government, 2018). The EC Landfill Directive (99/31/EC) is seeking to avoid waste generation and to use waste as a resource, and should help move the EU closer to a "recycling society". In particular, the Sixth Community Environment Action Programme calls for measures aimed at ensuring the source separation, collection and recycling of priority waste streams. In line with that objective and as a means to facilitating or improving its recovery potential, waste should be separately collected if technically, environmentally and economically practicable, before undergoing recovery operations that deliver the best overall environmental outcome. Member States are asked to support the use of recyclates, such as recovered paper, in line with the waste hierarchy and with the aim of a recycling society, and whenever possible should not support the landfilling or incineration of such recyclates. In order to implement the precautionary principle and the principle of preventive action enshrined in Article 174(2) of the Treaty, it is necessary to set general environmental objectives for the management of waste within the Community. By virtue of those principles, it is for the Community and the Member States to establish a framework to prevent, reduce and, as far as possible, eliminate from the outset the sources of pollution or nuisance by adopting measures whereby recognised risks are eliminated. It is necessary, in order to enable the Community as a whole to become self-sufficient in waste disposal and in the recovery of mixed municipal waste collected from private households and to enable the Member States to move towards that aim individually, to make provision for a network of cooperation regarding disposal installations and installations for the recovery of mixed municipal waste collected from private households, taking into account geographical circumstances and the need for specialised installations for certain types of waste. Effective schemes need the flexibility to design, adapt and operate systems in ways which best meet current social, economic and environmental conditions. These are likely to change over time and vary by geography. The need for consistency in quality and quantity of recycled materials, compost or energy, the need to support a range of disposal options and the benefit of economies of scale, all suggest that integrated waste management should be organised on a large-scale, regional basis. Any scheme incorporating recycling, composting or waste-to-energy technologies should be market-orientated. There should be markets for products and energy arising from those waste treatments else they are counterproductive. There is also a strong argument for national coordination if national targets are to be met. Ongoing discussion as to whether there would be sufficient waste treatment capacity across the UK in 2020 was the driver for this work, which aimed to evaluate infrastructure needs for resource management in the future. It is therefore worth restating that this is not about taking a position as to who is right or wrong in these discussions, in other words, this is not a question of underestimating or overestimating treatment capacity but of understanding infrastructure needs in the future. It is important to understand such needs before strategies change following any quantification (prediction) that takes place. In that respect the framing of the DEFRA question is possibly rather misleading, as it seems that its main question has focused simply on whether there will be theoretical overcapacity or under-capacity of residual waste treatment in the future rather than first understanding what the needs are (and we would argue should not be limited to the EU targets).

Providing infrastructure for resource management is a much more complex issue. Limited and poor information on waste generation provides an incomplete and scattered picture of waste arisings, and conflicting data on treatment capacity make it difficult to make reliable estimates of infrastructure needs. Taking into account the uncertainty associated with forecasting, any attempt to base policy making and investment decisions on such ‘predictions’ seems risky. The resulting uncertainty can have widespread consequences on market stability and business engagement, critical conditions not just for any forecasts of overcapacity to realise but for that capacity to be put in place in the first place. Forecasting how much waste will be generated in the future is a process that involves estimating future behaviour of individuals and businesses and the markets within which they operate, all influenced by a range of policy and fiscal drivers both locally, nationally, and internationally. With producer responsibility initiatives for packaging having recently been extended to other products, e.g. batteries, electrical goods and electronic equipment and vehicles; waste prevention initiatives (e.g. light-weighting of packaging within industry and commerce) and national and local campaigns to encourage the public to use, food and resources more efficiently and reduce the waste they generate; possible effects of end-markets for recycled materials; and increased collections and services for recycling and composting, forecasting waste generation reliably seems a real challenge. This was demonstrated only recently by the potential difference of 33.6 million tonnes, between the 52.8 million tonnes of waste that required thermal, organic or sorting treatment reported by Ricardo-AEA for the CIWM, (reduced in the future as a result of new waste treatment facilities coming online resulting in 15.3 million tonnes of capacity gap in 2020), compared to the 12 million tonnes of excess capacity by 2020 that England would potentially have, as forecasted by DEFRA. In order to establish needs for the future it is necessary to understand the position now, as it is the difference between the current state in terms of infrastructure and what is required in the future that will determine the 'need'. The first step is to gain an understanding of how much waste requires management, and where it comes from. An understanding of the materials that make up this waste stream allows a more detailed analysis of the types of facilities that are required. This is the need for the right infrastructure to treat the right type of resources (out of our MSW) and in the right geographical context not just to meet regulatory drivers but to provide society with a net benefit in terms of environmental, economic and social considerations.

In this sense, municipal waste (or any subsequent residual wastes) should not be seen as a homogeneous mass but a combination of resources. MSW composition and collection practices are critical to the selection of treatment required and the spatial distribution of available treatment facilities is an important factor in identifying infrastructure needs. This is even more critical in the case of residual waste, as both its arisings and need for treatment depend on the parameters above. The variation between local authority collections, market uncertainties with regards to resources recovery, and even regulatory changes with regards to definitions increase the uncertainty of stochastic methods of calculating or predicting future infrastructure needs. Any benefits from doing this are shadowed by the potential costs attached to the resulting underestimation or overestimation of those needs.

The EU Commission recently considered views on issues such as:- whether to have a single target and calculation method based only on the quantity of municipal waste collected, which would mean that there would also need to be a consistent definition of 'municipal waste'; should targets reflect environmental weightings for materials (for example, through reference to greenhouse gas savings achieved through recycling)?; should recycling targets be extended to include additional waste streams such as wood, food waste and textiles?; should businesses be required to sort a range of waste materials for recycling and composting/anaerobic digestion?

Findings of this infrastructure study indicate that regional variations and variations in technology selection may undermine the reliability of some previous predictions of waste treatment capacity. Results demonstrate a high probability of not having enough or not having enough of the right capacity where it is needed (per region). This analysis, taking waste composition into account, suggests that the variation behind the agglomeration of infrastructure needs may result in an underestimation of the capacity gap, predicted to be a more significant deficit rather than a marginal surplus as presented in one of the studies. Although there is merit in transfer of waste between some regions, this should be based on realistic assumptions and should take into account additional costs and burdens such as transport.

To be able to predict infrastructure needs in the future, one should start with understanding those needs now. And this is not just a matter of reliable data but also a function of an integrated and coherent national strategy. It comes down to waste management delivering for real sustainability targets rather than mere regulatory requirements. We would suggest an integrated waste management infrastructure strategy should be developed and reviewed in light of these findings. The optimised development of an integrated waste infrastructure cannot smoothly derive from the indirect targets of increasing recycling, or biowaste diversion from landfill, or from economic incentives that do not have by themselves the power to rationalise plant distribution, number and scale, and any attempt to base decisions solely on forecasts of demand and capacity is likely to fail. Acting on the findings of the work outside the context of existing strategies comes with associated risks that have not been the subject of our work. Providing infrastructure for resource management is a much more complex issue. Regional planning bodies or local authorities or the private industrial sector cannot by themselves solve the problem of rapidly building an integrated infrastructure for managing waste when decisions on investments are taken this way. Thorough strategic planning is vital when seeking to meet challenging objectives, and strategies should both reflect community aspirations and ensure cost-effective compliance with all existing statutory obligations.

The development of a Municipal Waste Management Strategy must be a dynamic process and should result in a clear framework for the management of municipal waste and waste from other sectors as appropriate. This should set out how authorities intend to optimise current service provision as well as providing a basis for any new systems or infrastructure that may be needed. Any study that offers new findings on predictions in terms of waste arisings or facilities should really be used to inform and support the preparation of local development plan documents by the Waste Planning Authorities involved or affected by the study. Existing and under-construction facilities may suggest that the demand might be met, but often the scale of the proposed plants is suboptimal, and the location not finalised. Without the possibility of contributing to specific national goals, local authorities and waste disposal authorities have been planning for a massive number of thermal treatment plants and confronting citizens' opposition in the absence of a national policy reference framework.

As a result of this lack of direction, we have seen that the PFI projects have proposed, sometimes without selecting any, three very different energy from waste strategies: • energy recovery from established combustion; • pre-treatment of residual waste followed by energy recovery from Solid Recovered Fuel (SRF) in a newly built dedicated thermal plant; • pre-treatment of residual waste to produce 'fuel from waste' (SRF) to be recovered elsewhere. *Klaus Koegler,* head of unit of sustainable production and consumption at the European Commission, has said that waste management could contribute to reducing environmental pressure. "*That can be done by making less waste and by using the waste that we are creating in a more efficient way. A main step in doing that is of course to improve the way and to improve the efficiency with which we are re-using waste in the sense of recycling and energy recovery."*

The Waste Hierarchy lays down a priority order of what constitutes the best overall environmental option in waste legislation and policy, while departing from such a hierarchy may be necessary for specific waste streams when justified by life cycle analysis, for reasons of, inter alia, technical feasibility, economic viability and environmental protection. In other words, the Waste Hierarchy has little scientific or technical basis, unless we consider in tandem the underlying materials we seek to treat in each part of the hierarchy. There is no scientific reason, for example, why materials recycling should be preferred to energy recovery. In an integrated waste management system, the hierarchy cannot suffice, for example, to decide whether composting combined with incineration of the residues would be preferable to materials recycling plus landfilling of residues.

What is needed in practice is an overall assessment of the whole system, and the Waste Hierarchy cannot provide or address its costs and therefore cannot help assess the economic affordability of waste systems. In DEFRA's Forecasting 2020 Report, life cycle analysis (LCA) is not mentioned once. The LCA necessary to compare the full range of environmental impacts of waste management systems in order to improve processes, support policy and provide a sound basis for informed decisions have been replaced by stochastic models that leave little space for experts to be able to evaluate the approach taken or for the public to understand what has been done. Moving away from life cycle analysis cannot be a sustainable move for anyone. LCA has a great potential to support planning and strategy development and should be used in decision making.

This study has not aimed to provide absolute amounts, but to evaluate the limitations of the DEFRA's 2020 Forecasting Report. Findings demonstrated that there is an additional unmet requirement for treatment in some regions and that the most important thing is for local authorities to ensure that they have planned for the right number and type of facilities in the right place as part of an integrated waste management strategy that goes beyond just meeting regulatory requirements but also delivers real sustainability benefits.

We believe successful infrastructure forecasting can be achieved if we design and deliver a policy which evolves and necessitates a system change which itself leads to the right amount of infrastructure being developed rather than studies and calculations which are inherently complex and lead to perverse incentives to build certain infrastructure over other based on political sensibilities.

A more robust approach for forecasting total quantities of material arising and the consequent demand for facilities was proposed which addressed the main limitations of simply adding different tonnages. A more appropriate method for calculating treatment capacity requirements for each region was proposed. This way, more informed assumptions about how inputs are prioritised to different facilities can be made (e.g. sorted recyclables go to MRFs, residual material goes to ERFs), so that by subtracting the relevant existing treatment capacity from calculated regional requirements, the composition of the waste remaining untreated and subsequent future infrastructure needs can be easily and more reliably estimated.

Advantages of this alternative method

- Focuses on regional analysis to determine appropriate infrastructure needs
- Estimates arisings of waste materials and their treatment needs
- Empowers local authorities to make best use of existing infrastructure
- Empowers local authorities to determine demand for additional infrastructure

Infrastructure learnings from the DEFRA approach are that geographical and compositional approach needs to account for different wastes and if they can really be separated. There is also a strong case to consider the position of the investors who are unlikely to invest if there is no anticipated market. DEFRA as a government body had set out to provide clarity on a very specific point, that is, was there sufficient capacity to comply with the EU Landfill Directive and diversion of biological waste. It turns out this is a very different question to simply is there enough infrastructure and emphasises the importance and relevance of the question being asked.

10.2 Public policy and public perception

DEFRA, the government body responsible for waste in England has put forward a far-reaching set of regulations for waste which reaches out beyond the landfill levy, addressing a 5-year hiatus in policy. This is significant since new policy generally takes 5-10 years to bite and building a Circular Economy for waste could bring £32bn of value and 175,000 jobs to the UK (Kirkman et al, 2016). It is generally accepted that a Landfill tax and an obligation on local authorities to collect recyclables has allowed up to 50% of household waste (excluding bulky and demolition wastes) to be recycled in the UK via recycling and composting. Around another 20% is going to energy recovery, with the remainder being landfilled whilst the UK determines should we recycle more or put more to energy recovery.

The limiting factor on increasing recycling rates further is mainly the ability to actually technically recycle many of the objects / packaging in the bin. Much product packaging, pots, tubs, trays and films is inherently not recyclable due to material choice or construction design, something which could be improved significantly if the right incentive was in place.

It seems likely that the proposed EPR (extended producer responsibility), DRS (deposit return scheme) and Harmonisation proposals of DEFRA along with a Treasury move to levy non-recyclable content in packaging will deliver the following outcomes. The policies:

- *have a high public acceptance and support from citizens.*
- *are generally well received by industry, which was initially reticent, but eventually saw this is what they are all stating in their sustainability policies anyway, and therefore this provides the level playing field they need to deliver their goals.*
- *will shift the cost of recycling / disposal from local authorities who cannot change the design of packaging, to producers who can, and consumers who consume, which is equitable, doesn't increase overall cost and has the potential to reduce cost in the mid-term.*
- *will incentive real design for recycling by producers who will be incentivised to do so, given that consumers stand to gain from recyclable choices being cheaper under an EPR package.*
- *deliver potential for increased recycling and composting up to 60-70% with the remaining waste suitable for ERF, eventually achieving almost 100% landfill diversion for these materials from households.*
- *are an essential building block of the Circular Economy.*

A new braver approach to public consultation may be to actively involve the public in the problem definition and primarily to accept the waste is derived from human activity, by us all, and from a technical perspective there must be a number of treatments built, operated and functioning to properly manage those arisings.

Public communication

It seems prevalent cross the world that people don't want anything built near them. Whilst it is true that waste management facilities tend to be built in less developed areas, this has no evidential impact on property price and there is some evidence that these areas can benefit from iconic designs (e.g. Leeds city council RERF facility, Denmarks famous Ski Slope ERF).

The proliferation of solutions that have not yet been proven nor delivered despite past attempts suggest that we may sometimes be following an illusive holy grail, whilst the fully functional well performing solution sits in the wings. This dilemma can set us back several years, if not a decade (since facilities can take 3-5 years to plan, and 3-5 years to build), the UK development of MBT being a case in point, infrastructure which now largely sits mothballed, since end markets for the arising feedstocks did not emerge. The communication of science and how that is exercised more generally in society to have optimal outcomes is something that should be addressed in the age of popularism and decision by Twitter.

It might be useful for further explore 'nudging' as a way to influence consumers in both making environmentally based purchasing decisions which will influence retailers, and also in discarding objects into the right recycling containers. This could draw together the ideas embodied in life cycle assessment, rather than myths surrounding what is the best packaging and also improve efficacy of collection systems. The work of Sunstein & Thaler (Sunstein, 2008), suggests that we can influence public behaviour in the most subtle of ways, subconsciously and to great effect, and that has been widely demonstrated in many ways with a relevant example of packaging in terms of healthy produce choices (Jones, 2019). Consumers are influenced by pack colour, material and labelling. Creating a choice architecture for environmental packaging in terms of the disposal cycle, one which mandates a good decision in the split second when the consumer decides which bin to place a discarded wrapper in, could revolutionise the success rate of recycling, where today 25% error rates into recycling containers Is not unusual (Rubicon, 2018).

The importance of framing the research question

DEFRA as a government body had set out to provide clarity on a very specific point, that being will the UK fulfil the needs of the European Landfill Directive and in that respect is there sufficient infrastructure. This is quite different to answering the more global question of is there enough infrastructure for delivering a Circular Economy or an optimal waste management system, and that became apparent in the analysis. It might be that DEFRA sought to stem future PFI funding in order to preserve taxpayers expenditure, particularly when debt and equity funding had become self-perpetuating and sufficient private money was funding infrastructure build. This is a valid exercise, however, the specific nature the question DEFRA answered was lost and the conclusion was being drawn that no further infrastructure was needed, which had impacts on public perception and planning determinations (Fitchner, 2020).

An important conclusion of this work is that the rise to 12.6mt residual waste treated by energy recovery in 2020, a rise of 7.1mt since 2014 and largely from infrastructure which were not conceived in 2014 (Page 47, Figure 5.30, Tolvik) supports the analysis in this report, that a gap of >11.2mt indeed existed and was filled over the relevant period. DEFRAs assertion that there was no capacity gap was not correct, however, they were inadvertently right that in that the private sector filled the void and invested in the additional treatment.

It is also relevant to note that this gap was largely made up over this 6-year period with incineration (energy recovery) capacity and not recycling alternatives despite the alternatives being higher in the waste hierarchy. Since development of this (ERF) type of capacity is harder to develop, more expensive and takes longer to construct than recycling and composting activities (which arguably can also be more easily expanded on existing sites) one might consider that recycling reaches a natural barrier at circa 50% rates for a given composition of materials and public behavioural circumstances.

This consideration is also supported by the policy research which also indicates that material recycling becomes more difficult at above 50% rates due to physical recyclability of materials and composites and the ability to effectively collect, recycle and find end uses for material. If that is true then to increase recycling needs further and deeper policy instruments which enforce and scale design changes to products and packaging, public support and behaviour change, and a number of other approaches as discussed such as Extended Producer Responsibility.

Overhauling the planning system

There should be local and national advocacy for planning or authorities will not deliver much needed infrastructure and ultimately fall behind commercially, which will eventually have broad societal and environmental impacts. Strong local authority support at councillor level is normally lacking but much needed, but they must be supported by strong and clear policy direction at all levels. There should be a stance that this is for the community - and the private sector having competitively tendered the solution offers a strong driver for cost control.

10.3 Value from the Circular Economy

It has been established that a Circular Economy is desirable from an environmental perspective in terms of resource preservation but also economically with £32bn and between 72,000 and 175,000 jobs of value indicated. This research provided useful indication that the contribution could be a major one to UK GDP, circa $3 billion per annum over a 10-year period would release circa 1% to GDP (UK Government, 2017).

10.4 Technology of the future

Government is not generally good at selecting technology, technology suppliers are inclined to sell it whether it works or not and operators just want proven technology which is straight forward and reliable to operate. To utilise the right new technology at the right time for the right application, the right system changes and incentives need to be in place. Our research indicates current and future technology and societal scenarios are likely to benefit from the current UK policy drivers.

10.5 Policy for Circularity

The starting point for policy for waste seems to be landfill tax, and recycling targets, which will get you halfway there, and at around 50% recycling and composting levels, After that more fundamental system change is required and strong producer responsibility seems to be the most powerful forward policy driver, with far reaching impacts of levelling and incentivising sustainable design practice of fast moving consumer goods, with deposit schemes producers, and harmonisation and simplification for the public is required.

The policy drivers and incentives discussed here, at least in the UK context, are popular enough to be politically executed, partly because of the media "war on plastics" and "blue planet", but also because the public have demanded waste must be reused.

We set out to test the following measures of circularity;

a. is the industry likely to utilise materials 'at a scale' which could be considered industrialised;

This study determined that currently the Circular Economy was at scale in some sectors, in the paper sector and metals sectors but not in the plastics nor glass sectors and certainly not for the many composite materials which constitute the majority of wastes (non-recyclable fractions >50% of the flows). The EPR proposed for England is commencing with packaging and will be a robust product stewardship model backed by regulation, incentives and a business model that could be rolled out across different products offering a really industrialised polluter pays principle at scale.

b. **is the industry practice industry widespread across sectors;**

As stated for (a) above the industry practice varies by sector significantly with packaging, cars, building sectors performing very well but with specialist products made from more than one material component or complex chemicals fairing much worse, such as solar panels, wind turbines, mattresses. The EPR would need to be applied across all sectors in order to have the desired outcome, and the Resources and Waste strategy envisages this.

c. **is the practice self-sustaining from an economic perspective, when taking into account relevant fiscal instruments currently in place;**

As stated in (a) the proposed England EPR polluter pays regulation appears to be a suitable model since it captures the costs in the product sales and internalises a previous externality, a key principle of environmental progress. Thus, the cost becomes internalised as part of the economic cycle.

It appears from the analysis of the proposed new policy that, particularly with EPR, but across the main pillars of the strategy the three tests can be significantly met.

10.6 Limitations of this work

Waste data remains problematic, working with the data and having knowledge of other sectors it is probably exaggerated and no worse than in manufacturing or production industries in terms of publicly available data (one might argue more is available publicly and is derived from regulatory requirements and as such is better quality), however, uncertainty over how different countries calculate their recycling performances means comparison to other countries is difficult.

10.7 Data quality

Contrary to popular belief, with *Wastedataflow* (the electronic tool used by local authorities), and Environment Agency returns on waste recycled, composted, landfilled and sent to energy from waste, and a raft of studies by consultants waste data is arguably of better quantity and quality than in other manufacturing and industrial sectors where disclosure is not a regulatory requirement. However, the couple nature of waste composition and the subtitles of where it is collected, separated, transformed, potentially double counted and considered as volume rather than by weight adds some opaqueness to the datasets. Indeed, at a European level, whilst confirming to the same EU legislative instruments, there remains a disparity in the reported recycling and landfill diversion levels achieved, with the potential for discretion in the detail of the reporting methods between member states (Holder, 2015).

It is likely that this kind of benchmarking data (in Figure 10.1) depicting global recycling rates does not fully account for scope and reporting differences.

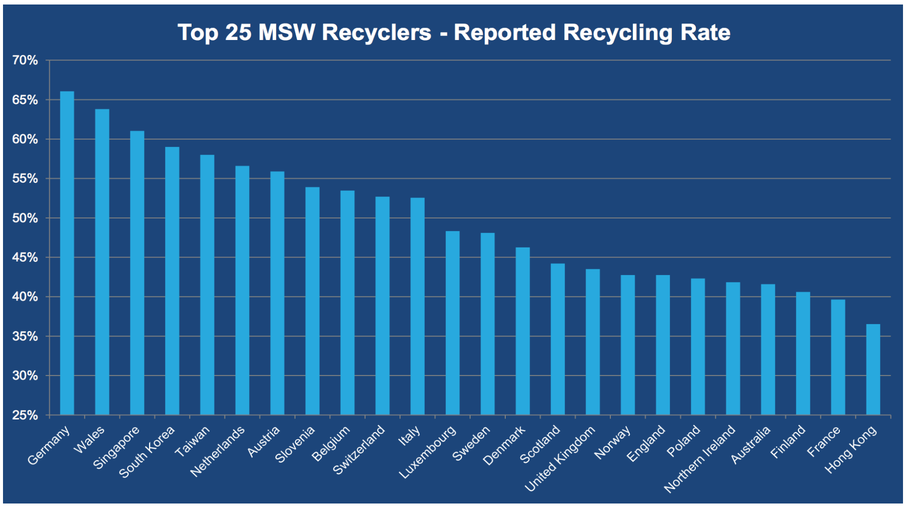


Figure 10.1 Reported Recycling Rates across Europe, (European Environment Bureau, 2019).

By way of example, Wales decided to include bottom ash derived from Energy Recovery in its recycling performance, thus boosting its recycling by some 5% (Eminton, 2016). The European Commission has proposed to introduce a single EU calculation method for measuring real recycling rates for municipal waste, at the input into the final recycling process, (Eurometaux, 2016), and industry is progressively introducing digital systems to manage waste with on-board weighing, and collection of per bin weights, volumes and collection characteristics. Furthermore, the harmonisation of collection methods as discussed in Chapter 8 will further allow uniform data to be analysed.

10.8 Sensitivity

A sensitivity analysis of the capacity calculation is undertaken in Appendix 3 which concludes no significant variation to our conclusions with a high degree of latitude in the assumptions.

10.9 Definitions

A potential limitation of this work is the discussion around infrastructure relied on some work which considered all types of infrastructure (DEFRA) and some which only considered the lack of Energy Recovery facilities for residual waste (Tolvik). We do not think this impacted the results nor the conclusions significantly since the latter analysis of 2020 evidenced that there was still insufficient capacity of at least some type of technology and that remained valid.

There is also a debate over whether a Circular Economy can include Energy Recovery at all since materials are destroyed and cannot be further cycled when we recover energy. However, we consider that this is a pragmatic effort to install as far a penetrating Circular Economy as can be achieved accepting physical constraints and the limitations of circulation. We also consider that if the recovered energy (either from biological or thermal treatment) is reutilised to recycle materials it would directly contribute to the Circular Economy.

This debate comes out in the respective works of Eunomia (2018) and Tolvik (2019a/b), where Eunomia tend to assume that all landfill and energy recovery wastes can be recycled or composted and where Tolvik assume all residual waste not today recycled and composted needs to be incinerated. The answer lies somewhere between the two extremes and the progress that can be made between them should be led by life cycle thinking, since recycling every last tonne would have exponentially high cost and potentially be counterproductive in environmental terms. This accepted it still remains a proposal of this research that the EPR policy lever would allow business to determine the most cost-effective outcome whilst internalising the environmental costs.

The author of this work is an industry practitioner and existing practice and conduct in the regulatory bodies, policy makers and operators remain that energy recovery will be an important component of future waste management for at least 30 years hence.

10.10 Carbon and climate

Carbon remains external to these assumptions, and this must be addressed, given that so many companies have committed to net zero it seems that these policy directives will merge or reach loggerheads in the near future.

