Towards a circular economy – Waste management in the EU

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Towards a circular economy - Waste management in the EU

Study

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Abstract

This report examines the role of waste management in the context of a circular economy transition. Key challenges relate to moving beyond the perception of 'waste as a