10.11 Areas of useful further work

The England policy is about to enter a watershed moment with the retailers and big brands coming on board with EPR, and study of the success, costs and benefits to society will be important. A key question is will this really drive product design for recycling, will it inspire new models of reuse and return schemes, and will it be successful in achieving the goal of a Circular Economy.

It might be useful to study the Product Stewardship (voluntary measures) application of EPR in comparison to regulatory means. Australia currently follows a Stewardship model and comparison of respective results might be useful in the context of inefficiencies that regulation might bring.

Further work around the performance of Wales in the context of diversion from landfill is worth noting. Whilst Wales performance is some 10% higher in diversion that England there is a difference in the calculation methods applied, with Wales including ashes from Energy Recovery in the recycling figures. Further work could usefully be undertaken to consider whether Wales policies are more effective that England's policies with consideration for equivalency in cost of implementation.

10.12 A final word

The Resource Council, the industry body that has proposed a waste sector plan for the UK, recently issued a report which suggests the implementation of the resources and waste strategy would unlock circa £20bn of investment. This thesis was being finalised in the midst of a global financial impact arising from the global COVID19 pandemic which has hit all parts of the world. Whilst green investment was temporarily on hold, the public and commercial discourse has resumed as to how we should return - not to business as normal - but to a green recovery, something which was first attempted after the 2008 global financial crisis, but which didn't take a significant foothold. It is perhaps time for a new way to communicate about waste and for planning to be fast tracked for the public good, relying on provision of an educational shift, where we seek to provide the learning tools rather than relying on the dissemination of information. There is even a prospect of providing local guarantees on health and environmental impact when building infrastructure which will underpin the claims made about safety, and to cement trust with those locally impacted.

The conclusion is hopeful, in that, despite ecological decline, biodiversity, rampant consumerism, COVID19, and globalism impacts, governments are maintaining their policies in this field of sustainability. The USA has, under President Biden, re-joined the Paris agreement, the UK indicates it will maintain EU standards post Brexit and has a very progressive waste policy in the making, and China has implemented stringent controls across its recycling sectors (via the Chinese Sword policies). Certainly, environmental concerns are a board room matter, and the net zero carbon commitments of the blue-chip companies stands testament to their concerns over investor and share price impacts. As people 'get better off', that is, their health and wealth increases, they have more time to concern themselves with future generations, and the post COVID world is littered with the idea of green recoveries and far-reaching industrial investment into green technology without regression into a deeper carbon intense outlook. Only time will tell, and it is hoped the overall contribution of this thesis is to provide an evidence-based guide to policymakers, investors and industry as to the effects, benefits and outcomes of different policy measures with the expectation that they will be inspired to address the ecological transformation of business and industry required to avert the global decline of nature.

References

Accorsi, Riccardo & Versari, Lorenzo & Manzini, Riccardo. (**2015**). Glass vs. Plastic: Life Cycle Assessment of Extra-Virgin Olive Oil Bottles across Global Supply Chains. Sustainability. 7. 2818-2840. 10.3390/su7032818.

Achenbach, J., (**2015)**. War on science (The Age of Disbelief), National Geographic Society, New Washington, DC: March 2015 issue, 227, 3.

Allwood, J.M., **(2014). ** Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies, in: Worrell, E., Environ Int. 2009 Nov;35(8):1256-66. DOI: 10.1016/j.envint.2009.07.009. Epub 2009 Aug 13.

Andersen, M.S., (**2007**). An introductory note on the environmental economics of the Circular Economy. Sustain. Sci. 2, 133–140.

Alademi, R. (**2020**). The National Sword Policy of China and its Effect on Global Policy.

Albers, A., Beloin-Saint-Pierre, D., Helias, Arnaud., Tiruta-Barna, L., Fantke, P., Levasseur, A., Benetto, E., Benoist, A., Collet, P., (**2020**) Addressing temporal considerations in life cycle assessment, Accepted 1 July 2020, Available online 9 July 2020.

Aloini, D., Dulmin, R., Mininno, V., Stefanini, A., Zerbino, P., **2020**, Driving the Transition to a Circular Economic Model: A Systematic Review on Drivers and Critical Success Factors in Circular Economy, Sustainability 2020 https://doi.org/10.3390/su122410672

Amienyo, Gujba, Stichnothe, and Azapagic, 'Life cycle environmental impacts of carbonated soft drinks'; H. H. Khoo, R. B. H. Tan, and K. W. L. Chng, 'Environmental impacts of conventional plastic and bio-Based carrier bags', International Journal of Life Cycle Assessment , 15/3 (**2010**), 284–93.

Amienyo, Gujba, Stichnothe, and Azapagic, 'Life cycle environmental impacts of carbonated soft drinks'. Int J Life Cycle Assess (**2013**) 18:77–92.

Amouyal J, Burchett N, Cole C, Kirkman R, Voulvoulis N, (**2019**) Keeping the lights: Operating without fossil fuels, Veolia UK.

Arena, U., (**2012**). Process and technological aspects of municipal solid waste gasification. A review. Waste Manag. 32, 625e639.

Armitt, J., (**2013**). The Armitt Review an Independent Review of Long Term Infrastructure Planning Commissioned for Labour's Policy Review. London: Labour Party. http://www.yourbritain.org.uk/uploads/editor/files/The_Armitt_Review_Final_Report.pdf

Arena, U., (**2012**). Process and technological aspects of municipal solid waste gasification. A review. Waste Manage. 32, 625-639.

Atkinson, W., New, R., (**1993**). An overview of the impact of source separation schemes on the domestic waste stream in the UK and their relevance to the government's recycling target. National Environmental Technology Centre. Warren Spring Laboratory, Stevenage.

Baker, R. (**2017**) Reformation or Re-formation? Richard Baker's Blog . May 6 2017. https://bakerbalham.wordpress.com/2017/05/06/reformation-or-re-formation/ [Accessed: 15 August 2017].

Ball, A., Broadbent, J., Jarvis, T., (**2006**). Waste management, the challenges of the PFI and 'sustainability reporting'. Bus. Strat. Environ. 15, 258-274.

Baumol, W. J. (**1977**) On Recycling as a Moot Environmental Issue, Journal of Environmental Economics and Management, Vol. 4, pp. 83-87.

BBC, 'Scotland's food waste causing more greenhouse gas than plastic', (**2019**).

BBC, 2001, The Blue Planet, David Attenborough bbc.co.uk/programmes/b008044n

Beaurain C, Chembessi C, Cloutier G, **(2021)** Understanding the scaling-up of a Circular Economy (CE) through a strategic niche management (SNM) theory: A socio-political perspective from Quebec, Environmental Challenges, Volume 5, 2021.

Becker, A., Judge, R., (**1993**) Motivating recycling: A marginal cost analysis, Contemporary Economic Policy, July 1993, https://doi.org/10.1111/j.1465-7287.1993.tb00390.x

Bennett E, Biggs R, Carpenter S R, Cornell S E, de Vries W, de Wit C A, Fetzer, I, Folke C, Georgina M, Gerten D, Heinke J, Mace G M, Persson L M, Ramanathan V, Reyers B, Richardson K, Rockström J, Sörlin S; Planetary boundaries: Guiding human development on a changing planet, *Science* 13 Feb **2015**: Vol. 347, Issue 6223, 1259855 DOI: 10.1126/science.1259855

Berglund, C., and Söderholm, P. (**2003**) An Econometric Analysis of Global Waste Paper Recovery and Utilization, Environmental & Resource Economics, Vol. 26, pp. 429-45.

Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B., **2016**. Product design and business model strategies for a Circular Economy. J. Ind. Prod. Eng. 33, 308–320.

Boons, F., Montalvo, C.,Quist, J. & Wagner, M., **2013**. Sustainable innovation, business models and economic performance: an overview. J. Clean. Prod., 45, 1-8.

Boulding, K.E. (**1966**). The Economics of the Coming Spaceship Earth, in: H. Jarrett (ed.) 1966. Environmental Quality in a Growing Economy, pp. 3-14.Baltimore, MD: Resources for the Future/Johns Hopkins University Press.

Bouton, S., Creyts, J., Kiely, T., Livingston, J., Nauclér, T., **2010**. Energy efficiency: A compelling global resource. McKinsey Sustainability & Resource Productivity.

Brandt B., and Pilz H, 'The impact of plastic packaging on life cycle energy consumption and greenhouse gas emissions in Europe. Executive Summary', July (**2011**), 1–7.

Braungart, M., McDonough, W., Cradle to Cradle: Patterns of life, 29th January **2009**, Random House. ISBN 9780099535478

Brennan, G., Tennant, M. and Blomsma, F., **2015**. Business and production solutions: Closing the Loop in Kopnina, H. and Shoreman-Ouimet, E. (Eds).

Bright Blue, 'Plastics and climate change: unwrapping the evidence', (**2018**).

Brooks, Ben, S&P GLOBAL PLATTS 23 Jan, **2020**, Recycled plastics market will feel the heat from consumer demand in 2020.

Brown A, Busch J, Hahladakis J, Lacovidou E, Millward-Hopkins J, Purnell P, Velis C A, Zwirner O, A pathway to Circular Economy: Developing a conceptual framework for complex value assessment of resources recovered from waste, Journal of Cleaner Production, Volume 168, **2017**, Pages 1279-1288,ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2017.09.002.

Brundtland, G.H., **1987**. Our common future: Report of the 1987 World Commission on Environment and Development. United Nations, Oslo.

BTEC, **2015**. Navigating the Biomass Thermal Project Decision Making Process, Understanding and Responding to Needs of Stakeholder Groups, a Focus on Commercial and Institutional Class Buildings. Available at: https://www.biomassthermal.org/programs/Stakeholder%20Overview%202013%20Final_05012022.pdf [Accessed: 1 October 2015].

Burnley, S.J., **2007**. A review of municipal solid waste composition in the United Kingdom. Waste Manage. 27, 1274-1285. Cabinet Office, 2002. Public Attitudes towards Recycling and Waste Management, Quantitative and Qualitative Review. Research Study Conducted for The Strategy Unit, Cabinet Office. CBI, 2014.

Burchett, **2020**, Companies and organisations communicating their net zero ambitions, collated 10th October 2020, provided by Nick Burchett, Veolia, 2020.

Cabalova I, Kacik F, Geffert A and Kacikova D, The Effects of Paper Recycling and its Environmental Impact. Published: July 5th **2011** DOI: 10.5772/23110.

Cabinet Office, **2002**. Public Attitudes towards Recycling and Waste Management, Quantitative and Qualitative Review (Research Study Conducted for The Strategy Unit, Cabinet Office). https://www.ipsos.com/sites/default/files/migrations/en-uk/files/Assets/Docs/Archive/Polls/waste_recycling.pdf

CEAA, **2008**. . Public Participation Guide: a Guide for Meaningful Public Participation in Environmental Assessments under the Canadian Environmental Assessment Act, Chapter 4: Planning for Public Participation. Canadian Environmental Assessment Agency. May 2008. Available at: http://www.ceaa.gc.ca/default.asp?lang.En&n.46425CAF-1&offset.6&toc.show#fn1b.

Center for International Environmental Law, Fuelling Plastics. Fossils, Plastics, & Petrochemical Feedstocks, (**2017**).

CGRi, **2021** The Circle Economy’s Circularity Gap Report https://www.circularity-gap.world/2021

Chandrappa, R., Brown, J., **2012**, Solid Waste Management Principles & Practice. Springer, Heidelberg New York. Chen, X., Geng, Y., Fujita, T., 2010. An overview of municipal solid waste management in China. Waste Manage. 30, 716-724.

Chen X, Geng Y, Fujita T, An overview of municipal solid waste management in China, Waste Management Journal 30 (**2010**) 716–724

Chertow, M.R., **2001**. The IPAT Equation and Its Variants: Changing Views of Technology and Environmental Impact. J. Ind. Ecol. 4, 13–29.

CIWM, **2014**. The Circular Economy: What Does it Mean for theWaste and Resource Management Sector. Available at: http://www.ciwm-journal.co.uk/downloads/CIWM_Circular_Economy_Report-FULL_FINAL_Oct_2014.pdf.

Clark, W., Crutzen, P., **2005**. Science for global sustainability: toward a new paradigm. KSG Working Paper. 120, 1–28.

Cleary J, Life cycle assessments of municipal solid waste management systems: a comparative analysis of selected peer-reviewed literature, Environ. Int., 35 (**2009**), pp. 1256-1266, 10.1016/j.envint.2009.07.009

Cleary J, ‘Life cycle assessments of wine and spirit packaging at the product and the municipal scale: A Toronto, Canada case study’, Journal of Cleaner Production, 44 (**2013**), 143–51.

Cohen, M.J., **2006**. Ecological modernization and its discontents: The American environmental movement’s resistance to an innovation-driven future. Futures 38, 528–547.

Cole C, Kirkman R, Voulvoulis N, (**2016**) Imagine 2050: The future of water, waste and energy - How UK industry will need to adapt for tomorrow, Veolia UK, Contributors: Conway T (University of Sheffield), Deakin C (Chris Deakin Associates), Evans S (University of Cambridge), Gaye M (Bellwether Food Trends), Hilton L (Business Consultant), Pearson I (Futurizon), Worzel R (Futuresearch), Helias V (P&G), Madden P (Arla foods), Quin B (Intel), Hurst K (Veolia).

Cole C, Kirkman R, Voulvoulis N, (**2015**) Imagine 2050: The innovations we will need in waste, water and energy to ensure a sustainable future. Veolia UK, Contributors: Brachlianoff E (Veolia), Coyne M (Veolia), Burnley S (Open University), Helias V (P&G), Non-attributed, consultancy Roland Berger, Quin B, (Intel), Evans S (University of Cambridge).

Commoner, B., **1971**. The closing circle: Nature, man, and technology. Random House, New York.

Commons library, Mind the gap: Challenges for future UK energy policy Insight. Published Tuesday, 29 January, **2019** https://commonslibrary.parliament.uk/science/energy/mind-the-gapchallenges- for-future-uk-energy-policy/.

Confederation of British Industries (CBI), UK. The low-carbon 2020s A decade of delivery, Report, November **2019**.

CBI, **2014**. Building Trust, Making the Public Case for Infrastructure. Available at: http://news.cbi.org.uk/news/building-trust/.

Connor P.M., **2003**. UK renewable energy policy: a review. Renew. Sust. Energ. Rev. 7, 65-82.

Conrad, J.M. **1999** Resource economics. Cambridge University Press.

Copper, **2015**. Independent survey of attitudes to infrastructure in Great Britain 2015. Available at: http://www.icaro.uk.com/images/uploads/project_downloads/20151203_Attitudes-to-infrastructure-inGreat-Britain-2015_FINAL-PDF.pdf

Dalal-Clayton, B. and Bass, S. (**2009**) The challenges of environmental mainstreaming: experience of integrating environment into development institutions and decisions. Environmental Governance No. 3 International Institute for Environment and Development, London. http://pubs.iied.org/pdfs/17504IIED.pdf [Accessed: 30 July 2017].

Daly, H.E. & Townsend, K.N.,**1993**. Valuing the earth: economics, ecology, ethics. MIT Press, Boston.

Damigos D (**2006**) An overview of environmental valuation methods for the mining industry. J Clean Prod 14(3–4):234–247. doi:10.1016/j.jclepro.2004.06.005.

Davies, A., **2003**. Waste wars-public attitudes and the politics of place in waste management strategies. Irish Geogr. 36, 77-92.

Davies, S., **2007**. Politics and Markets; the case of UK Municipal Waste Management, Working Paper 95, School of Social Sciences, Cardiff University.

Decker, E.H., Elliott, S., Smith, F.A., **2002**. Megacities and the environment. Sci. World J. 2, 374-386. EU Commission, 1999. Landfill Directive 1999/31/EU, Official Journal of the European Communities, L182.1.

Dechezlepretre, A., and Sato, M. (**2014**) The impacts of environmental regulations on competitiveness. Policy brief November 2014.

DEFRA, **2009a**. Managing the waste PFI programme, Report by the Controller and auditor general, HC 66 Session 2008-2009.

DEFRA (**2009b**) Municipal Waste Composition: A Review of Municipal Waste Component Analysis Waste Research Report WR0119. Available at: http://randd.DEFRA.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=15133 [accessed 20 November 2013].

DEFRA (**2010a**) Spending Review 2010 – Changes to Waste PFI Programme: supporting analysis. Available at: http://archive.DEFRA.gov.uk/environment/waste/localauth/funding/pfi/documents/pfi-supporting-analysis-waste101206.pdf
[accessed 23 January 2014].

DEFRA, 2011a. Government review of waste policy in England 2011. Published 14 June 2011, DEFRA.

DEFRA, **2011b**. The Economics of Waste and Waste Policy, Waste Economics Team Environment and Growth Economics, DEFRA.

DEFRA, **2013a**. Statistics on waste managed by local authorities in England in 2012/13.

DEFRA, **2013b**. Waste management plan for England, July 2013.

DEFRA (**2013c**) Incineration of Municipal Solid Waste. Available at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/221036/pb13889-incineration-municipal-waste.pdf
[accessed 24 January 2014].

DEFRA (**2013d**) Forecasting 2020 Waste Arisings and Treatment Capacity. **Revised February 2013 Report Published October 2013.** Available at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251567/pb13883-forecasting-2020-waste-arisings-131017.pdf
[accessed 22 November 2013].

DEFRA, **2014**. Refuse derived fuel market in England, DEFRA response to the call for evidence, December 2014 Available at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/381626/rdf-marketDEFRA-response-201412.pdf

DEFRA, **2015**, Resource management: a catalyst for growth and productivity, February 2015

DEFRA, **2018**, Our Waste, Our Resources: A Strategy for England. December 2018
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/765914/resources-waste-strategy-dec-2018.pdf

DEFRA, 'Greenhouse gas reporting: conversion factors 2019', (**2019**).

DEFRA, Government Statistical Service, UK Statistics on Waste, 19th March **2020a**
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/918270/UK_Statistics_on_Waste_statistical_notice_March_2020_accessible_FINAL_updated_size_12.pdf

DEFRA, Guidance**:** Straws, cotton buds and drink stirrers ban: rules for businesses in England, 21st September **2020b**, https://www.gov.uk/guidance/straws-cotton-buds-and-drink-stirrers-ban-rules-for-businesses-in-england

Deloitte, 2020, The Deloitte Global Millennial Survey 2020: Resilient generations hold the key to creating a "better normal". https://www2.deloitte.com/global/en/pages/about-deloitte/articles/millennialsurvey.html

Dinan, T.M. (**1993**) Economic efficiency effects of alternative policies for reducing waste disposal. Journal of environmental economics and management, 25(3), pp.242-256.

Doan, M.H., Sassen, R., (**2020**) The relationship between environmental performance and environmental disclosure: A meta-analysis, Journal of Industrial Ecology, Volume 24, Issue 5, Pages 1140-1157, October 2020.

Dora M, and Lacovidou E, 'Why some plastic packaging is necessary to prevent food waste and protect the environment', (**2019**).

ECA, 2012. Is structural measures funding for municipal waste management infrastructure projects effective in helping member states achieve EU waste policy objectives. Special Report No. 20. Available at: http://www.eca.europa.eu/Lists/ECADocuments/SR12_20/SR12_20_EN.PDF

EDIE, 2018, Plastics and packaging: The UK's 'waste mountain' in charts, 23 February 2018. https://www.edie.net/news/5/The-UK-s--waste-mountain--in-charts/

Ekins, P., Domenech, T., Drummond, P., Bleischwitz, R., Hughes, N. and Lotti, L. (**2019**), "The Circular Economy: What, Why, How and Where", Background paper for an OECD/EC Workshop on 5 July 2019 within the workshop series "Managing environmental and energy transitions for regions and cities", Paris.

Ellen MacArthur Foundation (**2015**) Delivering the Circular Economy: A Toolkit for Policymakers. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_PolicymakerToolkit.pdf [Accessed: 5 August 2017].

EMF, (**2016**), The New Plastics Economy: Rethinking the future of plastics, Ellen McArthur Foundation, 2016: Downloaded https://emf.thirdlight.com/link/faarmdpz93ds-5vmvdf/@/preview/1?o

Elliott, S.J., McClure, J., **2009**. "There's just hope that no one's heath is at risk": residents' reappraisal of landfill siting. J. Environ. Plann. Manage. 52, 237-255.

Eminton S, Lets Recycle, Incinerator bottom ash boost for Wales**,** June **2016** https://www.letsrecycle.com/news/latest-news/incinerator-bottom-ash-boost-for-wales/

Environment Agency (n.d.) Position statement Energy from Waste http://www.environment-agency.gov.uk/static/documents/Leisure/position_statement.pdf [accessed 10 December 2013]

Environment Agency (**2010**), Data on facilities covered by environmental permitting. [available on request from the Agency]

Environment Agency (**2012**), Waste Data Tables 2012. Available at: http://www.environment-agency.gov.uk/research/library/data/150326.aspx [accessed: 24 January 2014]

EPA, Greenhouse Gas Equivalencies Calculator (March **2020** update)

ERM, **2006**. Carbon balances and energy impacts of the Management of UK Wastes, Final Report for DEFRA R&D Project WRT 237.

Ernst & Young's analysis for the British Plastics Federation, **2019**. Plastic Packaging Tax Consultation: Update Workshop 16th April 2019. https://unearthed.greenpeace.org/2019/05/10/industry-calls-on-philip-hammond-to-weaken-his-planned-plastics-tax/

ESA (Environmental Services Association), **2013**, *Going for Growth: A practical route to a Circular Economy* (June 2013)

ESA (Environmental Services Association), UK Residual Waste: 2030 Market Review Final November **2017**, a report by Tolvik.

Eunomia, **2011**. Residual Waste Infrastructure Review, High-level Anal. - Issue 4. Fischer, T.B., Potter, K., Donaldson, S., Scott, T., 2011. Municipal waste management strategies, strategic environmental assessment and the consideration of climate change in England. J. Environ. Assess. Policy Manage. 13, 541-565.

Eunomia (2015) Residual Waste infrastructure review - Detailed Analysis, Issue 8. Available from Eunomia.com

Eunomia (2013) Residual Waste Infrastructure Review – Detailed Analysis, Issue 4. Available from Eunomia.com

European Commission (**1999**), COUNCIL DIRECTIVE 1999/31/EC of 26 April 1999 on the landfill of waste, 1999

European Commission (**2012**), Proposal for a Decision of he European Parliament and of the Council on a General Union Environment Action Programme to 2020 "Living well, within the limits of our planet"

European Commission, **2014**. Towards a Circular Economy: A Zero Waste Programme for Europe, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels.

European Commission, **2015**. Closing the loop - An EU action plan for the Circular Economy, Com(2015) 614 communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions. European Commission, Brussels.

European Environment Agency (**2015**) Decoupling demystified. Resource efficiency. European briefings. 18 Feb 2015

European Commission, ‘A European Strategy for Plastics’, European Commission , (**2018**).

Eurostats, 2004, 2011 https://ec.europa.eu/eurostat/web/national-accounts/data/main-tables

Eurostat 2012, https://ec.europa.eu/eurostat/statistics-explained/index.php/Packaging_waste_statistics

Eurostats, 2017, https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/DDN-20200312-1

Extinction Rebellion, This is not a drill: An extinction rebellion handbook, 13th June **2019**, Penguin Press

Fisher, Joseph L., Environmental Pollution and the Future of Man's Earth, Social Education, 35, 1, 5-9 25, Jan **1971**

Fischer, T.B., Potter, K., Donaldson, S., Scott, T., **2011**. Municipal waste management strategies, strategic environmental assessment and the consideration of climate change in England. J. Environ. Assess. Policy Manag. 13, 541e565.

Fletcher E, Jones P, Kelly J, (**2018**) Marking time: England's 2016-17 recycling statistics, Isonomia, January 19th, 2018. https://www.isonomia.co.uk/marking-time-englands-2016-17-recycling-statistics/

Forcinio, H, 'RPET OK in Canada, SPC Metrics, Concentrated Detergent', Sustainability Times , 4/2.Volume 4, Issue 2 **n.d.**

Frerot, A. (2015) A global carbon tax would create a vital incentive for businesses to work against climate change. CITYA.M Newsletters http://www.cityam.com/230123/global-carbon-tax-would-create-vital-incentive-businesses-work-against-climate-change [Accessed: 15 August 2017]

Friends of the Earth, (2010) More jobs, less waste: Potential for job creation through higher rates of recycling in the UK and EU, September 2010, https://www.foeeurope.org/sites/default/files/publications/foee_more_jobs_less_waste_0910.pdf

Fullerton, D. and Kinnaman, T.C. (**1995**) Garbage, recycling, and illicit burning or dumping. Journal of environmental economics and management, 29(1), pp.78-91.

Fullerton, D. and Wu, W. (**1998**) Policies for green design. Journal of environmental economics and management, 36(2), pp.131-148.

Gallagher, L., Ferreira, S., Convery, F., **2008**. Host community attitudes towards solid waste landfill infrastructure: comprehension before compensation. J. Environ. Plann. Manage. 51, 233-257.

Geyer, R., Jambeck, J. R. & Law, K. L. (**2017**). Production, use, and fate of all plastics ever made. Sci Adv 3, e1700782, doi:10.1126/sciadv.1700782.

Ghisellini, P., Cialani, C., Ulgiati, S., **2016**. A review on Circular Economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32.

Government of Western Australia, Extended Producer Responsibility: Policy Statement, 29 June **2005**. https://www.wastenet.net.au/assets/documents/content/information/050628_epr_policy.pdf

Green Investment Bank (GIB), Tuesday, July 29, **2014** - 16:02, Agg-net: UK needs more waste infrastructure, says GIB, https://www.agg-net.com/news/uk-needs-more-waste-infrastructure-says-gib

Giusti, L., **2009**. A review of waste management practices and their impact on human health. Waste Manage. 29, 2227-2239. GLA, 2015. The London Plan: The spatial development strategy for London consolidated with alterations since 2011, March 2015. Available at: https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/London%20Plan%20March %202015%20(FALP).pdf

Gray, M.J., **1997**. Environment, Policy and Municipal Waste Management in the UK. T. I. Brit. Geogr. 22, 69-90. Hampshire County Council, 1989. Waste Management Plan (Winchester, Hampshire County Council)

GLA, **2015**. The London Plan: the Spatial Development Strategy for London Consolidated with Alterations since 2011. March 2015. Available at: http://www.london.gov.uk/sites/default/filesgla_migrate_files_destinationLondon%20Plan%20March%202015%20(FALP).pdf.

Green Alliance, ‘Losing the bottle: why we don’t need single use containers for water’. Author(s): Libby Peake, Jonathan Ritson, Melissa Petersen **(2019)**

Grimmond T, McPherson B, Sharip M, The impact on life cycle carbon footprint of converting from disposable to reusable sharps containers in a large US hospital geographically distant from manufacturing and processing facilities. PeerJ. **2019** Feb 22;7:e6204. doi: 10.7717/peerj.6204. PMID: 30809428; PMCID: PMC6388662.

Guardian Online, August **2018**, *Crunch time for Walkers over non-recyclable crisp packets*, Rebecca Smithers, Sun 5 Aug 2018 https://www.theguardian.com/environment/2018/aug/05/walkers-plastic-crisp-packet-non-recyclable

Hampshire County Council, 1989. Waste Management Plan. Hampshire County Council, Winchester.

Hansard, Restoring Nature and Climate Change. Committee for the Environment Food and Rural Affairs. Volume 667: debated on Monday 28 October **2019**

Hasselbalch J, Holmberg K, Nielsen T D, Stripple J, Politics and the plastic crisis: A review throughout the plastic life cycle, First published: 08 August **2019** https://doi.org/10.1002/wene.360

Hee, J., Quicker, P., **2013**. Clean incineration fact or fiction? Waste Manage. World, 14, 10-14.

Higgs, G., **2006**. Integrating multi-criteria techniques with geographical information systems in waste facility location to enhance public participation. Waste Manage. Res. 24, 105-117.

HM Treasury (**2010**) Cm7942 Spending Review 2010 Norwich: The Stationery Office Ltd.

Holder, M, New CIWM president highlights 'inconsistent' EU recycling data, Letsrecycle.com October **2015** https://www.letsrecycle.com/news/latest-news/new-ciwm-president-highlights-inconsistent-eu-recycling-data/

Hayward-Highham, **2017**, 'Mind the Gap **2017**-2030' **Suez** report. https://www.suez.co.uk/-/media/suez-uk/files/publication/mindthegap20172030-1709-web.pdf

HMRC, (2021), National Statistics: Environmental Taxes Bulletin Commentary June 2021, first Published June 2021. https://www.gov.uk/government/statistics/environmental-taxes-bulletin/environmental-taxes-bulletin-commentary-june-2021.

HoCEAC (House of Commons Environmental Audit Committee), **2015**, Growing a Circular Economy: Ending the throwaway society, Third report of Session 2014–15

Hoornweg, D., Bhada-Tata, P., Kennedy, C., **2013**. Environment: Waste production must peak this century. Nature, 502, 615-617.

HPA, **2010**. The Impact on health of emissions to air from municipal waste incinerators. Advice from the Health Protection Agency. Available at: http://www.plymouth.gov.uk/hpa_impact_on_health_of_emissions_to_air.pdf

Huitt, W. (1992), Problem solving and decision making: Consideration of individual differences using the Myers-Briggs Type Indicator. *Journal of Psychological Type, 24*, 33-44. Available at http://www.edpsycinteractive.org/papers/1992-huitt-mbti-problem-solving.pdf

Humbert, S., Rossi, V., Margni, M., Jolliet, O. and Loerincik, Y., 2009. Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots . The International Journal of Life Cycle Assessment, 14(2), pp.95-106.

Ikiz Kaya, D.; Pintossi, N.; Dane, G., An Empirical Analysis of Driving Factors and Policy Enablers of Heritage Adaptive Reuse within the Circular Economy Framework. Sustainability **2021**, 13, 2479. https://doi.org/10.3390/su13052479

Independent, (18th January 2018), Editor Ben Chu, *PFI: What are Private Finance Initiatives, will they really cost the taxpayer £200bn and is it finally time to get rid of them.* https://www.independent.co.uk/news/business/analysis-and-features/pfi-what-private-finance-initiatives-good-bad-carillion-collapse-public-sector-contracts-government-a8165971.html

IPPC, Summary for policy makers. In: Climate change **2013**: The Physical Science Basis. Contribution of Working group I to the Fifth Assessment report of the Intergovernmental Panel of Climate Change. Stocker, T.F., Qin, D., PLattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (eds) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. JNCC, 2011.

Iranpour, R., Stenstrom, M., Tchobanoglous, G., Miller, D., Wright, J. and Vossoughi, M. (**1999**) Environmental engineering: energy value of replacing waste disposal with resource recovery. Science 285(5428):706–711. doi:10.1126/science.285.5428.706

Jacobs (**2011**) Commercial and Industrial Waste Survey 2009 – Final Report. Department for Environment Food and Rural Affairs. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/190220/ci-project-report.pdf [accessed 25 September 2013]

JNCC, **2011**. The Global Land Use Impact of the United Kingdom's Biomass Consumption Part I: Biomass Flows through the UK Economy, an Overview of Biomass Sources and Overseas Land Requirements. Available at: http://jncc.defra.gov.uk/pdf/JNCC452_web.pdf.

Jones A, Neal B, Reeve B, et al, (**2019**) Front-of-pack nutrition labelling to promote healthier diets: current practice and opportunities to strengthen regulation worldwide, BMJ Global Health 2019;4:e001882.

Katrin, M.-B., ‘Prioritization guidelines for green food packaging development’, British Food Journal, 118/10 (**2016**), 2512–33

Khoo, H.H., Tan, R.B.H. Environmental impacts of conventional plastic and bio-based carrier bags. *Int J Life Cycle Assess* **15,** 338–345 (**2010**). https://doi.org/10.1007/s11367-010-0163-8
Kim, J., McMillan, S.J., **2008**. Evaluation of Internet Advertising Research: A Bibliometric Analysis of Citations from Key Sources. J. Advert. 37, 99–112.

Kirkman R, Voulvoulis, N, **2014,** Waste Infrastructure Requirements for England Centre for Environmental Policy Imperial College London, March 2014

Kirkman R, Voulvoulis N, (**2015**) The circular revolution: An Imperial College London report commissioned by Veolia; Leading author Dr Nick Voulvoulis, Centre for Environmental Policy.

Kirkman R, Voulvoulis, N, **2017**, The role of public communication in decision making for waste management infrastructure,, Journal of Environmental Management, Volume 203, Part 2, 2017, Pages 640-647

Kirkman R, Voulvoulis N, Metivier, P, **(2019),** Shaping the Circular Economy - Taxing the use of virgin resources: The case for a plastic packaging tax in the UK, A report, Published 2019.

Kirkman R, Voulvoulis, N, **2018,** The role of policy in shaping the Circular Economy: A business tax on use of virgin resources, Centre for Environmental Policy, Imperial College.

Kirkman R, Kyle, C**,** Voulvoulis N, **(2020),** Material choices, life cycle assessment of material impacts, 2020”. A report, Published 2020.

Kitching J, Hart M, Wilson N. (**2015**) Burden or benefit? Regulation as a dynamic influence on small business performance. International Small Business Journal. 2015;33(2):130-147. doi:10.1177/0266242613493454

Kharas, H. (**2017**) The Unprecedented Expansion of the Global Middle Class: An Update. Global Economy and Development Working Paper 100. The Brookings Institution.

KPMG, **2020**, Potential economic pay-off of a Circular Economy for Australia, KMPG Economics, 28th April 2020

Kyle, C., Veolia **2018**, *Veolia provided graph from company data.*

Kyriakopoulos, Grigorios L., Vasilis C. Kapsalis, Konstantinos G. Aravossis, Miltiadis Zamparas, and Alexandros Mitsikas. **2019**. "Evaluating Circular Economy under a Multi-Parametric Approach: A Technological Review" *Sustainability* 11, no. 21: 6139. https://doi.org/10.3390/su11216139
Leung J. Y. S., Russell B. D., and Connell S. D., 'Adaptive Responses of Marine Gastropods to Heatwaves', One Earth, 1/3 (**2019**), 374–81.

Local Government Association, **2015**, Waste management: Waste and recycling services are among the most visible services councils run. https://www.local.gov.uk/our-support/efficiency-and-income-generation/waste-management

Lutz W, Scherbov S, The public understanding of Science, Royal Society, **1985**.
https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/1985/10700.pdf

Madival, Auras, Singh, and Narayan, 'Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology'. September **2009**, Journal of Cleaner Production 17(13):1183-1194

Maga D., Hiebel M, and Aryan V, 'A comparative life cycle assessment of meat trays made of various packaging materials', Sustainability (Switzerland) , 11/19 (**2019**); R. Geyer, J.
McKinsey, 2017, Mapping the benefits of a Circular Economy, McKinsey Quarterly. June 2017.

Markard, J., Raven, R., Truffer, B., **2012**. Sustainability transitions: An emerging field of research and its prospects. Res. Policy 41, 955–967.

Martin A, Scott I, (**2003**) The Effectiveness of the UK Landfill Tax, Journal of Environmental Planning and Management. pages 673-689 Volume 46, 2003 - Issue 5, Published online 3rd June 2010

McDonough, W., Braungart, M., **2002**. Cradle to cradle: Remaking the way we make things, 1st ed. North Point Press, New York.

McPherson B, Sharip M, Grimmond T. **2019**. The impact on life cycle carbon footprint of converting from disposable to reusable sharps containers in a large US hospital geographically distant from manufacturing and processing facilities. *PeerJ* 7:e6204
https://doi.org/10.7717/peerj.6204

Meadows, D. H.; Randers, J.; Meadows, D. L., **2004**: The limits to growth. The 30-year update. Routledge, London.

Metal Packaging Europe, 'Can logistics: lighter, greener and more efficient', (**2020**).
Middleton, N., & O'Keefe, P., **1993**. Tears of the Crocodile: From Rio to Reality in the Developing World. Pluto Press

Miedema, A.K., (**1983**) Fundamental economic comparisons of solid waste policy options. Resources and energy, 5(1), pp.21-43.

Modak, P., Jiemian, Y., Hongyuan, Y., Mohanty, R., **2011**. Municipal solid waste management: Turning waste into resources, In: Shanghai Manual – A Guide for Sustainable Urban Development in the 21st century, Chapter 5, United Nations Bureau International des Expositions, Shanghai 2010 World Exposition Executive Committee.

Mossalanejad, A. (**2011**) Evaluating the Developed Countries Policy Making Toward Environmental
Cases. International Journal of Environmental Research, 6(1), pp.71-80.

National Audit Office, The packaging recycling obligations July 23, **2018**.
https://www.nao.org.uk/press-release/the-packaging-recycling-obligations/

National Infrastructure Commission (NIC), 2018, National infrastructure Assessment: An assessment of the United Kingdom's infrastructure needs up to 2050. Final Report Complete. Published: 10 Jul 2018

Norfolk Council Energy from Waste Project: (**2014**), Unfavorable Currents. Cleaner-Energy Investments, Springer India, 165-174. Available at
https://link.springer.com/chapter/10.1007%2F978-81-322-2062-6_13

OECD, **2009a**, Share of packaging waste in total household waste (OECD).
https://www.grida.no/resources/5861

OECD (**2011**) Environmental Taxation: A Guide for Policy Makers. Organisation for Economic Co-operation and Development. https://www.oecd.org/env/toolsevaluation/
48164926.pdf [Accessed: 10 August 2017]

Office for National Statistics (ONS), December **2018**, Chemical industries data, Regional economic activity by gross value added (balanced), UK: **1998 to 2017**. ons.gov.uk

Olivier JGJ, Schure KM, Peters JAHW (**2017**) Trends in global CO2 and total greenhouse gas emissions. 2017 report. PBL Netherlands Environmental Assessment Agency, The Hague.

Ostman, M., **2008**. Ageing Landfills –Development and Processes, Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala 2008.

Palmer, K.L. and Walls, M.A. (1999) Extended product responsibility: an economic assessment of alternative policies. Washington: Resources for the Future.

Parau, C., Joss, S., **2003**. "The South-East London Combined Heat and Power Incinerator (SELCHP)." research paper prepared for: The Public Accountability in Contemporary European Contexts, London: Centre for the Study of Democracy.

Pasqualino, Meneses, and Castells, 'The carbon footprint and energy consumption of beverage packaging selection and disposal'. Journal of Food Engineering Volume 103, Issue 4, April **2011**, Pages 357-365

Peake L., Brandmayr L., Klein B. (**2018**) Completing the circle Creating effective UK markets for recovered resources, published by Green Alliance, June 2018 ISBN 978-1-912393-08-4

Pearce, D.W. and Turner, R.K. (**1989**). Economics of Natural Resources and the Environment, John Hopkins University Press.

Pearce, D.W. and Turner, R.K. (**1993**) Market-based approaches to solid waste management. Resources, Conservation and Recycling, 8(1-2), pp.63-90.

Petts, J., **2000**. Municipal Waste Management: Inequities and the Role of Deliberation. Risk Anal. 20, 821– 832. Petts, J., 2001. Evaluating the Effectiveness of Deliberative Processes: Waste Management Case-studies. J. Environ. Plann. Manage. 44, 207-226.

Petts, J., **2001**. Evaluating the effectiveness of deliberative processes: waste management case-studies. J. Environ. Plan. Manag. 44, 207e226.

Petts, J., **2004**. Barriers to participation and deliberation in risk decisions: evidence from waste management. J. Risk Res. 7, 115-133. Price, J.L., 2001. The landfill directive and the challenge ahead: demands and pressures on the UK householder. Resour. Conserv. Recy. 32, 333-348.

Petts, J., **2006**, Managing public engagement to optimize learning: Reflections from urban river restoration, Human Ecology Review, Volume 13, Pages 172-181
Price, J.L., **2001**. The landfill directive and the challenge ahead: demands and pressures on the UK householder. Resour. Conserv. Recycl. 32, 333e348.

Purnell, P., Velenturf, A.P.M. **(2021)**, Principles for a sustainable Circular Economy, Sustainable Production and Consumption Journal, Volume 27, July 2021, Pages 1437-1457

PWC, Price Waterhouse Cooper, 2021, Building a more circular Australia: The opportunity of transitioning to a Circular Economy, March 2021. https://www.pwc.com.au/assurance/esg/building-a-more-circular-australia.pdf

Rabobank, March **2019**, How Denmark became a food waste success story: Food waste down 25% in five years. https://www.rabobank.com/en/raboworld/articles/what-the-world-can-learn-from-denmark.html

Rachelson, D., 14 Recycling Contamination Facts That Will Blow Your Mind, October 31, **2018**. https://www.rubicon.com/blog/recycling-contamination-facts/: accessed 21/12/2021.

Radetzki, M., Eggert, R.G., Lagos, G., Lima, M. and Tilton, J.E. (**2008**) The boom in mineral markets: How long might it last? Resources Policy, 33(3), pp.125-128.

Raworth, Kate. Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist, Paperback, 384 pages, Published April 6th **(2017)** by Random House Business.

Reichel A, **2013** (European Environmental Agency), Transitions to sustainable lifestyles in Europe in a 2050 perspective, Published on Dec 9, 2013. Available at: https://www.slideshare.net/danielduartescp/reichel-transitions-to-sustainble-lifestyles-workstudio-45-nov-2013berlinppt97 [Accessed 05-02-2021].

Resource Council – Sector plan 2020, Anthesis (unpublished, out of print, available on request) Resources council sector plan, https://www.anthesisgroup.com/smart-waste-data-deliver-resources-waste-strategy/

Rhodes J & Thair M**,** The Reality Gap UK residual waste treatment capacity – making sense of the arguments September **2015**, Biffa.

Ricardo AEA (**2013**) CIWM Report 2013 Commercial and Industrial Waste in the UK and Republic of Ireland. http://www.ricardo-aea.com/cms/commercial-and-industrial-waste-arisings-management-and-capacity-gaps/ [Accessed 10 December 2013]

Roland Berger, 2019, Climate What now? https://www.veolia.com/sites/g/files/dvc2491/files/document/2019/02/climate-Press-Day-2019-UKv2_1.pdf

Rosiek, J. (**2015**) September. The impact of environmental tax policy on sustainable development of the eu economies. Dea approach. In 11th international conference of asecu “openness, innovation, efficiency and democratisation as preconditions for economic development” (p. 233).

Sagan, C., Druyan, A., (**1995**), The Demon Haunted World; Science as a Candle in the Dark, Random House.

S&P Global Platts, 2021, Analytics expects higher grades of recycled PET to average a premium of around $150/mt over virgin equivalents, S&P Global, 2021. https://www.spglobal.com/platts/en/our-methodology/price-assessments/petrochemicals/eu-recycled-pet

Sá Earp, H N, Romeiro, A R, The Entropy Law and the Impossibility of Perpetual Economic Growth, Open Journal of Applied Sciences, Vol.5 No.10, October **2015**

Seethaler, Sherry & Evans, John & Gere, Cathy & Rajagopalan, Ramya. (**2019**). Science, Values, and Science Communication: Competencies for Pushing Beyond the Deficit Model. Science Communication. 41. 378-388. 10.1177/1075547019847484.

Seliger, G., **2007**. Sustainability in manufacturing: Recovery of resources in product and material cycles. Springer, Berlin, Heidelberg.

Schandl, H., Fischer-Kowalski, M., West, J., Giljum, S., Dittrich, M., Eisenmenger, N., Geschke, A.,Lieber, M., Wieland, H.P. and Schaffartzik, A. (**2016**) Global Material Flows and Resource Productivity. A Report of the Working Group on Decoupling of the International Resource Panel.

Sigman, H. A. (**1995**) A Comparison of Public Policies for Lead Recycling,RAND Journal of Economics, Vol. 26, No. 3, pp. 452-478.

Simon J. M., Rosa F., Allen C., Wilson M., and Moon D., 'Changing trends in plastic waste trade: Plastic waste shipments report', Zero Waste Europe, November (**2018**).

Skjærseth, J.B. (2000) Environmental "Voluntary" Agreements: Conditions for Making Them Work. Swiss Political Science Review, 6 (2), 57-78.

Slack, R.J., Gronow, J.R., Voulvoulis, N., **2009**. The management of household hazardous waste in the United Kingdom. J. Environ. Manage. 90, 36-42.
Söderholm, P. (2011) Taxing virgin natural resources: Lessons from aggregates taxation in Europe. Resources, conservation and recycling, 55(11), pp.911-922.

Sonnemann G, **Valdivia** S, (**2017**), Medellin Declaration on Marine Litter in Life Cycle Assessment and Management : Facilitated by the Forum for Sustainability through Life Cycle Innovation (FSLCI) in close cooperation with La Red Iberoamericana de Ciclo de Vida (RICV) on Wednesday 14 of June 2017. The international journal of life cycle assessment 2017 v.22 no.10. pp. 1637-1639.

Statista, Plastic waste in the uk - statistics and facts, **2020**.
https://www.statista.com/topics/4918/plastic-waste-in-the-united-kingdom-uk/

Statista, 'Production of polyethylene terephthalate bottles worldwide from 2004 to 2021', (**2020**).

Statistica. UK GDP data, https://www.statista.com/statistics/281744/gdp-of-the-united-kingdom/ Accessed 5-2-21.

Statistica. UK chemical industry data, https://www.statista.com/topics/5599/chemical-industry-in-the-uk/ Accessed 5-2-21.

Statystyczny Z.W., **2012**. Zużycie energii w gospodarstwach domowych w 2009 r., [Energy consumption in households in 2009] (in Polish).

Steg, L., Vlek, C, (**2009**) Encouraging pro-environmental behaviour: An integrative review and research agenda. J. Environ. Psychol. 29, 309-317. Strategy Unit, 2012.

Stegemann J A, Van Ewijka S, Limitations of the waste hierarchy for achieving absolute reductions in material throughput, Journal of Cleaner Production, Volume 132, 20 September **2016**, Pages 122-128

Stindt, D., Sahamie, R., **2014**. Review of research on closed loop supply chain management in the process industry. Flex. Serv. Manuf. J. 26, 268–293.

Sunderasan, S., **2015**. Waste not, Want not: A strategy for tackling the waste problem in England.

Sunstein, C.R., Thaler, R., (**2008**) Nudge: Improving Decisions about Health, Wealth, and Happiness, University of Chicago, first published in 2008.

Taxscan, **2019**, Italy introduces plastic tax despite industry outcry, https://www.taxscan.in/italy-introduces-plastic-tax-despite-industry-outcry/45041/

Thunberg, G (**2019**), No One Is Too Small to Make a Difference, June 6, **2019**.

Tolvik (2019a) Filling the Gap – The Future for Residual Waste in the UK, Tolvik, February 2019

Tolvik (2019b) UK Energy from waste statistics - 2018, Tolvik June 2019

Travis D. Edwards and Luis Gautier, Measuring net environmental impact from population growth and alternative energy, First online: 4 June **2020**

UK Government (**2017**) Environmental taxes, reliefs and schemes for businesses. Available at: https://www.gov.uk/green-taxesand-reliefs [Accessed: 5 August 2017]

UK Government, (2017) Environmental taxes, reliefs and schemes for businesses. Available at: https://www.gov.uk/green-taxes-and-reliefs [Accessed: 5 August 2017]

UK Government, Gross Domestic Product (GDP): What it means and why it matters
Gross Domestic Product (GDP) measures if and how much the economy is growing. Here we explain what it actually is and how it's measured. Published 26 January **2017.**

UK Government, Consultation outcome, Plastic packaging tax. HM Treasury Published 18 February **2019**. https://www.gov.uk/government/consultations/plastic-packaging-tax

UK Office for National Statistics (ONS), Chemical industries data, *Regional economic activity by gross value added (balanced), UK: **1998 to 2017**.* ons.gov.uk

UKWIN, **2011**. Table of Potential, Existing and Prevented Incinerators, Available at: http://ukwin.org.uk/resources/table/ [Accessed: 3 October 2015]

UNEP, 2006. Circular Economy. An alternative model for economic development. United Nations Environment Programme, Paris.

(UN) United Nations Department of Economic and Social Affairs (**2015**) World population projected to reach 9.7 billion by 2050. 29 July 2015. http://www.un.org/en/development/desa/news/population/2015-report.html [Accessed: 6 August 2017]

United Nations Development Programme (**UNDP**), May 28, **2021**, Greenhouse gas emissions generated by waste are three times higher in the Republic of Moldova than globally, the sector demanding urgent intervention. https://www.md.undp.org/content/moldova/en/home/presscenter/pressreleases/2021/in-republica-moldova--deeurile-emit-de-trei-ori-mai-multe-gaze-c.html

(UN) UN General Assembly, 2005. Resolution adopted by the General Assembly. 60/1. 2005 World Summit Outcome, New York. http://www.un.org/womenwatch/ods/A-RES-60-1-E.pdf. Accessed June 18, 2014.

Veolia, **2012** Hampshire Heads for Zero Waste, Available at: http://veolia.co.uk/hampshire/about/aboutus/news/hampshire-heads-zero-waste [Accessed: 2 October 2015]

Veolia (**2015**) Veolia calls for corporate carbon tax. Available at: https://www.veolia.co.uk/media/media/veolia-calls-corporate-carbon-tax [Accessed: 31 July 2017]

Veolia, **2020**, Website on Ecological Transformation, https://www.veolia.com/en/eco-transform

Voulvoulis, N, Skolout, JWF, Oates, CJ and Plant, JA. From chemical risk assessment to environmental resources management: the challenge for mining, Environmental Science and Pollution Research, 20 (**2013a**), 7815-7826.

Voulvoulis N., Skolout J.W., Oates C.J., Plant J.A., **2013b**. From chemical risk assessment to environmental resources management: the challenge for mining. Environ. Sci. Pollut. Res. 20, 7815-26.

Voulvoulis, N. **2014,** Understanding systems and their complex interrelationships: a prerequisite to solving environmental problems. http://uest.ntua.gr/conference2014/pdf/voulvoulis.pdf
Voulvoulis, N. The potential of water reuse as a management option for water security under the ecosystem services approach, Desalination & Water Treatment, 53 (12) (**2015**), 3263-3271.

Voulvoulis, N. **2016,** From waste management to resource recovery: the waste management sector in the Circular Economy.
http://uest.ntua.gr/cyprus2016/proceedings/pdf/nvoulvoulis_keynote.pdf

Voulvoulis, N. Water reuse from a Circular Economy perspective and potential risks from an unregulated approach, Current Opinion in Environmental Science and Health, 2 (**2018**), 32-45.

Wheatley, R., Hedgecock, J.J., **1993**. Waste to energy in South East London. Renew. Energ. 17-19, Conference Publication No. 385.

Williams, P.T., **2005**. Waste Treatment and disposal, 2nd edition, John Wiley & Sons Ltd.

Wilkins M, More Recycling Won't Solve Plastic Pollution on July 6, **2018**. Scientific American.

Wolsink, M., **2010**. Contested environmental policy infrastructure: Socio-political acceptance of renewable energy, water, and waste facilities. Environ. Impact Assess. 30, 302-311.

Wolsink, M., Devilee, J., **2009**. The motives for accepting or rejecting waste infrastructure facilities. Shifting the focus from the planners' perspective to fairness and community commitment. J. Environ. Plann. Manage. 52, 217-236.

Woods, J. S., Veltman, K., Huijbregts, M. A. J., Verones, F. & Hertwich, E. G. Towards a meaningful assessment of marine ecological impacts in life cycle assessment (LCA). *Environ. Int.* 89–90, 48–61 (**2016**).

World Bank, 2009. Urban Development Series – Knowledge Papers. Chapter 2: Global Waste Management Practices, Available at: http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/Chap2.pdf [Accessed: 30 March 2016]

World Business Council for Sustainable Development (WBCSD), **2010**. Vision **2050**. The new agenda for business. Conches-Geneva.

World Health Organization, **2013**. Urban population growth.
http://www.who.int/gho/urban_health/situation_
trends/urban_population_growth_text/en/index.html. [Accessed: 4 April 2013]

WRAP, Life cycle assessment of example packaging systems for milk, (**2010**)

WRAP, n.d. What are mixed plastics?
https://www.wrap.org.uk/sites/files/wrap/What%20are%20mixed%20plastics.pdf
WRAP (**2020**), National Household Waste Composition 2017, National Compositional Estimates For Local Authority Collected Household Waste and Recycling in the UK. Research date: March 2019 Publication Date: January 2020

WRAP, January **2020a**, Food surplus and waste in the UK – key facts Updated January 2020.
https://wrap.org.uk/taking-action/food-drink/actions/action-on-food-waste

YouGov, 'Most Brits support ban on harmful plastic packaging', (**2019**).

Young, G.C., **2010**. Municipal solid waste to energy conversion processes: economic, technical, and renewable comparisons. John Wiley & Sons, 1

Zero Waste Europe (2012) Zero waste & taxes – shift from labour to resource use. Empowering our communities to redesign. https://www.zerowasteeurope.eu/2012/03/zero-waste-taxes-getting-the-prices-right/ [Accessed: 7 August 2017]

Zero Waste Europe (2020), Climate Blog Series, No Time To Waste: The Climate Impacts of Incineration and Waste-to-Energy, Author: Eilidh Robb, 10/09/2020.
https://zerowasteeurope.eu/2020/09/no-time-to-waste-incineration-and-waste-to-energy/

Zheng J and Suh S, 'Strategies to reduce the global carbon footprint of plastics', Nature Climate Change , 9/5 (**2019**), 374–78.

Appendices

Appendix 1. ***Glossary of terms***

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Appendix 1. Glossary of terms

AC - Available Capacity

AD - Anaerobic Digestion

BMW - Biodegradable Municipal Waste

C&I - Commercial and Industrial

CE - Circular Economy

CIWM - Chartered Institution of Wastes Management

DEFRA- Department of Environment, Food and Rural Affairs

EA - Environment Agency

EC - European Commission

EfW - Energy-from-Waste

ERF - Energy Recovery Facility

EU - European Union

LAs - Local Authorities

LAC&I - Local Authority Commercial and Industrial (waste)

LACMW - Local Authority Collected Municipal Waste

LACW - Local Authority Collected Waste

LATS - Landfill Allowance Trading Scheme

LCA - Life Cycle Analysis

MBT - Mechanical Biological Treatment

MRF - Material Recycling Facility

MSW - Municipal Solid Waste

PFI - Private Finance Initiative

WAG - Welsh Assembly Government

WEEE - Waste Electrical and Electronic Equipment

Appendix 2. Infrastructure study: detailed regional analysis

The process first of all involved distributing material streams to suitable treatment options as per Table 8 proportionately to their regional arisings. If the available treatment capacity of recycling, composting or AD was insufficient to cover the regional needs, the untreated materials were directed towards incineration subject to the availability of spare capacity, a process which was also carried out proportionately to the regional arisings of the materials.

The process of distributing materials to suitable technologies was therefore done following this two-step approach. It is noted that if AD capacity was not sufficient to cover the treatment needs for food waste and other organics, these were directed to any spare composting capacity first before incineration.

The regional results are further presented according to this two-step process. The approach uses spare residual capacity to process untreated recyclables. In practice, even after the recycling process has taken place any remaining materials will be mixed and not generally suitable for treatment in recycling/composting facilities, and therefore are likely to require residual waste treatment technologies.

The regional profiles dealing with the distribution of waste to the available infrastructure capacity and with identifying the remaining materials are further presented. In each section the regional arisings in contrast to the available capacity per region and per technology are presented, since it is up to the LAs to decide how each waste stream should be treated (Figures A2.1, A2.2, A2.4, A2.6, A2.8, A2.10, A2.12, A2.14, A2.16 and A2.18).

Also, in each regional profile we show a possible scenario of the distribution of materials into the facilities and the theoretical remaining materials, where household waste goes first into the facilities.

Figure A2.1 summarises the materials in each region categorised by composition and according to which treatment they are suited, notably this visually shows more incineration in the south and more green waste treatments in the north, indicating some misalignment of uniform infrastructure deployment.

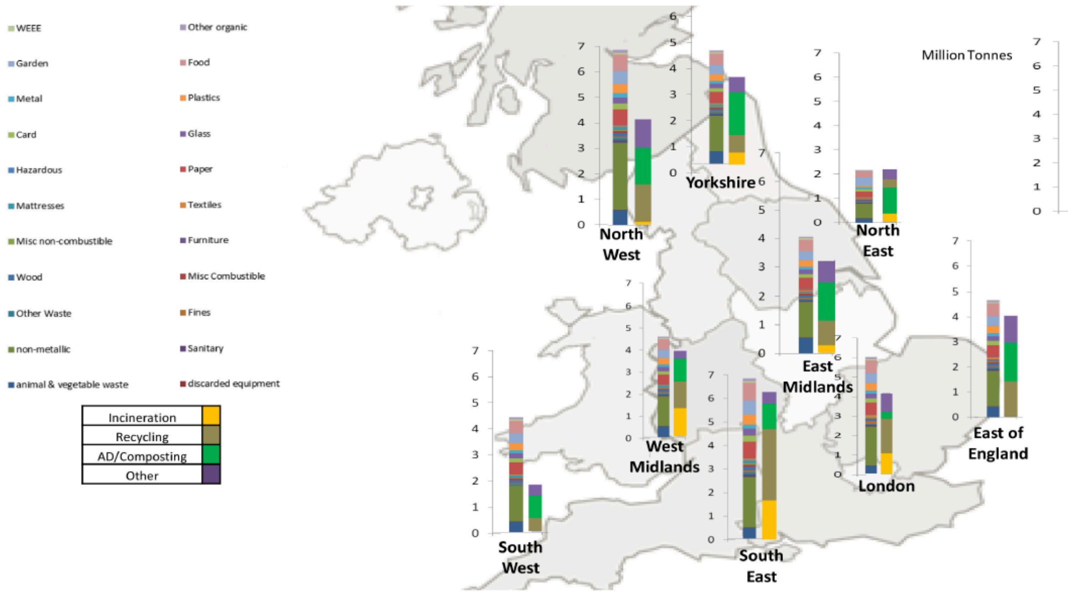

Figure A2.1. Map of England showing compositional waste arisings and available capacity per technology regionally (million tonnes)

EAST MIDLANDS

The available capacity (permitted) in this region is presented in Table A2.2 (EA, 2010, 2012).

Table A2.2 Permitted treatment capacity in East Midlands, 2014

Permitted capacity	Tonnes
WEEE Treatment	507,500
MRF	724,994
Incineration	260,000
Composting	927,493
MBT	125,000
AD	165,000

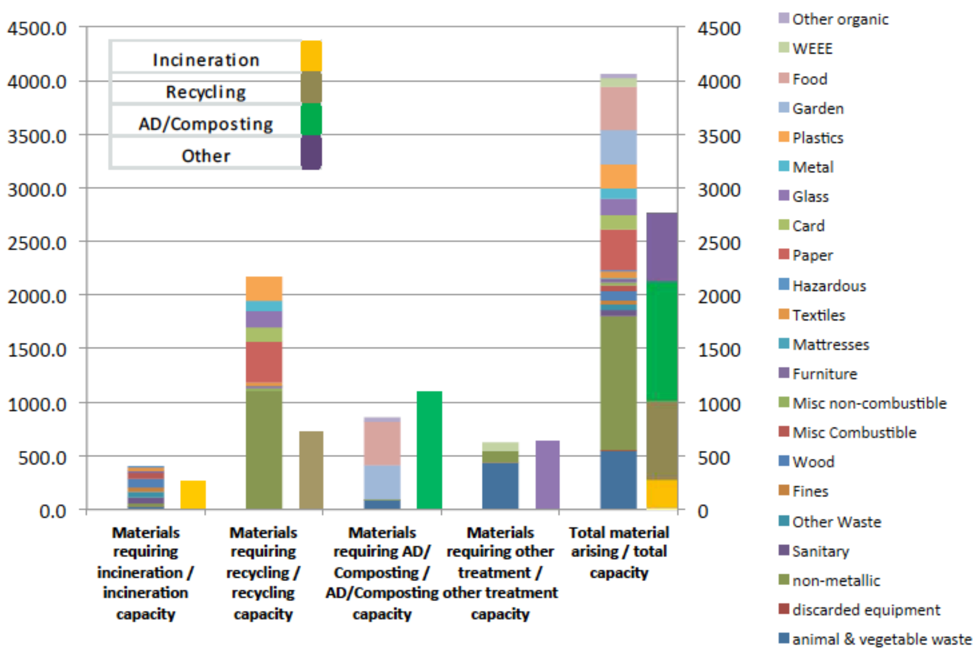

Figure A2.3 LACW arisings (compositional analysis) in relation to available capacity (per technology) in East Midlands

While distributing waste components to suitable treatment options, AD could only cover part of the requirement for the treatment of food waste, with the remaining amount as well as the other organics being diverted to composting in stage 2, reducing the available composting capacity from 608 to 330. The spare capacity for incineration after step 1 (38,000 tonnes), was used to treat an equal amount of untreated materials requiring recycling after step 1 (Table A2.4).

Table A2.4 Distribution of LACMW to permitted treatment capacity in East Midlands ('000 tonnes)

Technology	Available capacity	Available capacity after the treatment of LACMW waste (step 1)	Remaining waste (step 1)	Available capacity after the treatment of LACMW waste (step 2)	Remaining waste (step 2)
WEEE	507	457	0	457	0
MRF	725	0	345	0	307
AD	165	0	278	0	278
Incineration	385	38	0	0	0
Composting	927	608	0	330	0

The arisings and composition of the untreated materials are shown in Figure A2.5. The actual composition will depend on how the LA chooses to prioritise its waste. As discussed previously in our examples household waste is given priority.

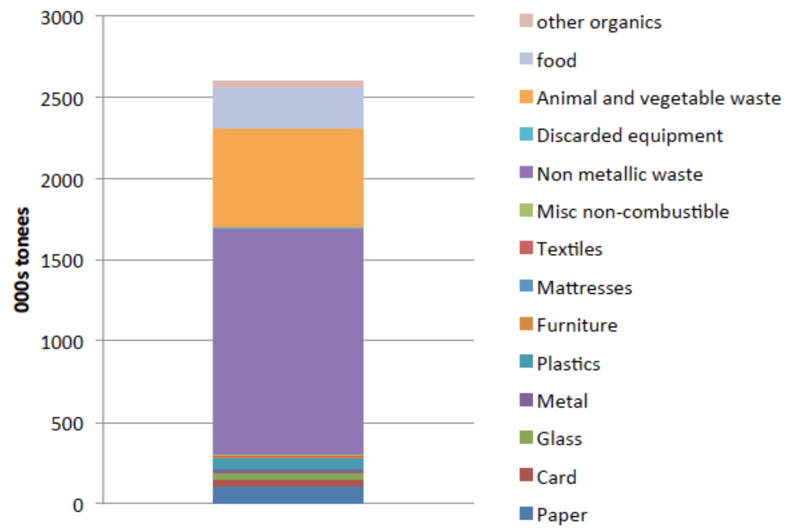

Figure A2.5 Breakdown of remaining LACW materials in East Midlands

EAST

The analysis was based on combining the information on arisings and waste composition as previously presented and the availability of treatment capacity, the main technologies of which are presented in Table A2.6 (EA, 2010, 2012).

Table A2.6 Permitted treatment capacity in the East of England

Permitted capacity	Tonnes
WEEE Treatment	458,602
MRF	1,191,499
AD	82,000
MBT	415,000
Incineration	0
Composting	1,194,794

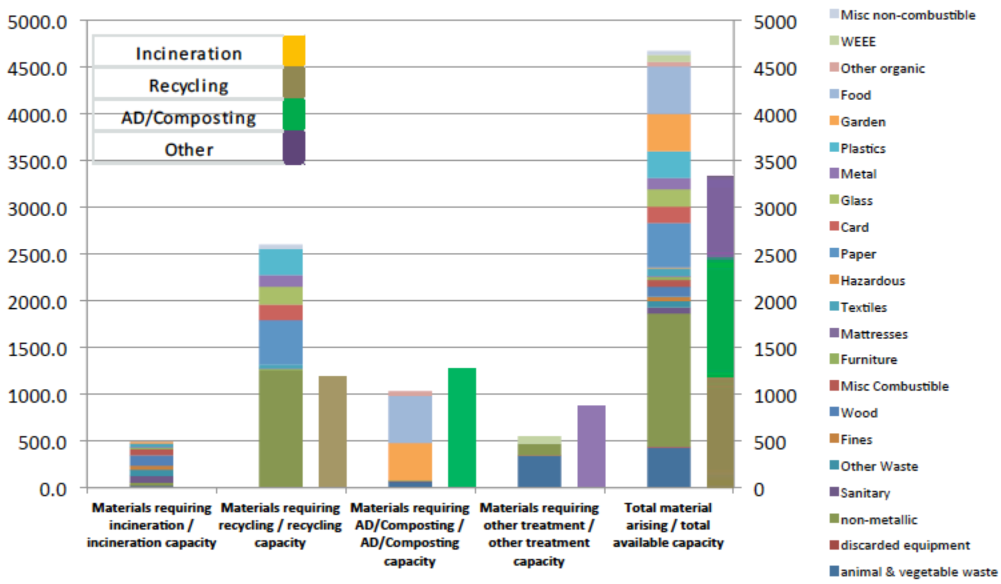

Figure A2.7 LACW arisings (compositional analysis) in relation to available capacity (per technology) in East of England

The steps that were undertaken to calculate the capacity gap using the arisings of the individual components and progressing through the stages of Table A2.8, were:

- allocation of food waste to AD;
- allocation of garden waste, remaining food waste and organics to composting;
- use of the available MBT capacity for the treatment of materials that require residual treatment based on the proposed approach;
- calculation of the composition and arising of remaining household components requiring treatment (Figure A2.9)

This demonstrates the following:

- MRF capacity was insufficient to treat all materials requiring recycling leaving 151 thousand tonnes untreated;
- there was an observed surplus in composting;
- the waste landfilled, which according to the calculations consists of soil and half of the miscellaneous non combustible materials, is 45 thousand tonnes.

Table A2.8 Distribution of LACMW to permitted treatment capacity in the East of England (thousand tonnes)

Technology	Available capacity	Available capacity after the treatment of LACMW (step 1)	Remaining waste (step 1)
AD	82	0	0
Composting	1,195	320	0
MRF	1,191	0	151
MBT	415	0	21
WEEE	459	396	0

The composition and arisings of the untreated materials is shown in Figure A2.9.

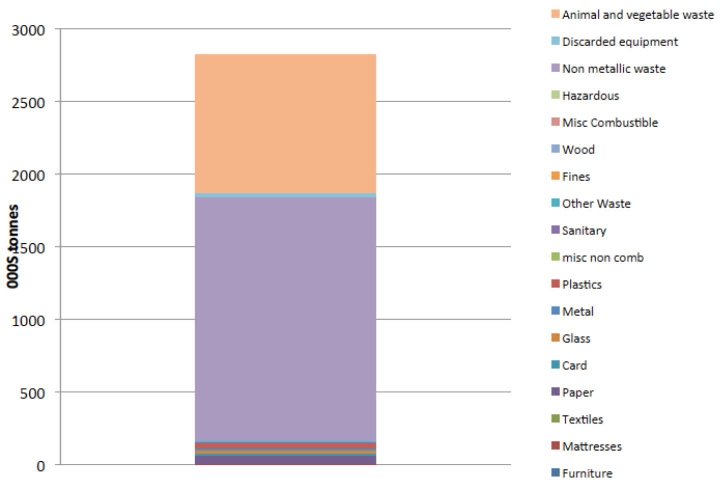

Figure A2.9 Breakdown of remaining LACW materials in the East of England

LONDON

Results for permitted treatment in the London region are shown in Table A2.10 (EA, 2010, 2012).

Table A2.10. Permitted treatment capacity in London

Permitted capacity	Tonnes
WEEE Treatment	458,800
MRF	1,822,430
AD	0
MBT	562,000
Incineration	1,088,000
Composting	353,200

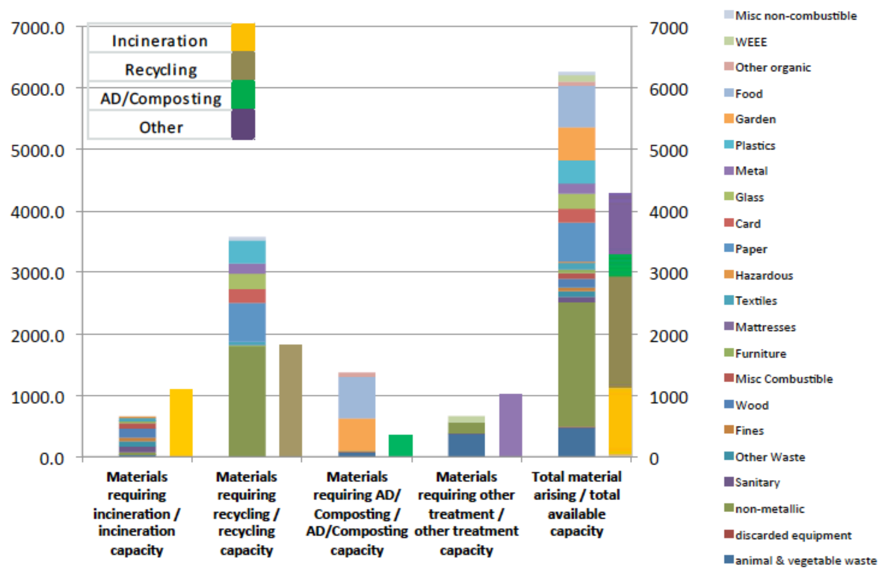

Figure A2.11. LACW arisings (compositional analysis) in relation to available capacity (per technology) in London

The next step was the distribution of LACMW waste to the available capacity (Table A2.12).

The first action was to attribute materials to the most suitable technologies. If recycling or composting/AD treatment capabilities were insufficient to treat their corresponding waste streams these were directed to incineration in the next step. This was done in order to make the greater possible use of existing facilities prior to creating a requirement for additional infrastructure. In this example, composting capacity was insufficient to treat all the organic household material that would ideally need to be handled by it, and the untreated material (181) along with food waste and other organics that have not been treated due to the absence of AD capacity were directed to incineration in step 2, reducing the availability of residual treatment capacity from 1069 thousand tonnes to 146 thousand tonnes. The LACMW landfilled is 60 thousand tonnes.

Technology	Available capacity	Available capacity after LACMW treatment (step 1)	Remaining waste (step 1)	Available capacity after LACMW treatment (step 2)	Remaining waste (step 2)
MRF	1822	32	0	32	0
Incineration	1650	1069	0	146	0
Composting	353	0	181	0	0
WEEE	459	376	0	376	0

Table A2.12. Distribution of LACMW to permitted treatment capacity in London ('000 tonnes)

Figure A2.13 shows the breakdown of the remaining materials, which in this case consists only of materials originating from the LAC&I waste stream.

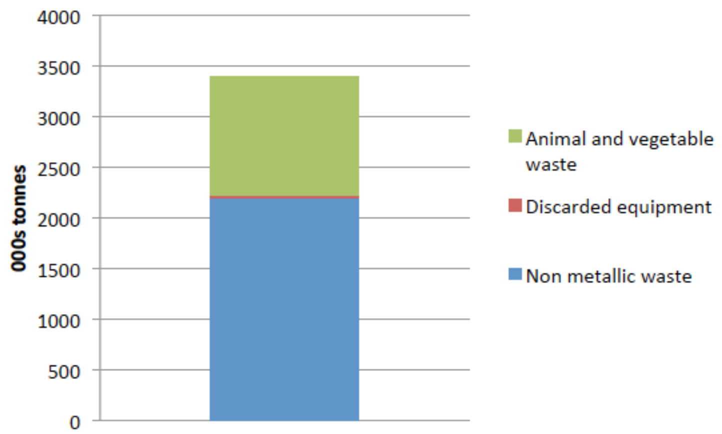

Figure A2.13. Breakdown of remaining LACW materials in London

NORTH EAST

Results for permitted treatment in the North East region are shown in Table A2.14 (EA, 2010, 2012).

Table A2.14. Permitted treatment capacity in the North East, 2014

Permitted capacity	Tonnes
WEEE Treatment	93,000
MRF	1,100,000
AD	0
MBT	195,000
Incineration	375,000
Composting	161,997

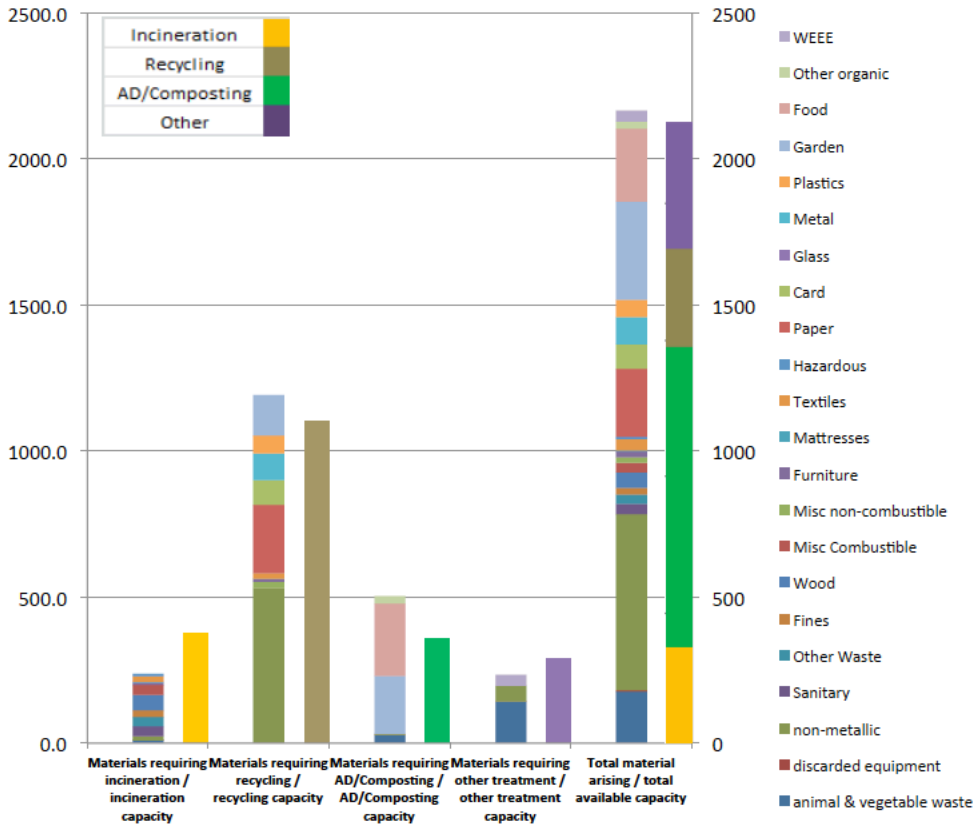

Figure A2.15. LACW arisings (compositional analysis) in relation to available capacity (per technology) in North East

Following the steps of the calculations, household waste was attributed to suitable facilities (Table 2.15).

Table A2.16. Distribution of LACMW to permitted treatment capacity in the North-East (thousand tonnes)

Technology	Available capacity	Available capacity after the treatment of LACMW waste (step 1)	Remaining waste (step 1)	Available capacity after the treatment of LACMW waste (step 2)	Remaining waste (step 2)
MRF	1100	441	0	441	0
Incineration	570	356	0	48	0
Composting	162	0	35	0	0
WEEE	93	62	0	62	0

As presented in Table A2.16, there was spare capacity in all technologies except for composting. The requirement that cannot be met by composting, as well as food waste and other organics that were untreated due to the lack of AD were directed to residual treatment in step 2. The LACMW landfilled was 22 thousand tonnes.

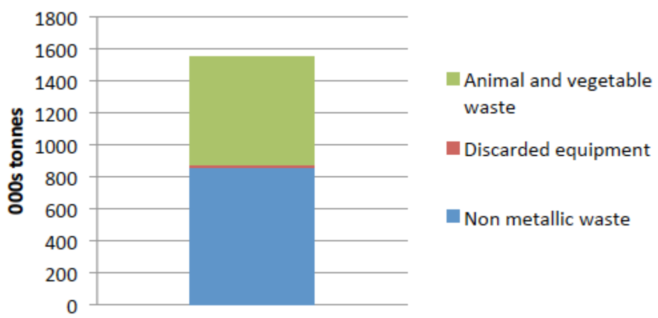

Figure A2.17. Breakdown of remaining LACW materials in the North East North West

Figure A2.17 shows the breakdown of the remaining materials in the North East.

NORTH WEST

Results for permitted treatment in the North West region are shown in Table A2.18 (EA, 2010, 2012).

Table A2.18. Permitted treatment capacity in the North West

Permitted capacity	Tonnes
WEEE Treatment	409,999
MRF	1,240,497
MBT	540,650
Incineration	127,000
Composting	1,213,993

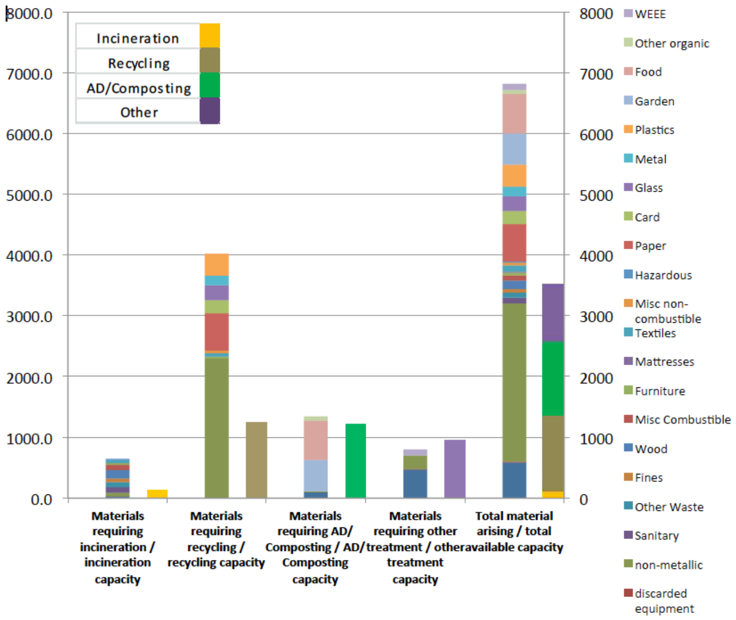

Figure A2.19. LACW arisings (compositional analysis) in relation to available capacity (per technology) in North West

Table A2.20 indicates that after step 1, there was an observed shortfall in recycling capacity to meet the need of 484 thousand tonnes. Moreover, after green waste was allocated to composting, and given that there was a considerable amount of spare capacity, food and other organics were further allocated to it, leaving only 14 thousand tonnes of untreated waste. The remaining capacity of residual treatment after step 1 (109 thousand tonnes) was used to cover part of the unmet demand for treatment from recycling and AD. The LACMW landfilled is 58 thousand tonnes.

Table A2.20. Distribution of LACMW to permitted treatment capacity in the North West (thousand tonnes)

Technology	Available capacity	Available capacity after the treatment of LACMW waste (step 1)	Remaining waste (step 1)	Available capacity after the treatment of LACMW waste (step 2)	Remaining waste (step 2)
MRF	1240	0	484	0	0
Incineration	668	109	0	0	0
Composting	1214	0	14	0	0
WEEE	410	330	0	62	0

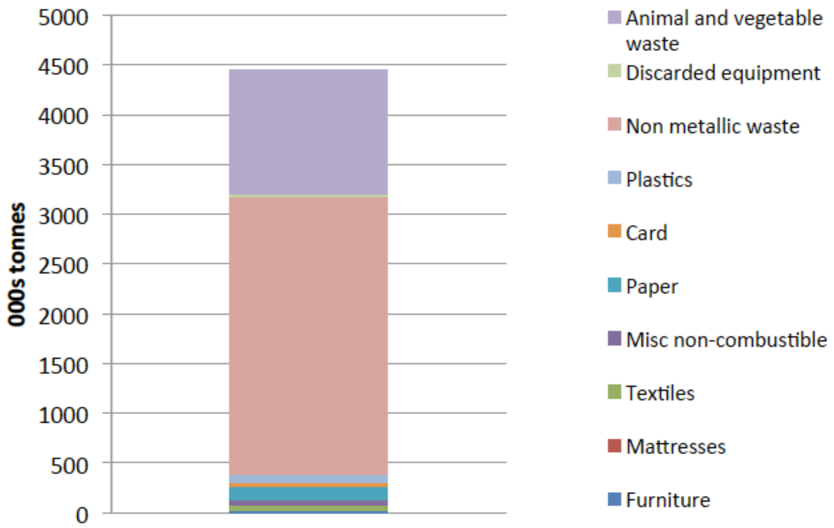

Figure A2.21. Breakdown of remaining LACW materials in the North West

Figure A2.21 shows the breakdown of the remaining materials in the North West.

SOUTH EAST

Results for permitted treatment in the South East region are shown in Table A2.22 (EA, 2010, 2012).

Table A2.22. Permitted treatment capacity in the South East

Permitted capacity	Tonnes
WEEE Treatment	246,986
MRF	2,448,521
MBT	200,000
Incineration	1,468,000
Composting	760,876
AD	120,000

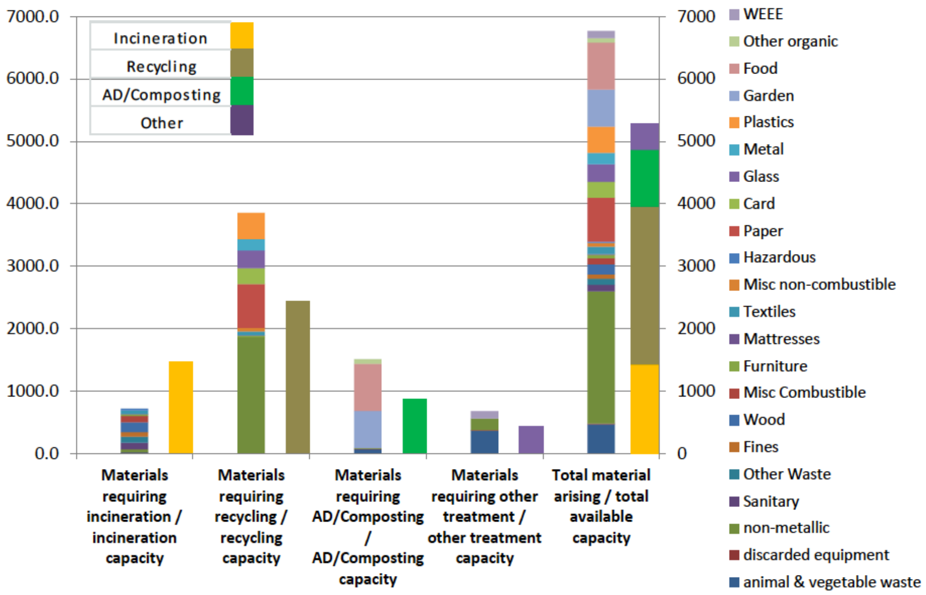

Figure A2.23 LACW arisings (compositional analysis) in relation to available capacity (per technology) in South East

In the first step green waste was first allocated to composting and given the fact that there was spare capacity (167 thousand tonnes), it was used to treat food and other organics for which there was insufficient AD capacity. This reduced the amount of untreated food and other organics from 705 to 538 thousand tonnes, which was treated in the spare residual capacity in step 2. No material was left untreated. The LACMW landfilled is 67 thousand tonnes

Table A2.24. Distribution of LACMW to permitted treatment capacity in the South East (thousand tonnes)

Technology	Available capacity	Available capacity after the treatment of LACMW waste (step 1)	Remaining waste (step 1)	Available capacity after the treatment of LACMW waste (step 2)	Remaining waste (step 2)
WEEE	247	155	0	155	0
MRF	2449	457	0	457	0
AD	1668	0	538	0	0
Incineration	761	1022	0	484	0
Composting	120	0	0	0	0

The arisings and composition of available materials can be seen in Figure A2.25.

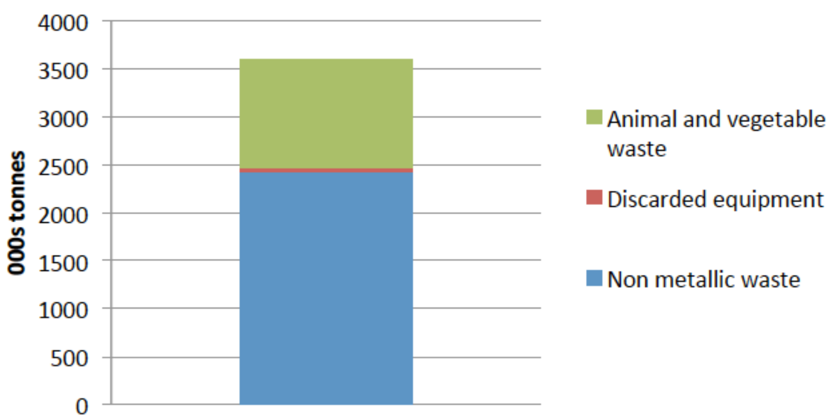

Figure A2.25. Breakdown of remaining LACW materials in the South East

SOUTH WEST

Results for permitted treatment in the South West region are shown in Table A2.26 (EA, 2010, 2012).

Table A2.26. Permitted treatment capacity in the South West

Permitted capacity	Tonnes
WEEE Treatment	212,450
MRF	440,198
MBT	150,000
Incineration	3,500
Composting	552,995
AD	170,000

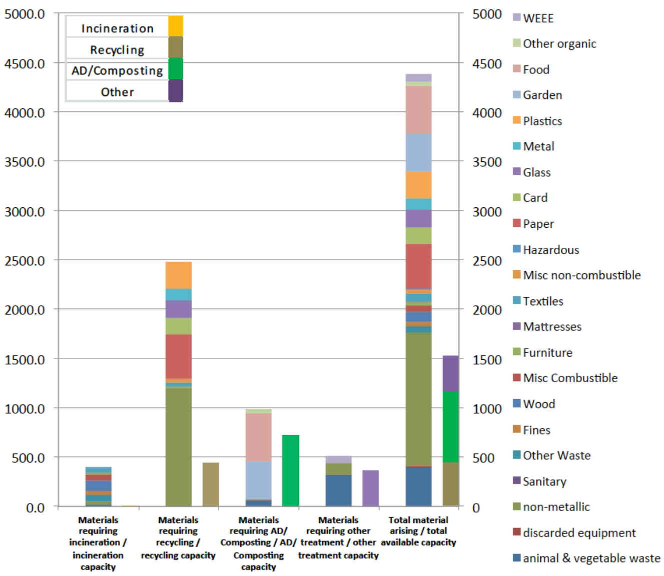

Figure A2.27. LACW arisings (compositional analysis) in relation to available capacity (per technology) in South West

In the process of distributing materials to suitable technologies, the following can be observed:

- there was a shortfall of MRF capacity, leaving untreated 842 thousand tonnes of recyclables, and other materials that required recycling;
- the treatment shortfall for AD was 361 thousand tonnes (for food waste and other organics), but as part of this waste was further directed to composting for which there was surplus capacity, the final remaining untreated amount of these two materials was 190 thousand tonnes.
- LACMW landfilled was 43 thousand tonnes.

Table A2.28. Distribution of LACMW to permitted treatment capacity in the South West (thousand tonnes)

Technology	Available capacity	Available capacity after the treatment of LACMW waste (step 1)	Remaining waste (step 1)
WEEE	212	153	0
MRF	440	0	842
AD	170	0	190
Incineration	154	0	262
Composting	553	0	0

The arisings and composition of available materials can be seen in Figure A2.29.

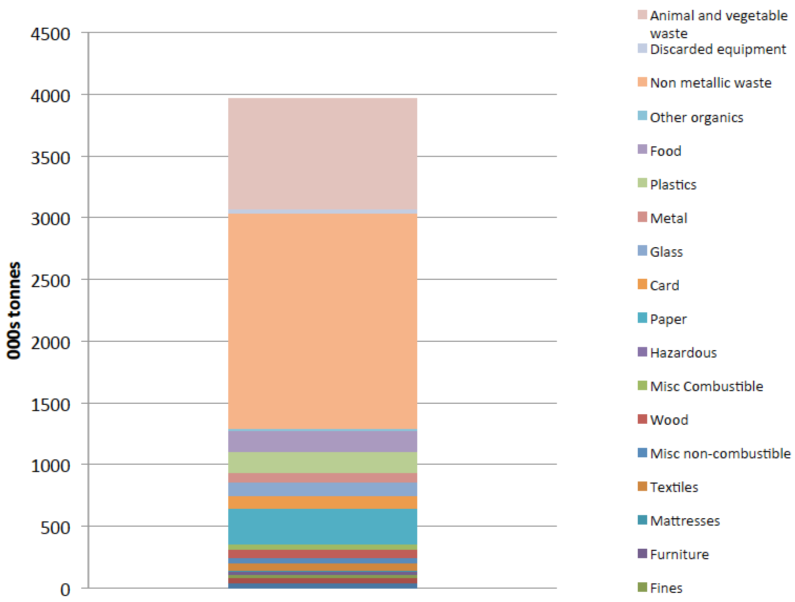

Figure A2.29. Breakdown of remaining LACW materials in the South West

WEST MIDLANDS

Results for permitted treatment in the West Midlands region are shown in Table A2.30 (EA, 2010, 2012).

Table A2.30. Permitted treatment capacity in West Midlands

Permitted capacity	Tonnes
WEEE Treatment	307,997
MRF	1,029,000
Incineration	1,140,000
Composting	871,498
AD	5,000

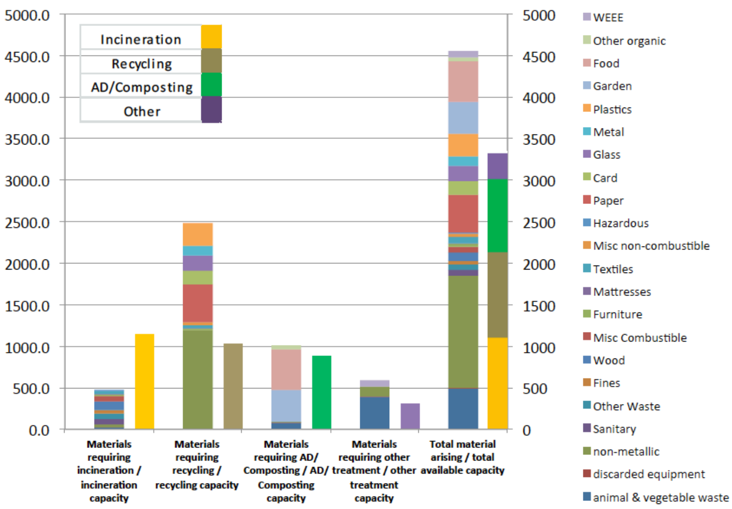

Figure A2.31. LACW arisings (compositional analysis) in relation to available capacity (per technology) in West Midlands

As can be seen in Table A2.32, residual treatment was available for the materials requiring recycling that could not be treated by the available MRF capacity (261 thousand tonnes of recyclables), as well as food and other organics that could not be treated by either composting or AD. LACMW landfilled was 43 thousand tonnes.

Table A2.32 Distribution of LACMW to permitted treatment capacity in the West Midlands (thousand tonnes)

Technology	Available capacity	Available capacity after the treatment of LACMW waste (step 1)	Remaining waste (step 1)	Available capacity after the treatment of LACMW waste (step 2)	Remaining waste (step 2)
WEEE	308	248	0	248	**0**
MRF	1029	0	261	0	**0**
AD	5	0	43	0	**0**
Incineration	1140	721	0	417	**0**
Composting	871	0	0	0	**0**

The arisings and composition of available materials can be seen in Figure A2.33.

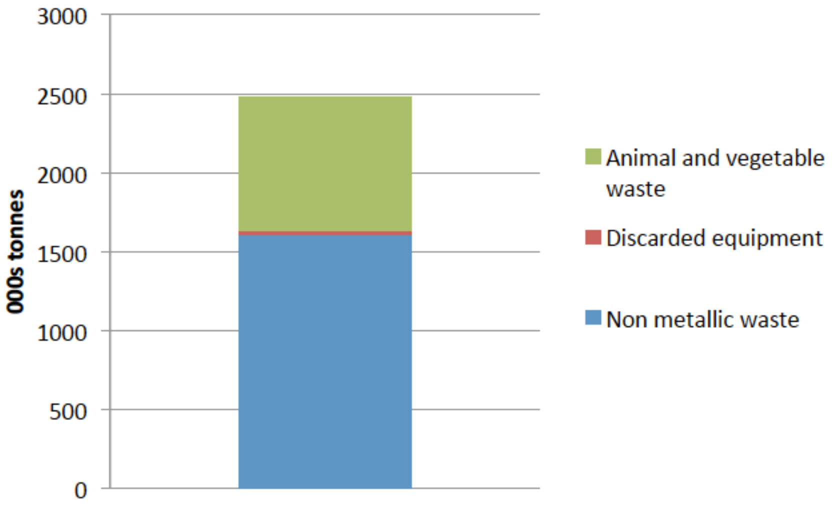

Figure A2.33. Breakdown of remaining LACW materials in the West Midlands

YORKSHIRE & HUMBER

Results for permitted treatment in the Yorkshire & Humber region are shown in Table A2.34 (EA, 2010, 2012).

Table A2.34 Permitted treatment capacity in Yorkshire and Humber

Permitted capacity	Tonnes
WEEE Treatment	344,997
MRF	555,248
Incineration	431,000
Composting	779,994
MBT	165,000

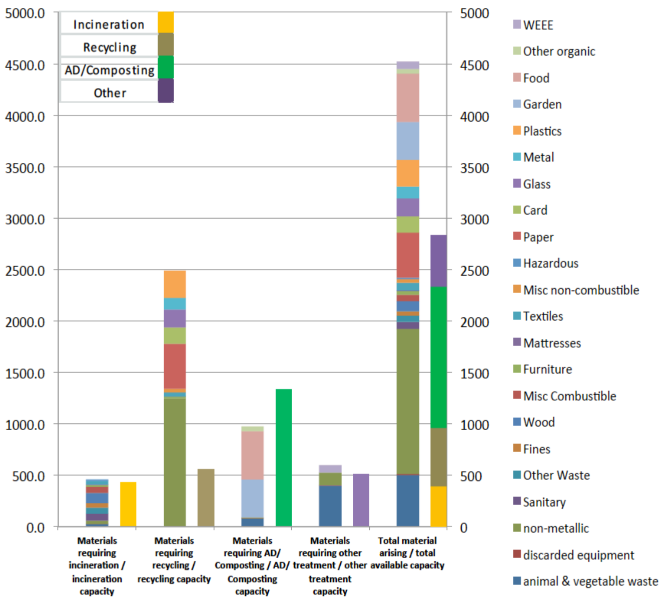

Figure A2.35. LACW arisings (compositional analysis) in relation to available capacity (per technology) in Yorkshire & Humber

As shown in Table 39, there was a shortfall of MRF capacity (684 thousand tonnes) and composting capacity (103 thousand tonnes). The remaining residual treatment capacity (194 thousand tonnes) was used to treat part of the materials that could not be handled in the MRF or composting facilities, therefore the untreated materials at the end amount to 593 thousand tonnes. The LACMW landfilled was 42 thousand tonnes.

Table A2.36. Distribution of LACMW to permitted treatment capacity in Yorkshire and Humber (thousand tonnes)

Technology	Available capacity	Available capacity after the treatment of LACMW waste (step 1)	Remaining waste (step 1)	Available capacity after the treatment of LACMW waste (step 2)	Remaining waste (step 2)
WEEE	345	288	0	288	0
MRF	555	0	684	0	515
Incineration	596	194	0	0	0
Composting	780	0	103	0	78

The arisings and composition of available materials can be seen in Figure A2.36.

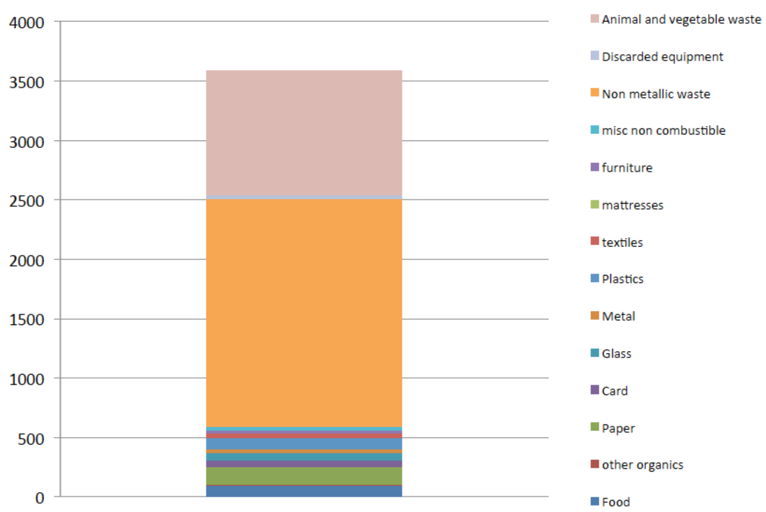

Figure A2.36. Breakdown of remaining LACW materials in Yorkshire and Humber

Appendix 3. Sensitivity analysis and forecasting potential for infrastructure

The analysis was performed for 2010. In order to investigate the accuracy of the data collated (available infrastructure and waste arisings) sensitivity analysis was performed. This was done both by comparing the waste arisings in 2009/10 (which is the year of reference) with those in 2012 and also by comparing the EA waste infrastructure data for 2010 with the 2012 EA Waste Interrogator Database. The latter did not provide information about incineration capacity and this was therefore sourced from the EA (2012).

The differences between these two years were quantified and evaluated. In terms of waste arisings, these were 25.3 million tonnes of LACMW in 2012 as opposed to 26.228 million tonnes in the reference year, showing that this parameter of the analysis only changed slightly. It has been identified that in 2012 a total of 167 additional permits were issued (in the categories of AD, composting, MBT, MRF and incineration) the breakdown of which is presented in Table 36. Their corresponding operational capacity in 2012 per technology and per region is shown in table 35. In addition to the data presented for 2012 more up to date information on incineration suggested that one additional facility operated in 2013 and also three more are expected to come into operation in 2014. The combined permitted capacity of these four facilities is 1,665 thousand tonnes (DEFRA, 2013a).

Table 40. Number of permits for main treatment technologies operating in 2012 but not in 2010 (EA, 2010, 2012)**.**

	East of England	London	East Midlands	South East	South West	North East	North West	West Midlands	Yorkshire and the Humber
AD	0	0	1	0	1	5	0	1	0
Composting	3	2	8	6	33	0	7	5	10
MBT	0	1	0	1	0	0	0	0	0
MRF	5	3	5	5	11	4	9	5	5
Incineration	0	1	0	2	0	0	0	0	0

Table 41. Capacity per technology from 2010 to 2012 per region (tonnes)

	East of England	London	East Midlands	South East	South West	North East	North West	West Midlands	Yorkshire and the Humber	Total
MRF	68,066	102,496	164,192	127,471	150,294	17,130	308,156	108,750	174,162	**1,220,717**
AD			618		5,476			10,464		**16,558**
MBT		196,963		149						**197,112**
Incineration		700,000		280,000						**980,000**
Composting	20,368	101,293	67,289	95,719	178,794	47,892	117,103	25,870	62,969	**717,297**
Total	88,434	1,100,753	232,099	503,339	334,564	65,022	425,259	145,084	237,13	**3,131,685**

Despite the fact there appeared to be a large number of additional facilities in 2012, it was observed that the waste processed by the facilities was highly variable, with many facilities having processed a 58 very small amount of waste (<500 tonnes). This suggested that the number of new permits was not a reliable metric of change over time, and it was further investigated.

The additional total capacity as displayed in Table 37 was compared with the 2010 capacity that was included in the analysis for the technologies of AD, Composting, MBT, MRF and incineration to see how significant the difference was. For these technologies the 2010 capacity was 25,709 thousand tonnes with the 2012 additional capacity (3,131 thousand tonnes) representing an increase of about 12.1%.

This is not a large increase over the two-year period suggesting that the findings were equally applicable in 2012.

Some caution was however required when evaluating this figure as the additional 2012 data capacity represented the waste that was actually received by the facilities in that year (incineration is an exception for which permitted capacity was used instead), whereas the 2010 data are the permitted capacity and, likely to be higher than the operational one.

The percentage increase in capacity per type of facility and per region was also calculated to provide an indication of the relative differences among regions and technologies. The results are presented in Table 38.

It is worth noting that the North East and the East of England have the lowest increases in infrastructure within the country; and that there was no increase in incineration availability apart from London.

	East of England	London	East Midlands	South East	South West	North East	North West	West Midlands	Yorkshire and the Humber	Total
MRF	5.7	5.6	22.6	5.2	34.1	1.5	24.8	10.6	31.4	11.6
AD	0.0	0.0	0.4	0.0	2.9	0.0	0.0	200.0	0.0	1.6
MBT	0.0	35.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	8.4
Incineration	0.0	64.3	0.0	19.1	0.0	0.0	0.0	0.0	0.0	20.0
Composting	1.7	28.6	7.2	12.6	32.4	29.6	9.6	3.0	8.1	10.5
Regional Total	4.0	38.2	6.1	10.1	25.4	3.5	13.6	4.8	9.5	12.2

Table 42. Percentage increase of capacity per technology from 2010 to 2012 per region

__Appendix 4. Infrastructure study compositional analysis - Figures A4.1 - A4.9__

These Figures A4.1 - A4.9 provide the analysis conducted into arising composition of materials in each region, demonstrating varied compositions and indicating different treatment needs for infrastructure.

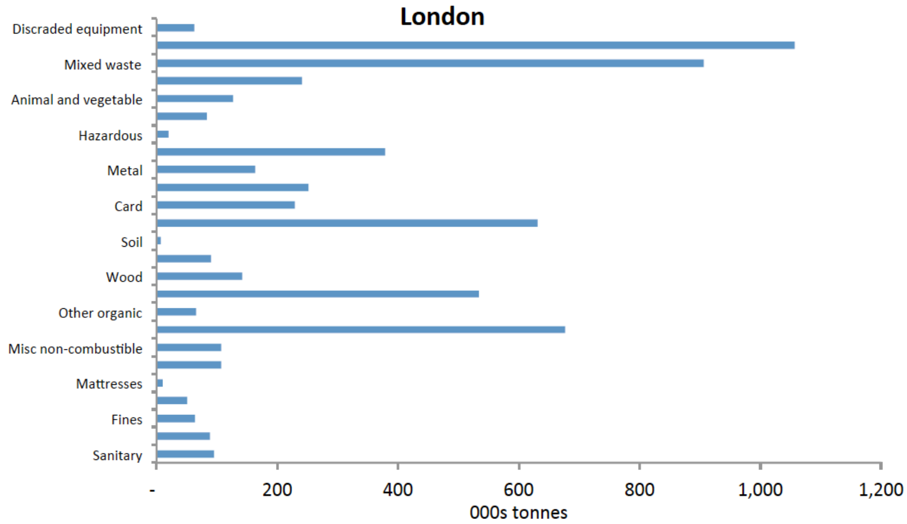

Figure A4.1 Material Arising in London

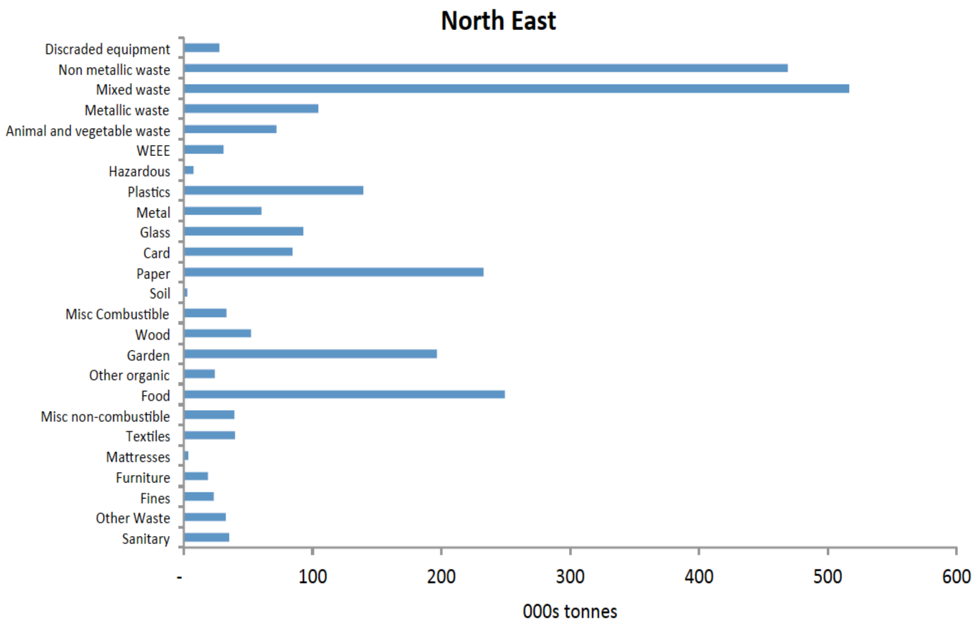

Figure A4.2 Material Arisings in the North East

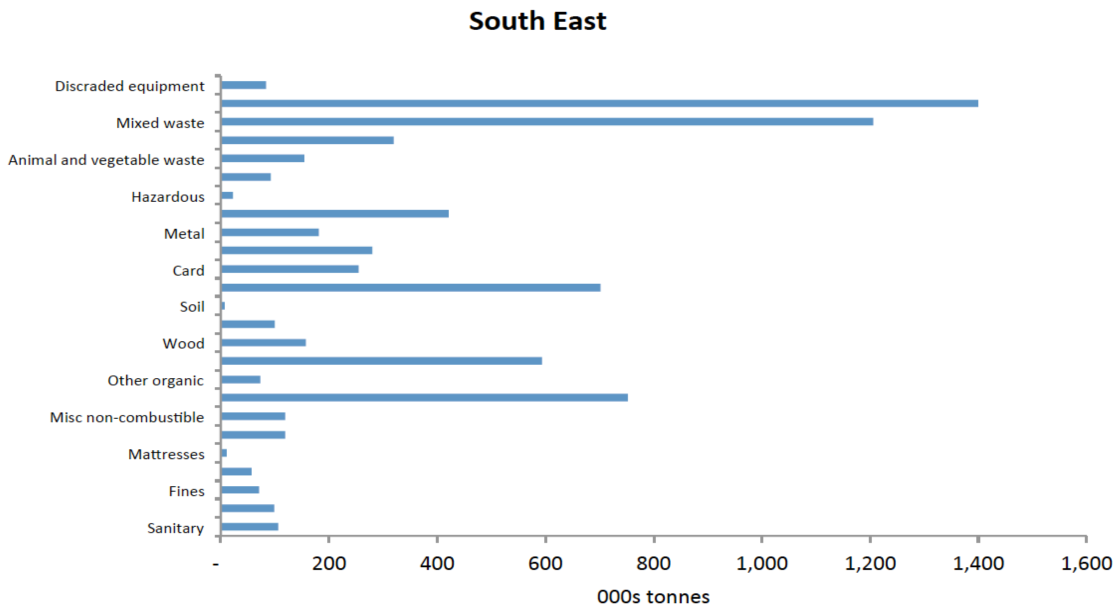

Figure A4.3 Material Arisings in the South East

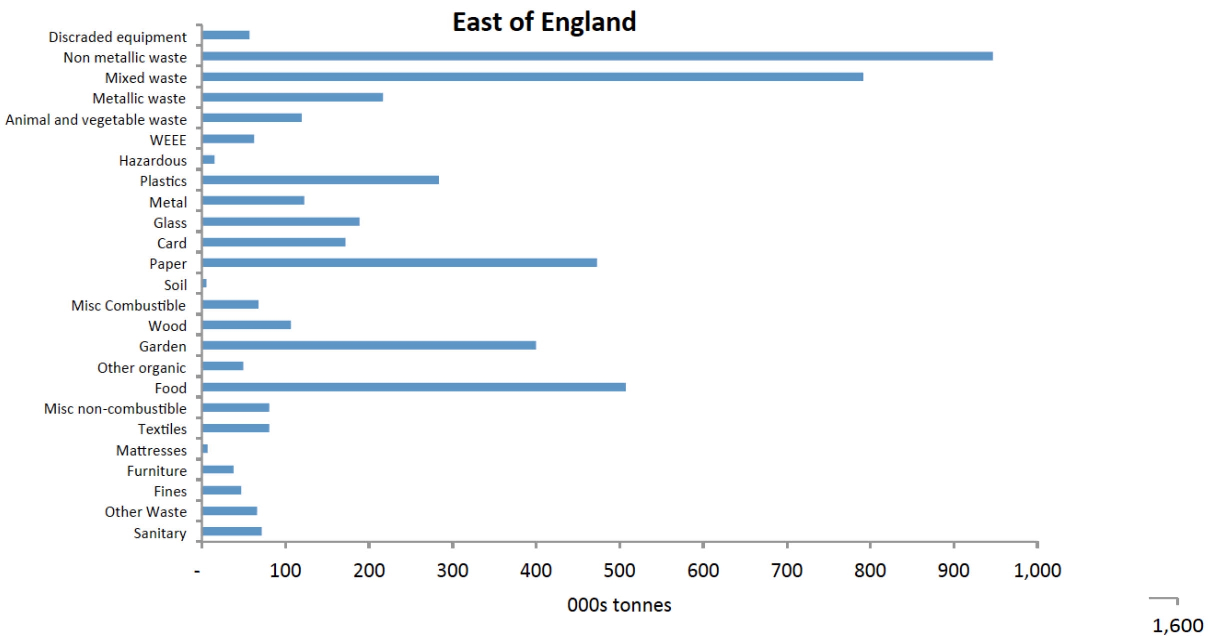

Figure A4.4 Material Arisings in the East of England

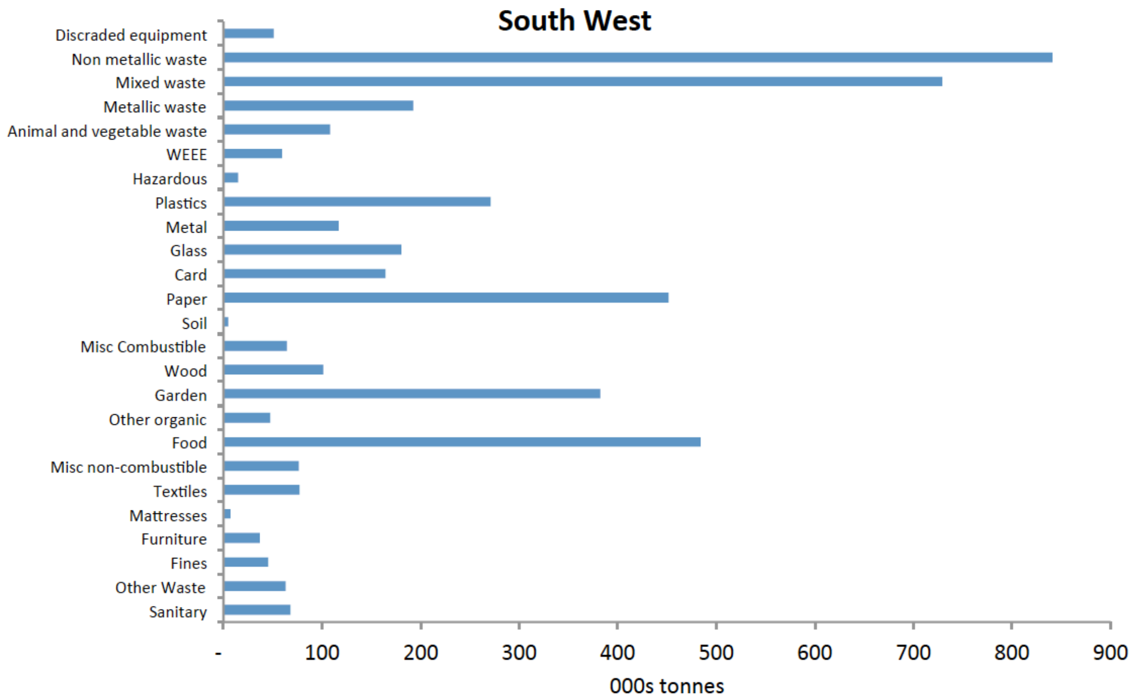

Figure A4.5 Material Arisings in the South West

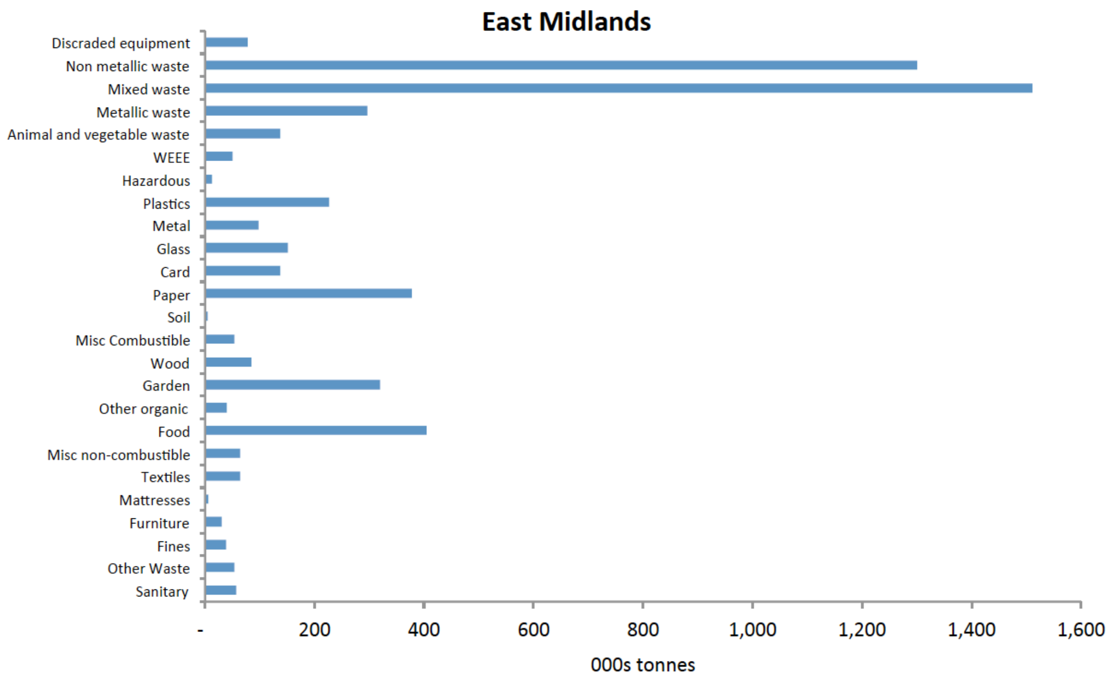

Figure A4.6 Material Arisings in the East Midlands

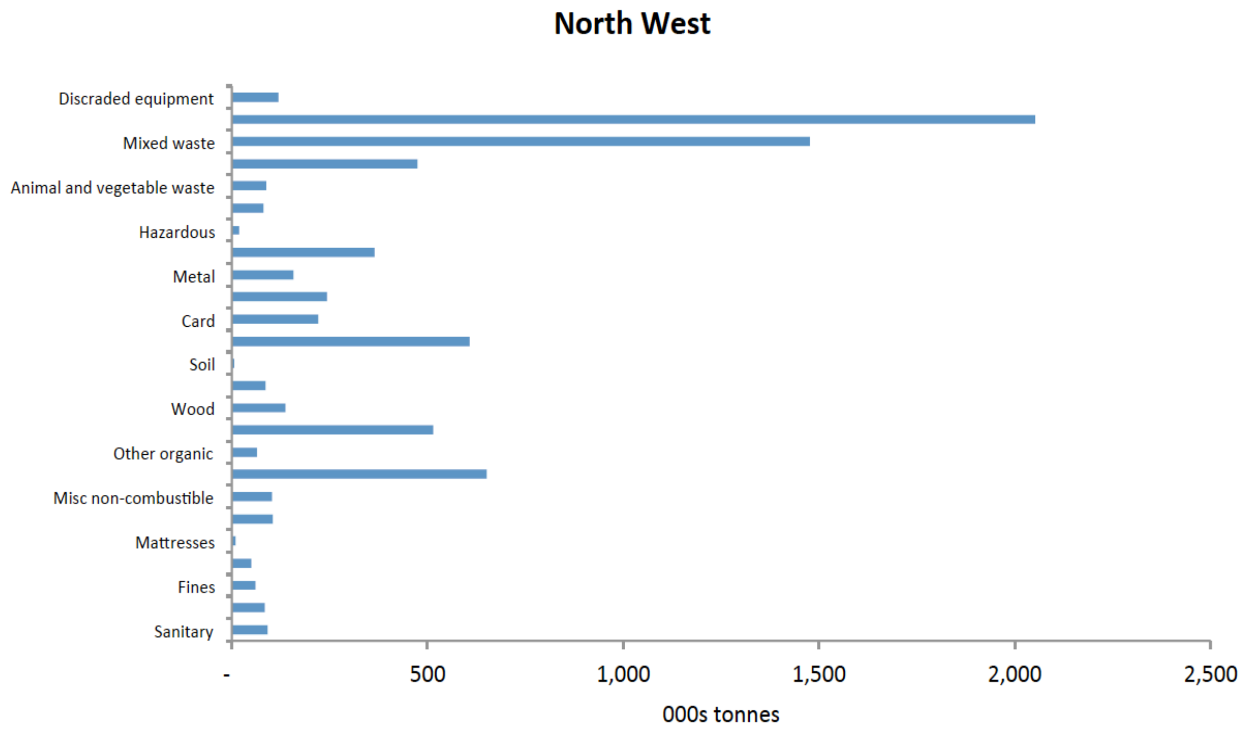

Figure A4.7 Material Arisings in the North West

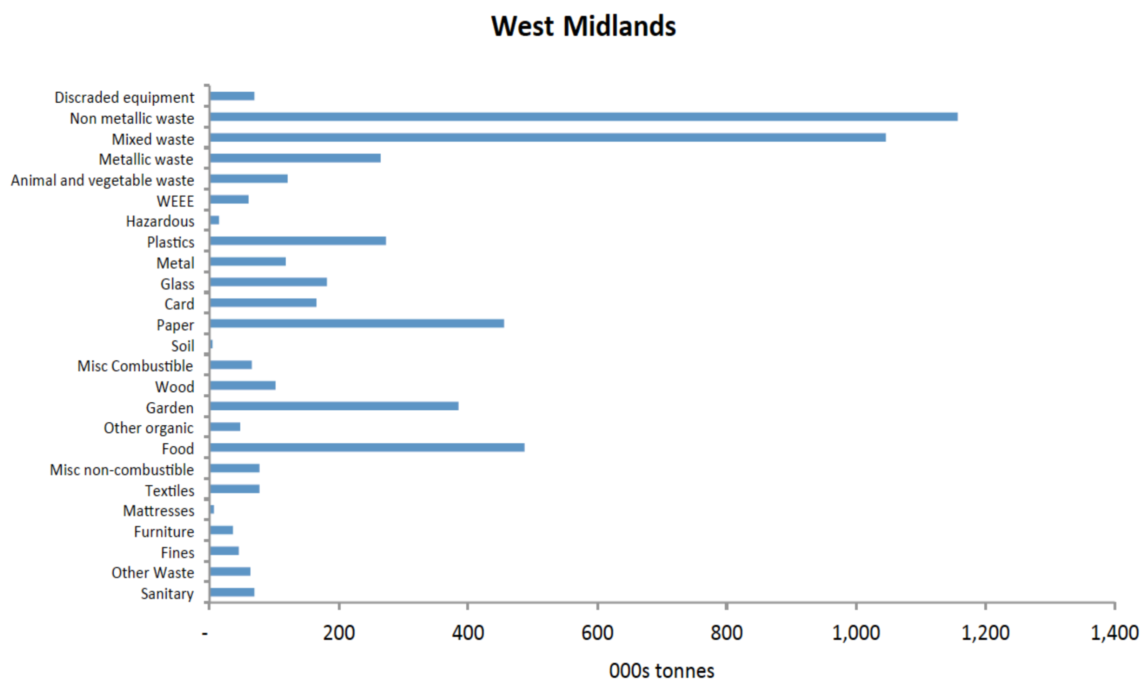

Figure A4.8 Material Arisings in the West Midlands

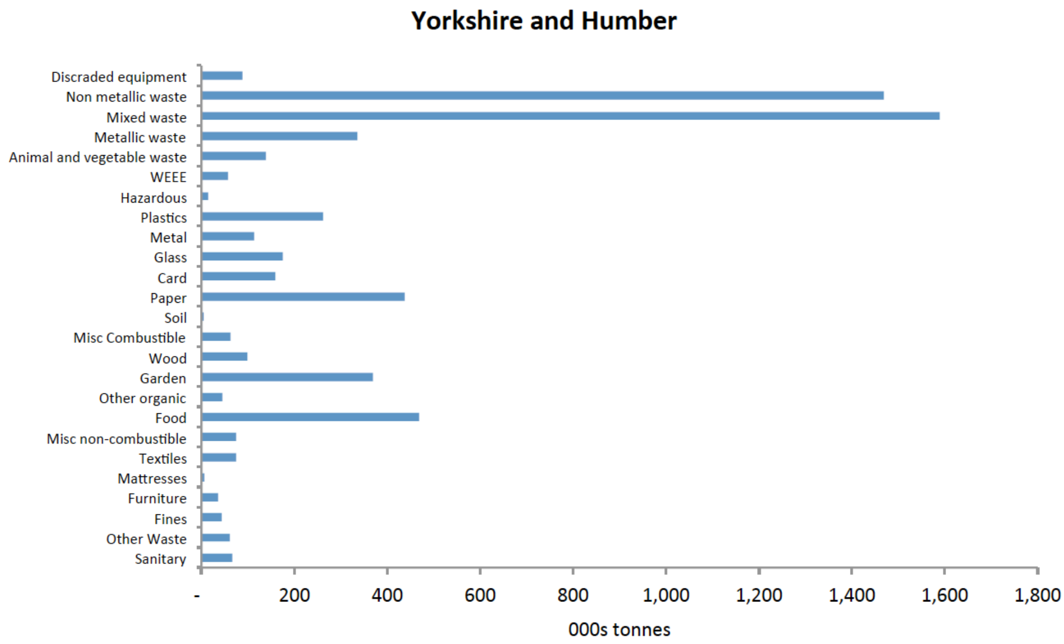

Figure A4.9 Material Arisings in the Yorkshire & Humber

Appendix 5. Large organisations communicating their net zero ambitions, 2019

***Companies and organisations communicating their net zero ambitions, collated 10th October 2020, provided by** Nick Burchett, Veolia, 2020.*

Companies publicly committing to Net Zero and by which date;

Retail

Sainbury's - 2040

Pandora - 2025

ASDA - 50% reduction by 2025

Fatface - 2025

Amazon - 2040

John Lewis - 2050

Tesco - 2050

Aldi - 2050

Co-op - 50% reduction by 2025

British Retail Consortium - 2050

Ocado - 2050

Lidl - 2050

Next - 2050

Booksellers Association of the UK - 2050

Greggs - 2050

Boots - 2050

Ikea - 2050

M&S - 2050

Best Buy - 2040

Manufacturers

Mercedes - 2039

Danone - 2030

Microsoft - 2030

Novartis - 2025

Carlsberg - 30% reduction by 2030

Dairy Crest - 2050

Arla - 2050

Astrazeneca - 2030

GSK - 2050

Cranswick Foods - 2030

Premier Foods - 55% reduction by 2025

Syngenta - 2040

Nestle - 2050

VW - 50% reduction by 2025
Unilever - 2030
Chemical Industries Association (national and international companies) - 2050
Jaguar Land Rover - 2018 (manufacturing and development facilities)
Adnams - 2050
Mars - 27% by 2025 and 67% reduction by 2050
Adidas - 30% by 2030
Archer Daniels Midland (ADM) - 25% by 2035
Takeda - 2040
Tetrapak - 2030
Kimberly-Clark 50% reduction by 2030
Evian - 2020
Apple - 2030
Ricardo - 2030
Siemens - 2040

Local Authorities
Oxford City Council - 2030
Cambridgeshire County Council - 2050
Greenwich Council - 2030
Manchester City Council - 2038
City of Bristol - 2030
Gateshead Council - 2030
Nottingham City Council - 2028
Epsom and Ewell Borough Council - 2035
Warwick District Council - 2025
London - 2030
Worcester City Council - 2030
Vale of White Horse District Council - 2030
Peterborough City Council - 2030
Exeter City Council - 2030
Colchester Council - 2030
Oxfordshire County Council - 2030
Swindon Council - 2030
Carmarthenshire Council - 2030
Richmond Council - 2030
Wokingham Borough Council - 2030
Newport City Council - 2030
Wandsworth Council - 2030
Bolton Council - 2030
Islington Council - 2030

Calderdale Council - 2038
Wandsworth Council - 2030
Liverpool City Council - 35% reduction by 2020
Surrey County Council - 2050
Hackney Council 2040

Aviation
Sustainable Aviation (coalition of UK airlines, airports, manufacturers, air navigation service providers) - 2050
Etihad Airways - 2050
Newcastle Airport - 2035
Heathrow - 2035
Air France - 50% reduction by 2030
Delta - 2030
Stansted Airport - 2050

Oil/Gas/Power Generation
Lundin (petroleum) - 2030
Equinor - 50% reduction by 2050
BP - 2050
Shell - 2050
Drax - 2030

Building/Construction/Property
Better Building partnership - 2050 - 26 companies involved
Barratt Developments - 29% reduction by 2025
Wates Group - 2025
Frasers Property - 2050
Janus Henderson Group Plc UK - 2030
UK Green Building Council , commercial offices target - Reduce energy demand by 60% by 2050
Mace - 2020
Architects: White Arkitekter, Foster & Partners, Mikhail Riches - 2030
Moorfield Group - 2030
AECOM - 2030
Argent LLP - 2030
Grainger PLC - 2030
Greengage Environmental Limited - 2030
Hoare Lea LLP - 2030
Jones Lang LaSalle (JLL) - 2030
Lendlease Europe - 2030
SOM (Skidmore, Owings & Merrill) – 2

Water

Anglian Water - 2030

Welsh Water - 2030

Southern Water - 2030

Scottish Water - 2030

Others

NHS - 2040

Sky - 2030

Ernst Young - 2020

Bank of America - 2020

Barclays - 80% reduction by 2025

F1 Racing - 2030

Formula E - 2020

Ørsted - 2040

Church of England - 2030

NFU (UK Farms) - 2040

EAUC (UK Universities) - 2050

NHS - before 2050

Skanska - 2045

PWC - 40% reduction by 2022

The Guardian - 2030

Insurers: Allianz, Zurich, Swiss Re, Generali - 2050

Banks: RBS, NatWest, Ulster Bank - 50% by 2030

Lloyds Banking Group - 50% by 2030

MITIE - 2025

Rio Tinto - 2050

National Express - 2035

Canary Wharf Group - 65% by 2030

Transport for London - by 2030

ITV - 2030

Schneider Electric - 2040

Network Rail - 2050

Appendix 6. Assessment of a plastics tax financial impact on UK households

Industry knowledge of pricing/plastics value as well as the 2019 Ernst & Young report for the BPF (British Plastics Federation), (Ernst & Young, 2019), and data therein on plastic arisings was used to estimate tax impacts on households. For all plastic packaging to reach the target of a minimum of 30% recycled content, and with the price difference between recycled and virgin plastic currently estimated around £500/tonne (recycled plastic = £1500/t ; virgin plastic = £1000/t from the Platts index), the revenue that the tax will need to generate can be estimated.

The minimum tax level needed to make costs to industry similar between using 100% virgin plastic packaging and having a minimum 30% recycled plastic used, therefore comes to £150 per tonne (0.015 pence per gram) of packaging produced ((£1500/t*30% + £1000/t*70%) - £1000/t = £150/t = 0.015p/g). If the overall tax burden cost (£230 million) was transferred by the packaging producers and retailers to UK households, the average impact of the plastic packaging tax would be 16p per week per household for a 30% increase of recycled content in packaging to be achieved.

However, this cost is expected to be even lower, considering the proportion of packaging already using more than 30% recycled plastic today. According to Ernst & Young's analysis for the British Plastics Federation (BPF) (Ernst & Young, 2019), the proposed tax would increase the proportion of packaging using at least 30% recycled plastic from a quarter in 2017 to three quarters of all packaging on the market in 2022. With 25% of all plastic packaging produced in 2017 already meeting the 30% recycled content criteria, this was projected to rise to 55% in 2022, even without the new tax being introduced (Figure A6.1).

In this case, the minimum tax level needed to make costs to industry similar for the 45% of the industry using 100% virgin plastic packaging to having a minimum 30% recycled plastic used (Figure A6.2), would cost £150 per tonne (0.015 pence per gram), to a total of £103 million. Transferred to households, the average impact of the plastic packaging tax would be 7p per week per household for a 30% increase of recycled content in packaging to be achieved for the remaining 45% of the packaging in the UK to meet the target.

According to the BPF, the total UK plastic packaging POM (placed on market) for consumers in 2017 was 1,532,000t and the number of households in the UK in 2017 was 27.2 million. So, the average plastic packaging consumption per households is 1,532,000t/27.2 mil = 56.3 kgs/year, so the average impact of plastic packaging tax on UK household would be: £8.44 per year or 16p per week. The BPF survey data revealed that 25% of all plastic packaging produced in 2017 already meets the 30% recycled content criteria. If no tax is introduced, this was projected to rise to 55% in 2022.ut should the tax go ahead, the figure would leap to 75% by 2022.

If 75% of the sector would not meet the 30% target, the tax would need to raise £173million coming to 12p per week per household, allowing for the tax to cover the price difference for the remaining 75% to reach the target.

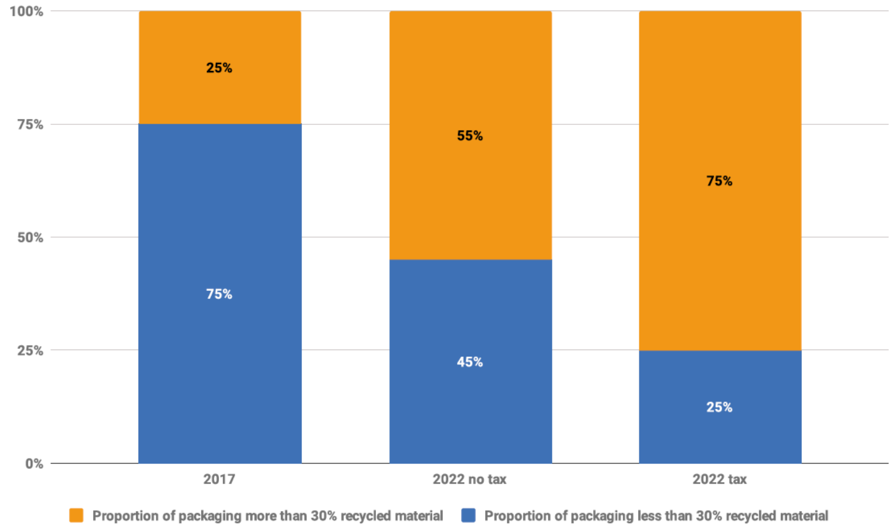

Figure A6.1 Share of packaging with less and more than 30% recycling content, assuming £500 per tonne tax (Ernst & Young, report for the BPF, 2019)

Slide from Ernst & Young's presentation to the British Plastics Federation. (Ernst & Young, 2019)

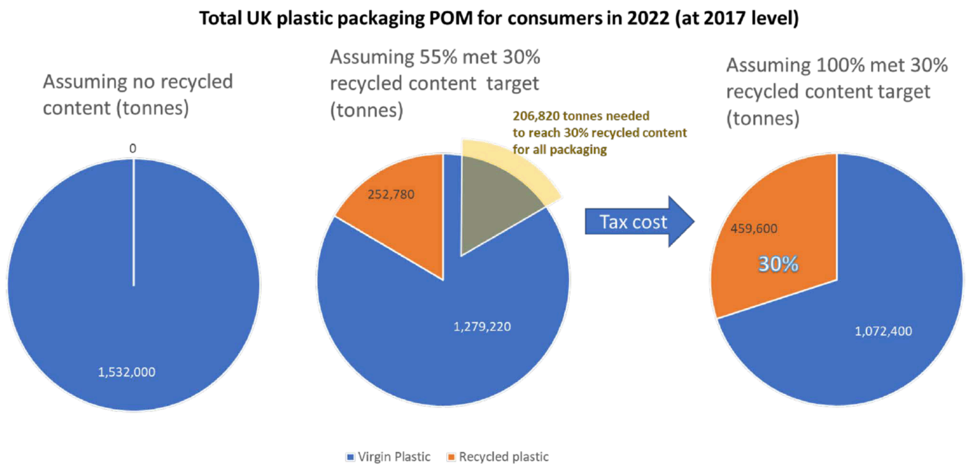

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Figure A6.2 The tax will need to cover the cost of 206,820 tonnes being sourced from recycled plastics in order to meet the targets 2022

Appendix 8. 72 LCA studies examined in Chapter 10

1. **Accorsi**, R., Cascini, A., Cholette, S., Manzini, R. and Mora, C., 2014. Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study . International Journal of Production Economics, 152, pp.88-101.
2. **Accorsi**, R., Versari, L. and Manzini, R., 2015. Glass vs. plastic: life cycle assessment of extra-virgin olive oil bottles across global supply chains . Sustainability, 7(3), pp.2818-2840.
3. **American Chemistry Council**, 2006. Brochure: Take a Closer Look at Today's Polystyrene Packaging—Safe, Affordable and Environmentally Responsible , United States.
4. **American** Chemistry Council, n.d. Packaging Flexes Its Resource Efficiency (brochure), United States.
5. **Amienyo**, D., Gujba, H., Stichnothe, H. and Azapagic, A., 2013. Life cycle environmental impacts of carbonated soft drinks. The International Journal of Life Cycle Assessment , 18(1), pp.77-92.
6. **Banar**, M. and Çokaygil, Z., 2009. A life cycle comparison of alternative cheese packages. CLEAN–Soil, Air, Water, 37(2), pp.136-141.
7. **Bertolini**, M., Bottani, E., Vignali, G. and Volpi, A., 2016. Comparative life cycle assessment of packaging systems for extended shelf life milk . Packaging Technology and Science, 29(10), pp.525-546.
8. **Bertoluci**, G., Leroy, Y. and Olsson, A., 2014. Exploring the environmental impacts of olive packaging solutions for the European food market . Journal of Cleaner Production, 64, pp.234-243. 9.
9. **Biona**, J.B.M.M., Gonzaga, J.A., Ubando, A.T. and Tan, H.C., 2015. A comparative life cycle analysis of plastic and paper packaging bags in the Philippines . In 2015 International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management, IEEE, pp. 1-6.
10. **Bø**, E., Hammervoll, T. and Tvedt, K., 2013. Environmental impact of refillable vs. non-refillable plastic beverage bottles in Norway. Int. J. Environment and Sustainable Development, 12 (4), pp 379-395
11. **Chaffee**, C. and Yoros, B., 2007. Life Cycle Assessment for three types of grocery bags–recyclable plastics, compostable, biodegradable plastic and recyclable paper. Bonstead Consulting and Associates Limited. United States.
12. **Cleary**, J., 2013. Life cycle assessments of wine and spirit packaging at the product and the municipal scale: a Toronto, Canada case study . Journal of cleaner production, 44, pp.143-151.

13. **De Monte**, M., Padoano, E. and Pozzetto, D., 2005. Alternative coffee packaging: an analysis from a life cycle point of view . Journal of food engineering, 66(4), pp.405-411.
14. **The Danish Environmental Protection Agency**, 2018. Life Cycle Assessment of grocery carrier bags , Denmark.
15. **Environment** Agency, 2011. Life cycle assessment of supermarket carrier bags: a review of the bags available in 2006 , United Kingdom.
16. **Franklin** Associates, A division of Eastern Research Group, 2011. Cradle-to-Gate Life Cycle Inventory of Nine Plastics Resins and Four Polyurethane Precursors , United States.
17. **Franklin** Associates, A Division of Eastern Research Group, 2014. Impact of Plastics Packaging on Life Cycle Energy Consumption & Greenhouse Gas Emissions in the United States and Canada , United States.
18. **Franklin** Associates, A division of Eastern Research Group, 2014. Life Cycle Assessment of Tetra Recart Cartons and Alternative Soup Containers on the U.S. Market , United States.
19. **Franklin** Associates, n.d. Plastics: An Energy Efficient Choice , United States.
20. **Franklin** Associates, 2006. Life cycle inventory of polystyrene foam, bleached paperboard, and corrugated paperboard foodservice products , United States. EXAMINING MATERIAL EVIDENCE THE CARBON FINGERPRINT 13
21. **Franklin** Associates, 2000. Plastics’ energy and greenhouse gas savings using house wrap applied to the exterior of single-family residential housing in the U.S. and Canada a case study. United States.
22. **Franklin** Associates, 2000. Plastics' energy and greenhouse gas savings using refrigerator and freezer insulation as a case study , United States.
23. **Franklin** Associates, A division of Eastern Research Group, 2006. Life cycle inventory of container systems for wine , United States.
24. 24. **Franklin** Associates, A division of Eastern Research Group, 2008. LCI summary for eight coffee packaging systems , United States.
25. **Franklin** Associates, A division of Eastern Research Group, 2008. LCI summary for four half-gallon milk containers . United States
26. **Franklin** Associates, A division of Eastern Research Group, 2008. LCI summary for six tuna packaging systems , United States.
27. **Franklin** Associates, A division of Eastern Research Group, 2011. Life cycle inventory of foam polystyrene, paper-based, and PLA foodservice products , United States.
28. **Franklin** Associates, A division of Eastern Research Group, 2011. Life cycle inventory of plastic fabrication processes: injection molding and thermoforming , United States.

29. **Franklin** Associates, A division of Eastern Research Group, 2011. Life cycle inventory of 100% post-consumer HDPE and PET recycled resin from post-consumer containers and packaging , United States.
30. **Franklin** Associates, A Division of Eastern Research Group, 2018. Life cycle impacts of plastic packaging compared to substitutes in the United States and Canada: Theoretical substitution analysis , North America.
31. **Fraunhofer** Institute, 1999. Life cycle assessment for fresh milk packaging . In Life cycle assessment Beverage cartons under test, Germany.
32. **Ghenai**, C., 2012. Life cycle assessment of packaging materials for milk and dairy products. Int. J. of Thermal & Environmental Engineering, 4(2), pp.117-128.
33. **Gironi**, F. and Piemonte, V., 2011. Life cycle assessment of polylactic acid and polyethylene terephthalate bottles for drinking water. Environmental Progress & Sustainable Energy, 30(3), pp.459-468.
34. **Hallberg**, L., 2016. Comparative LCA of beverage cartons with and without bio-based polymers , Sweden.
35. **Hanssen**, O.J., Vold, M., Schakenda, V., Tufte, P.A., Møller, H., Olsen, N.V. and Skaret, J., 2017. Environmental profile, packaging intensity and food waste generation for three types of dinner meals . Journal of Cleaner Production, 142, pp.395-402.
36. **Headley** Pratt Consulting, 1996. Understanding plastic film: Its uses, benefits and waste management options , United States.
37. **Huang**, C.C. and Ma, H.W., 2004. A multidimensional environmental evaluation of packaging materials . Science of the Total Environment, 324(1-3), pp.161-172.
38. **Humbert**, S., Rossi, V., Margni, M., Jolliet, O. and Loerincik, Y., 2009. Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots . The International Journal of Life Cycle Assessment, 14(2), pp.95-106.
39. **Hyder** Consulting Pty Ltd (2009) Zero Waste South Australia, Australia.
40. **Institute** for Energy and Environmental Research, 2006. Life cycle assessment of beverage cartons and disposable PET bottles . In Life cycle assessment: Beverage cartons under test, Germany.
41. **Institute** for Energy and Environmental Research, 2004. Life cycle assessment for fruit juice cartons . In Life cycle assessment: Beverage cartons under test, Germany. EXAMINING MATERIAL EVIDENCE THE CARBON FINGERPRINT 14
42. **Jelse**, K., Eriksson, E. and Einarson, E., 2009. Life Cycle Assessment of consumer packaging for liquid food: LCA of Tetra Pak and alternative packaging on the Nordic market . Environmental Research Institute. Sweden.

43. **Kang**, D., Sgriccia, N., Selke, S. and Auras, R., 2013. Comparison of bacon packaging on a life cycle basis: a case study . Journal of cleaner production, 54, pp.142-149.
44. **Khoo**, H.H., Tan, R.B. and Chng, K.W., 2010. Environmental impacts of conventional plastic and bio-based carrier bags . The international journal of life cycle assessment, 15(3), pp.284-293.
45. **Kimmel**, S.D. and Robert, M., 2014. Life cycle assessment of grocery bags in common use in the United States . Environmental Studies. pp. 1-193
46. **Le Guern**, Y., Tostivint, C., 2010. Nordic Life Cycle Assessment Wine Package Study , France.
47. **Madival**, S., Auras, R., Singh, S.P. and Narayan, R., 2009. Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology . Journal of Cleaner Production, 17(13), pp.1183-1194.
48. **Manfredi**, M. and Vignali, G., 2015. Comparative Life Cycle Assessment of hot filling and aseptic packaging systems used for beverages . Journal of Food Engineering, 147, pp.39-48.
49. **Markwardt**, S., Wellenreuther, M., 2017. Comparative Life Cycle Assessment of shelf stable canned food packaging, Institute for Energy and Environmental Research. Germany.
50. **McKinsey** & Company, 2009. Innovations for greenhouse gas reductions: A life cycle quantification of carbon abatement solutions enabled by the chemical industry, United States.
51. **OVAM**, 2011. Food loss and packaging, Belgium.
52. **PE** International, 2012. Life Cycle Assessment of Polymers in an Automotive Assist Step, United States.
53. **PE** International, 2012. Life Cycle Assessment of Polymers in an Automotive Bolster, United States.
54. **Pasqualino**, J., Meneses, M. and Castells, F., 2011. The carbon footprint and energy consumption of beverage packaging selection and disposal. Journal of food Engineering, 103(4), pp.357-365.
55. **Franklin** Associates, 1989. Resource and Environmental Profile Analysis of Polyethylene Milk Bottles and Polyethylene-coated Paperboard Milk Cartons, United States.
56. **Plinke**, E., Schonert, M., Meckel, H., Detzel, A., Giegrich, J., Fehrenbach, H., Ostermayer, A., Schorb, A., Heinish, J., Luxenhofer, K., Schmitz, S. 2000. Life cycle assessment for drinking Packaging Systems II, Germany.
57. **Poovarodom**, N., Ponnak, C. and Manatphrom, N., 2012. Comparative carbon footprint of packaging systems for tuna products. Packaging Technology and Science, 25(5), pp.249-257.

58. **Prognos**, IFEU, GVM and Pack Force, 2002. Life cycle assessment for beverage packaging II for alcohol-free beverages and wine. In Life cycle assessment: Beverage cartons under test, Germany.
59. **Quantis**, 2011. Comparative full life cycle assessment of B2C cup of espresso made using a packaging and distribution system from Nespresso Espresso and three generic products, Switzerland.
60. **Rivera**, X.C.S., Orias, N.E. and Azapagic, A., 2014. Life cycle environmental impacts of convenience food: Comparison of ready and homemade meals. Journal of cleaner production, 73, pp.294-309.
61. **Simon**, B., Amor, M.B. and Földényi, R., 2016. Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles. Journal of Cleaner Production, 112, pp.238-248. EXAMINING MATERIAL EVIDENCE THE CARBON FINGERPRINT 15
62. **Silvenius**, F., Katajajuuri, J.M., Grönman, K., Soukka, R., Koivupuro, H.K. and Virtanen, Y., 2011. Role of packaging in LCA of food products. In Towards Life Cycle Sustainability Management (pp. 359-370). Springer, Dordrecht.
63. **Singh**, S.P., Chonhenchob, V. and Singh, J., 2006. Life cycle inventory and analysis of re-usable plastic containers and display-ready corrugated containers used for packaging fresh fruits and vegetables. Packaging Technology and Science: An International Journal, 19(5), pp.279-293.
64. **Saraiva**, A.B., Pacheco, E.B., Gomes, G.M., Visconte, L.L., Bernardo, C.A., Simões, C.L. and Soares, A.G., 2016. Comparative lifecycle assessment of mango packaging made from a polyethylene/natural fiber-composite and from cardboard material . Journal of Cleaner Production, 139, pp.1168-1180.
65. **TRUECOST**, 2016. Plastics and Sustainability: A Valuation of Environmental Benefits, Costs and Opportunities for Continuous Improvement , United States.
66. **Tsiamis**, D.A., Torres, M. and Castaldi, M.J., 2018. Role of plastics in decoupling municipal solid waste and economic growth in the US . Waste Management, 77, pp.147-155.
67. **ULS** Report, 2016. A Study of Packaging Efficiency as it Relates to Waste Prevention . kaging Efficiency Study III (summary), United States.
68. **Wikström**, F., Williams, H., and Venkatesh, G., 2016. The influence of packaging attributes on recycling and food waste behaviour – An environmental comparison of two packaging alternatives , Journal of Cleaner Production, 137, 895–902
69. **Wikström**, F., Williams, H., Verghese, K. and Clune, S., 2014. The influence of packaging attributes on consumer behaviour in foodpackaging life cycle assessment studies-a neglected topic . Journal of Cleaner Production, 73, pp.100-108.

70. **Williams**, H., Wikström, F., 2011. Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. Journal of Cleaner Production, 19(1), pp.43-48.
71. **WRAP**, 2010. Life cycle assessment of example packaging systems for milk , United Kingdom.
72. **Xie**, M.H., Qiao, Q., Sun, Q.H. and Zhang, L.L., 2011, May. Environmental impacts from PET packaging waste management using Life Cycle Assessment: A case study in China . In 2011 International Symposium on Water Resource and Environmental Protection (Vol. 4, pp. 2478 - 2481). IEEE. 73. Zabaniotou, A. and Kassidi, E., 2003. Life cycle assessment applied to egg packaging made from polystyrene and recycled paper . Journal of Cleaner Production, 11(5), pp.549-559.

Appendix 9. Permissions to reproduce figures and tables

WRAP

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Figure 7.5 Main types of plastic in packaging (WRAP, n.d.)

Figure 7.12 Potential harmonised schemes from WRAP (WRAP, 2017)

TOLVIK

Permission granted by email from Adrian Judge, Director, 6th April 2021

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Figure 5.29 Rising EfW operational tonnage capacity (Tolvik 2019a)

Figure 5.30 Rising tonnages to energy from waste linked to new facilities (Tolvik 2019a)

Figure 5.31 Landfill versus Energy recovery markets (Tolvik 2019a)

Appendix 10. Technological Trends research, interviews, and surveys

We set about to bring together research, business and experts in the industrial fields at large and held workshops to imagine in each sector the future business shape which would respond to policy trends in the sector. Two principle workshops were held with groups from municipal/public sector and industrial backgrounds. The target set by the groups was to imagine 2050 for their field. Policy trends were considered, topic areas were posed against each trend, and the most pertinent or repeated comments were recorded after consensus was reached on the most important indicators. Two reports were produced summarising findings for both a Municipal and an Industrial focus. The emergent theme of Energy and the Energy crisis was also picked up and a third target group of energy managers was assembled in order to further unpick that topic. A final report was produced on energy futures.

Imagine 2050, Municipal Technology, 2015 (Cole, 2015).

Veolia Report: *"Imagine 2050: The innovations we will need in waste, water and energy to ensure a sustainable future"*.

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Imagine 2050, INDUSTRIAL Technology, 2017 (Cole, 2016).

Veolia Report: *"Imagine 2050: The future of water, waste and energy - How UK industry will need to adapt for tomorrow"*.

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Dr Linda Hilton, Innovation Process and Business Consultant
Ian Pearson, Futurologist Futurizon
Richard Worzel, Senior Futurist Futuresearch
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Paul Madden, Senior Purchasing Manager Arla
Brian Quin, COO of Labs Intel

The industrial sector was limited to and split into **Manufacturing**, **Pharmaceutical**, **Food** sectors relevant to the experts at hand.

Global megatrends were identified common to both threads, municipal and industrial, one respondent noting "There is a convergence of forces energising the economy, technological innovation, connected humans and a pressure on resource availability that together are driving responsible businesses to include environmental factors as a catalyst for their growth". The studies indicated that from climate change to autonomous vehicles, the challenges we'll face in the next 35 years will stem from two key megatrends: population growth and advancing technology. Together these will mean more people connecting in new ways, leading to an acceleration of ideas and innovation. 34% of the European population are estimated to be aged 60 years or over in 2050 (United Nations, 2006)

The specific transversal trend of Energy security, supply and resilience was identified particularly since its climate change contribution is significant and a further study was conducted with a similar approach to workshops of experts in order to elicit the value of energy and specifically the role waste may play. The report was called Keeping the lights: Operating without fossil fuels, Veolia UK, (Amouyal, 2019).

The results of the workshops and interviews are summarised here with the main Trends and listed and topic areas records.

<u>**MUNICIPAL Technology Study, 2017**</u>

The summary of the points raised, main trends identified and limbs of each trend (topics) is summarised here, and explained by example in the text.

Municipal Technology

TREND #1 - Population Growth
Topic: Resource Efficiency
Topic: Smarter waste to use space
Topic: Changes in healthcare

TREND #2 - New Technology
Topic: New skills / jobs for workforce
Topic: Smarter solutions
Topic: Role of Cities
Topic: Nanobot sorting (recycling)
Topic: Intelligent packaging
Topic: Underground waste collection

TREND #1 Identified - Population growth

Continuing population growth will lead to environmental degradation and changes to how we manage and consume energy, water and food. It is estimated we will double our resource and energy consumption by 2050 if businesses don't change. Legislating to regulate By 2050, advances in big data could lead to companies and governments having a firmer grasp on factors influencing CO_2. This will make them better at reporting and managing emissions. Before that we are likely to see changes in legislation.

By 2020, COP21 commitments and the interim Kyoto Protocol CO_2 targets will generate the realisation that we're not doing enough. We should already see emissions reducing but evidence suggests this isn't happening quickly enough. The development of a clear, long-term policy framework is essential for companies looking to progressively invest in low carbon technologies. This will encourage businesses to focus on higher emission reducing activities and longer-term gains.

Topic area: Can a growing population with declining resources improve efficiency?

More people means more food Food consumption will rise faster than population as the global middle class expands, leading to increased supply pressure and higher prices. We'll need to establish more dynamic, efficient and agile supply chains. The pressure of requiring more food will lead to a more joined-up approach to managing water and energy use, creating a food, water and energy network.

"We're already growing enough to feed the future world. We just don't feed people with it. We don't need to grow more stuff and we need to stop throwing away the edible stuff that we do grow." 55% increase in global water demand expected by 2050 OECD (Organisation for Economic Co-operation and Development) 80% is the amount the UK has committed to cut its emissions by in 2050, compared to 1990 levels", ***Anonymous, Consultancy, Roland Berger***

Topic area: Smarter ways to use space

Increasing urbanisation will mean a significant squeeze on space, affecting where and how we grow and manufacture. Growing cities will need industries to find more efficient ways of managing and moving urban water, energy and waste.

"The issue of waste management is critical for our industry. We are seeing population growth, increasing consumption and urbanisation which is increasing per capita waste generation – we play an important role in driving innovation to help find efficient ways of managing water, energy and waste.", ***Virginie Helias, VP Global Sustainability, P&G***

Denser populations within cities will need smart solutions. Japan is experimenting with innovative underground farming. A single 25,000 sq ft site currently produces 10,000 heads of lettuce every day. These space efficient farms use 40% less power, create 80% less food waste and use 99% less water than current practices.

Topic area: Changes in healthcare

An ageing population, growing costs of treatment and new medical technology will shape the future of healthcare. The Department of Health and Human Services believes that in the next 35 years, artificial and lab-grown organs will create a more permanent solution for transplants. This means patients will no longer have to wait for life-sustaining organs. Scientists are already trying to grow human organs inside pigs in an attempt to tackle a shortage of donors

TREND #2 Identified - Advancing technology

New technology deliverables will be accelerated by more powerful computers, enabling us to find previously impossible solutions.

For example 3D printing and nanotechnology are becoming prevalent. 3D printing will become embedded into supply chains by 2050. The combination of nanotechnology and novel materials will lead to bespoke production lines. Today, tooling and production mobilisation accounts for 70% of production costs and this could be reduced to 10%.

"3D printing is a genuinely disruptive technology. Currently we see it as a way of replacing spare parts but it will eventually be used for finishing operations.", ***Steve Evans, Director of Research, University of Cambridge***

Topic area: New skills in the workforce

Robotics and the rise of artificial intelligence will replace many low skill and repetitive job roles. The wider industry impact will see human workforces reskilling and upskilling for the workplace.

"Autonomous machines will be able to handle more complicated decisions and be able to think more quickly and effectively than humans. They May be able to learn from and self-correct mistakes but will still require humans to interact with them.", ***Brian Quin, COO of Labs, Intel***

Topic area: Smarter solutions

Smart utility metering will be taken to a new level, with more intelligent and responsive systems.

"By 2050, these systems will be more intelligent, and will take corrective measures by themselves to optimise utility usage." ***Mark Coyne, Project Development Director, Veolia***

Topic area: How influential are our cities for the future?
Increased fuel and food prices, declining levels of exploration of non-renewable resources and successful business models that achieve more with less have questioned our model of economic growth based on the exploitation of finite resources. Yet the transformation of the UK towards a Circular Economy remains slow, largely due to our politics and economy being locked into resource-intensive pathways that were dictated by previous technological and industrial revolutions.

However, increasing evidence suggests that this does not have to be the case and change can originate from our cities. We live in an age where rapid technology innovation has created a paradigm shift in the way we live, work and consume. With the majority of the world's population now urbanised, cities are at the centre of a resource revolution.

They are guiding citizens to lead sustainable lifestyles through high density living, sharing of goods and services and the reuse and remanufacturing of goods. More importantly, cities have the capacity to re-lock lifestyles into more sustainable and resource-efficient pathways by investing in innovative technologies that can accelerate this transition.

The report by the LSE provides a perspective on potential future lifestyle scenarios for UK cities in 2050, looking specifically at changes to energy, waste and water use patterns. It is based on an analysis of the wider academic literature on lifestyles and cities, and draws on existing scenarios and forecasting studies that provide insights into

Topic area: Nanobot sorting (recycling)
Products for recycling will be sorted by machines that separate mixtures of materials into categories based on their size, shape, colour and on their physical and chemical properties.

In the future, mixtures of materials could be shredded into microscopic particles and nanoscopic robots will be used to recognise different types of material and collect them in a pure form so they can be reused by industry. This will help to reduce the amount of waste that cannot be used and has to be thrown away to almost zero.

Things happening today that provide a lens on the future for municipalities:

Case study: Intelligent sorting

The Veolia Magpie Technology (Materials Acquisition and Gathering of Plastics by Intelligent Equipment) implemented at Padworth MRF, West Berkshire, uses near infra-red sensors and pneumatic separation technology to sort different types of plastic bottles based on their chemical composition. These sorted bottles can then be delivered directly to manufacturers allowing them to use large amounts of recycled plastic in new bottles.

Topic area: Intelligent packaging

Packaging will be active and able to control the environment inside the packaging providing optimum conditions. It will also self-degrade after the content expires. Intelligent packaging will contain substances that mop up any oxygen that leaks into the container. Coloured stickers on the outside of the packaging will change colour at a rate that is affected by the storage temperature. The sticker on a product kept in a cool fridge will show the safe to eat colour for longer than one kept in a warm room. Both these mean that food will last longer and less will need to be thrown away. Packaging will contain additives that modify the behaviour of the plastic film making it oxo-biodegradable. Chemically, it will cause the long chemical chains to break down into harmless substances which are part of the earth's natural cycles. Packaging could be designed to start breaking down any time from a few weeks to two years depending on the use of the packaging.

Topic area: Underground waste collection

All municipal waste will be collected via a pneumatic network transferring the waste flow to treatment facilities. This will reduce the presence of vehicles in the city and contribute to less greenhouse gas emissions, sound and visual nuisances which result from the collection of waste, and will be a 24/7 service. Multiple bins will be replaced by one pod integrated into walls allowing more space in rooms. The pods will then drive waste to the treatment facility.

Pneumatic collection consists of transferring household waste by an underground network, from fixed collection points to a unit that compresses material. This type of collection has several advantages:

- *suppression of noise,*
- *visual and odour nuisances related to storage; and*
- *reduction of need for collection.*

<u>INDUSTRIAL Technology Study, 2018.</u>

MANUFACTURING Industry

The summary of the points raised, main trends identified and limbs of each trend (topics) is summarised here, and explained by example in the text.

Industrial Technology

MANUFACTURING

TREND #1 - Hyper efficient business models
Topic: Adaptable production lines
Topic: Selling benefits, not products
Topic: Assets in the seas

TREND #2 - Next generation materials
Topic: Technological alternatives
Topic: Biological materials
Topic: Manufacturing wastes as a tradable asset

TREND #3 - Rise of Robotics
Topic: New era of efficiency
Topic: Connected thinking
Topic: Onshoring

TREND #1 - Hyper-efficient business models

Manufacturing businesses will need to be increasingly adaptive to prosper, thinking harder about how, where and what they make. Businesses will need to think about resource use, consumption and transport costs, potentially relocating around customers and resources. Manufacturers will have to decide whether to be closer to raw materials to guarantee supply, or closer to customers to meet demand.

"By embracing the revolution in big data, industry will see a step change in how it views and pays for services. This transformation will see complete contract visibility, faster forecasting and flexible payment based on performance that will radically improve the B2B customer experience." ***Kevin Hurst, COO, Industrial Customers, Veolia.***

Topic area: Adaptable production lines

Factories will increasingly be able to create a range of different products by physically reconfiguring to meet changing demand.

Topic area: Selling benefits, not products

A Circular Economy requires keeping resources in use for as long as possible, before deconstructing and re-engineering them to create new products. Today, manufacturers only monitor products for the warranty period. In the future, more manufacturers will retain ownership and responsibility for their products and their on-going performance. Customers will buy the benefits, not the product.

Topic area: Assets in the seas

The decommissioning industry has developed a unique strategy to decommission rigs that is based around asset recovery. Floating hotels can be made from accommodation units, and boilers and cranes sold on for further applications.

*The same factory might be able to produce an automobile, followed by a washing machine, followed by a dishwasher, followed by an industrial crane. That all comes from the concept of 3D printing." **Unattributed**.*

Things happening today that provide a lens on the future for industry:

Case study: Mr Robot

The waste sector is using automation technology as part of the deconstruction process of goods. An example is Veolia's new TV recycling facility that uses robotics to ensure safe and complete breakdown and reuse of products back into the economy. Flat screen TVs are dismantled by a robotised automated production line, demanufacturing the complex products providing reuse opportunity and increasing the value of what is otherwise shredded for approximate separation.

TREND #2 - Next generation materials

Today's technologies are limited by old materials. Future materials will be lighter, stronger and greener, providing new opportunities for innovation.

Topic area: Technological alternatives

We are likely to see leaner and greener materials of the future meaning more innovation. Research and development will lead to more lightweight yet durable materials, providing manufacturers with the opportunity to produce structures using less material and energy.

*"Graphene and nanotubes are several times stronger than steel and will be fairly cheap by 2050. They'll help us make structures much more elegant, and use far less material.", **Ian Pearson, Futurologist, Futurizon***

Topic area: Biological materials

The need for greener products that are cheap, strong and plentiful will lead to new perspectives on naturally sourced materials. Manufacturing cars uses significant resources, expensive tooling and excessive energy. Phoenix, a concept car designed by Albrect Birkner and Kenneth Cobonpue, challenges convention by using lightweight and natural materials, such as bamboo, on a frame that is built by hand using minimal tools and energy.

"Biology will become really big. I think, by 2050, about half of what we make will be biologically created, which might mean it's grown", **Steve Evans, Director of Research, University of Cambridge**

Topic area: Manufacturing wastes as a tradable asset

The concept of waste will be radically different in 2050. Manufacturers will see by-products as something of value that they can sell to other businesses or exchange for credit.

*"We are likely to see community pooled waste, where manufacturers trade materials that are not useful to them with other businesses. This might take the form of a credit system based on the value of these materials.", **Richard Worzel, Senior Futurist, Futuresearch***

TREND #3 - Rise of robotics

Industrial robots are on the verge of revolutionising manufacturing. As they become smarter, faster and cheaper, they'll be called upon to do even more.

Question posed: How should UK manufacturers implement disruptive robotics?

"Most British manufacturers have invested in some form of automation and/or robotics and 68% see potential for future investment", (Source: **Barclays**, Future-proofing UK Manufacturing Report).

Topic area: A new era of efficiency

As humans move off the production lines and into new engineering roles, factories will be able to operate longer, faster, more safely and with less waste – making way for greater productivity and quality assurance. Kurion, part of Veolia, creates technology solutions to access, separate and stabilise nuclear and hazardous materials and to safely isolate them from the environment. Through robotics, Kurion eliminates human risk in some of the most dangerous environments imaginable.

Topic area: Connected thinking

Through the Internet of Things (IoT), data capture will greatly benefit industry. Advanced analytics platforms could enable manufacturers to evaluate big data sourced from connected robotics to improve processes. Sensors will transmit data to alert and initiate preventative maintenance and adjust production speeds according to the market.

Topic area: Onshoring

The advance of robotics could reinvigorate UK manufacturing, making local production more cost effective than importing. Robotics developments will level the playing field and reduce the advantage enjoyed by China and other low-cost markets. This is already leading to some 'reshoring' of UK production, especially in textiles, an industry particularly affected by emerging markets.

PHARMACEUTICAL Industry

Industrial Technology

PHARMACEUTICAL

TREND #1 - New Dynamics
Topic: Collaboration and convergence
Topic: Shift the value

Topic: Mining metals (from waste)
Topic: Localised production

TREND #2 - Personalised health
Topic: Data driving customisation

TREND #3 - Biofutures
Topic: An evolving opportunity

TREND #1 - New dynamics

Traditional ways of working will give way to more dynamic operations and models. This will include increased collaboration across both industries and reimagining how products are manufactured and sold in order to create new efficiencies.

Topic area: Collaboration and convergence

The convergence of technologies will create opportunities to partner with competitors, customers and businesses in other sectors, leading to more innovative products. Google has partnered with Swiss pharmaceutical firm Novartis to develop its smart contact lenses. Novartis wants to develop alternatives that include the possibility of 'intraocular lenses' – contacts that are inserted permanently into the eye to correct vision.

Topic area: Shifting the value

Within the pharmaceutical industry, increasing costs and declining healthcare investment are creating a squeeze. We expect a growing number of alternative business models like pay-for-performance emerging to forge a closer link between value and effectiveness. Johnson & Johnson has started to introduce pay-for-performance drugs within Europe. In the UK they have agreed to reimburse Britain's National Health Service when patients don't respond to their blood-cancer drug Velcade. Other companies such as GSK and Roche have also been discussing these models.

The chemical industry is pioneering Chemical Leasing. This means shifting from selling chemical goods to selling chemical services. This idea has received renewed interest and support from the United Nations Industrial Development Organization.

Question posed: Can new business models subvert expectations?

"We're likely to see greater collaboration between these specialist businesses and also with outside partners. Brands like Google are already moving into that space.", ***Dr Linda Hilton, Innovation Process and Business Consultant***

Topic area: Mining metals

Veolia has a bespoke process for the recovery of precious metals from obsolete medication such as platinum. The high-grade metal is extracted and can then be reprocessed.

Topic area: Localised production

Advances in 3D printing technology might make it possible for the pharmaceutical industry to stop manufacturing entirely, instead focusing on blueprints and leaving most production to chemists. Bio3D produce advanced robotic 3D printing systems suitable for research and scientific applications, such as printing cells, bacteria, proteins, bio-gels, polymers and food materials. Their aim is to bring affordable and reliable 3D printing and bioprinting to every researcher, scientist, doctor, engineer, educator and student.

"The limitation of producing current drug formulations using 3D printers is that they don't react well to potential temperature changes and require rapid mass production. It's something we may see in the future with regards to 'personalised' medicine, but it's not quite ready yet. However, 3D printing remains a fabulous way to rapidly prototype medical devices, for both product evaluation and product development.", ***Dr Linda Hilton, Innovation Process and Business Consultant***

In 2015, the FDA approved the first 3D-printed drug, Spritam, from Aprecia Pharmaceuticals, showing that the technology exists but that regulations will have to change for it to be implemented.

TREND #2 - Personalised health

In 2050 we expect a shift from generic drugs to customised treatments designed around the patient, rather than the illness.

Topic area: Data will drive customisation

We'll see a considerable increase in the volume and sophistication of data, particularly through wearable devices, such as Fitbit and Apple Watch, which will bring about more tailored treatment plans. The testing and launch of new drugs could also speed up through access to live patient data, reducing dependence on long and costly clinical trials.

"Part of the driver for getting away from mass production is the customisation of medicine. Dosages, and maybe even composition, will be adjusted for our age, sex and weight.", ***Richard Worzel, Senior Futurist, Futuresearch***

Question posed: What impact will personal health have on the pharmaceutical industry?

The number of health apps downloaded has more than doubled over the past 2.5 years, (Source: Health App Developer Economics 2014, Research2Research, May 2014).

TREND #3 - Biofuture

Biotechnology is a different way of producing chemicals and pharmaceuticals, harnessing the power of living cells and getting them to work in predictable and controllable ways.

Topics area: An evolving opportunity

McKinsey claims that biopharma is growing at more than double the rate of conventional pharma and this is expected to continue into the foreseeable future. We also expect to see companies, particularly those related to food and agriculture, focus on the types of molecules that exist within their waste. These could ultimately be sold to the pharma industry.

"Biotechnology will radically change both industries. For chemicals, it will have a significant impact by creating kinder fertilisers and pesticides for the food industry. In pharma we'll see drugs that can cure rather than treat serious illnesses.", ***Dr Linda Hilton, Innovation Process and Business Consultant***

An example is the Watchfrog technology which uses fish larvae or tadpoles to detect the presence of endocrine disruptors in wastewater treatment plants. Through this innovative tool amphibians fluoresce when they are disturbed by these pollutants. There has been a 25% increase in annual biotech patents applications since 1995 (McKinsey, 1995).

FOOD Industry

Industrial Technology

FOOD

TREND #1 - Food but not as we know it
Topic: Cultured meat (grown form petri dish)

TREND #2 - Emotional investment
Topic: Deeper consumer connections
Topic: Technology and bespoke nutrition

TREND #1 - Food, but not as we know it

The types of food we consume may not change, but where it comes from will be radically different.

Topic area: Cultured meat

The meat industry accounts for 18% of our total greenhouse gas emissions, according to the Food and Agriculture Organization of the United Nations, which also predicts that the environmental footprint of livestock production will double from its 1999 levels by 2050. Mass producing cultured (lab-grown) meat is seen as a more resource-efficient, cost-effective and ethical alternative.

The world's first lab-grown burger was unveiled in 2013, and carried a $300,000 price tag. But long-term predictions suggest that cultured meat will be considerably cheaper than cattle sourced beef and will overcome concerns relating to animal welfare and environmental degradation.

A bug's life

One of the biggest challenges that future food production will face is around protein. Meat has long been the main source of protein for the UK, but given the economic impetus of the industry, we'll need to look for other sources in the future. That could mean a huge emerging market in the cultivation of insects, which are as high in flavour as they are in energy.

The Economist estimates that a cow requires 8kg of feed to produce 1kg of beef, but only 40% of the cow can be eaten. Whereas, crickets require just 1.7kg of food to produce 1kg of meat, and 80% is considered edible.

Data and advances in precision farming mean that it's increasingly possible to grow, cultivate and produce products that are unique to individual customers. The challenge will be how this is delivered without having a negative impact on the environment.

Technology is already enabling the beginnings of bespoke nutrition. Nima is a portable sensor that quickly tests liquid and solid foods for the presence of gluten. The device connects with a user's smartphone to display the amount of gluten that's present within the food, giving them more control over what they eat.

"We've already got tractors which know exactly where they are on the field, and exactly how much fertiliser each square metre of land needs. But what will happen is that this becomes linked to an individual customer. They will have a few square metres of field, growing their wheat or barley, based on their particular needs.", **Ian Pearson**, Futurologist, Futurizon

TREND #2 - Emotional investment

The expectation that we will have complete value chain transparency will lead to new production models and enhanced consumer relationships.

"Consumers will have a personal investment in products and food. Purchasing will be even more about relationship and trust.", ***Dr Morgaine Gaye, Food Futurologist, Bellwether Food Trends***

Topic area: Forming deeper consumer connections

We can already see consumers increasingly demand transparency on how our food is grown, sourced and made. This is likely to evolve into a new type of relationship, where the traditional boundaries of business and customers blur.

Topic area: Technology will enable bespoke nutrition

Data and advances in precision farming mean that it's increasingly possible to grow, cultivate and produce products that are unique to individual customers. The challenge will be how this is delivered without having a negative impact on the environment.

Technology is already enabling the beginnings of bespoke nutrition. Nima is a portable sensor that quickly tests liquid and solid foods for the presence of gluten. The device connects with a user's smartphone to display the amount of gluten that's present within the food, giving them more control over what they eat.

"We've already got tractors which know exactly where they are on the field, and exactly how much fertiliser each square metre of land needs. But what will happen is that this becomes linked to an individual customer. They will have a few square metres of field, growing their wheat or barley, based on their particular needs.", ***Ian Pearson, Futurologist, Futurizon***

The emergent topic of energy

Both groups cited energy, and their reliance on electricity, heating, steam, gas, and oil for transport as themes that constituted a topic in itself.

Method of obtaining industry views on energy

Veolia organised a survey and seminars with energy companies and spoke to hundreds of energy and business leaders across a spectrum of enterprises. The research was conducted by direct interview of senior decision makers via phone calls, direct interview face to face and workshops held in small focus groups. It was made up from energy managers, Veolia energy customers, facility managers, and industry and academic experts.

50%-52% of the senior decision-makers believed the UK is heading towards an energy crisis and our panel of energy managers were either very concerned or concerned about the reliability and security of their energy supply.

The qualitative research consisted of interviews with 50 energy managers within the manufacturing sector. Quantitative polling was undertaken by YouGov with 650 senior decision-makers with varying responsibilities for energy and budget in private sector companies of more than 250 employees. The research took place in December 2018.

According to a YouGov poll, half of senior decision-makers with responsibility for energy and budget agree with the likelihood of an energy crisis.

Survey Results - Adapt or fail

The demand for energy in the UK is unrelenting. One quarter of UK energy is used for manufacturing materials, chemicals and goods in the industrial sector. 80% of this is used for heat production where fossil fuels provide the lion's share of the energy. So what will businesses do when this capacity is significantly reduced?

The demand for energy in the UK is also changing. On our streets, electric vehicles are becoming more and more commonplace. It's estimated that by 2050 the energy demand will be 18GW - enough to power nearly 48 million homes and the output of 16 nuclear power stations.

Electricity, fed by renewable sources such as wind, is an obvious go-to in the battle to decarbonise our economy, especially after the Government's recent commitment to reduce carbon by 100% by 2050 compared with 1990 levels.

Our everyday lives will reflect this shift. Electric or district heating will almost certainly replace traditional domestic gas boilers in new homes. We all increasingly rely on the cloud for internet access, data storage and security and the power required to support data centre infrastructure is globally set to grow fivefold over the next few years. If the UK mirrors this trend, data centres will use the equivalent power consumed by more than 16 million homes. The increasing number of white goods and gadgets in our homes will add further to the future UK power demand requirements. And all that's before we factor in our growing population.

Businesses can adapt from within to meet the energy crisis head on. Once we start managing our own demand and resilience - becoming more energy efficient, self-sufficient and less reliant on an ageing centralised Grid, we'll be in a robust position to confront the energy crisis.

Meeting carbon targets will improve the bottom line for businesses and keep energy costs consistent and sustainable

Concerns over Security of Supply

We saw that the majority of respondents do see a looming crisis. Reviewing questionnaire responses, more than half (52%) of our panel of energy managers are either very concerned (16%) or concerned (36%) about the reliability and security of their energy supply. Half of the senior decision-makers believe the UK is heading towards an energy crisis, while four-in-ten disagree.

However, three-quarters (76%) acknowledge that having sufficient energy to support their business is important. Taking Grid capacity and resilience for granted does not appear to be in the best interests of UK plc.

Starting from here - our current energy infrastructure

It won't be easy to transform our complex energy infrastructure, especially when faced with the Government's commitment to "net zero" greenhouse gases by 2050. Nevertheless, whilst the UK is currently on track to hit the third carbon budget (a 37% reduction by 2020), it is unlikely we will meet the fourth (51%) or fifth (57%), which cover the period to 2032 (Amouyal, 2019).

To get back on track – and meet the increasing demands of electrification– will require huge investment in infrastructure. We asked our senior decision-makers and energy managers whether they believed government or private investment in infrastructure was enough to meet the growing needs of the UK. In short, they didn't: 58% of senior decision-makers and 82% of energy managers thought more was needed (Amouyal, 2019).

Indeed, when we asked our panel of energy managers what solutions their businesses were considering to offset a potential energy crisis, 64% said none. There's something of a contradiction when, on the one hand, they don't think enough is being done but are failing to take-charge and seek alternative solutions. One conclusion could be that our respondents are not looking far enough into the future. Or perhaps there is a knowledge gap about the energy gap. It's clear that energy specialists can play a big part in helping businesses look for solutions to increase their resilience.

Renewable energy is probably the most recognised energy source for a green future but it still only accounts for 33% of the energy needed for the UK. Alternative solutions, which may need greater promotion to ease reliance on the Grid, include heat and power facilities (CHP), battery storage or just being smarter in managing or purchasing energy.

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Price volatility - planning for the future and cost implications

During our conversations, we wanted to ascertain the importance of cost volatility. When asked how important this was to their business, two-thirds of managers (66%) felt volatility was a concern while 80% needed 'some' or 'complete' certainty over energy prices. When a similar question was posed to senior decision-makers, 73% agreed the price of energy was important.

To gauge the seriousness of the current uncertainty, it is worth undertaking risk analysis. Suppose your business was hit by a sudden increase of 20% in the cost of energy. Would your business be agile enough to adapt? We questioned our panel of energy managers to understand how they would try to offset such costs while maintaining business as usual.

Encouragingly, 88% of businesses already build energy price increases into annual cost forecasts, showing good strategic planning and a consideration of energy use. Of the senior decision-makers, 39% would look to buy energy more efficiently if costs rose unexpectedly, 29% would reduce or adapt operations to reflect higher costs and 27% would invest in new energy solutions (Amouyal, 2019).

The picture may not be wholly bleak but greater proactivity is needed to increase supply security and avoid being at the mercy of an ever-fluctuating market.

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Energy security: what solutions are being considered?

More than a third (38%) of our energy management panel (38%) have suffered a loss of supply due to either a failure of the Grid or because of the site's infrastructure. These losses of production and unplanned shutdowns can be very costly to a business. Despite that, only a similar proportion (36%) of managers are actively looking at solutions to prevent such setbacks. When we posed the same question to senior decision-makers, they set out which solutions they favoured. Reducing demand through energy efficiency was the most popular answer with 32%, 17% would consider battery storage technology 17% energy procurement and demand-side response, 15% CHP and 7% district heating (Amouyal, 2019). From our perspective, this is putting more emphasis on prevention than cure. Given the importance of maintaining energy supply, this issue does not appear to be being taken sufficiently seriously when one considers the potential consequences and an 'energy gap' is apparent and discussed by policy makers in the UK (Commons library, 2019).

Capturing the results from Technology studies in Industry, Communities and Energy contexts: Three bespoke texts were captured from the workshops, interviews and investigations and published for the municipal and technological industries of the future, and for energy futures, independently vetted and co-authored with Imperial College (Kirkman et al were key authors).

Imagine 2050 : The innovations we will need in waste, water and energy to ensure a sustainable future *(Cole, 2016)*.
Imagine 2050: The future of waste water and energy (How UK industry will need to adapt for tomorrow) *(Cole, 2016)*.
Keeping the lights on: Operating without fossil fuels (Amouyal, 2019).

THE END -

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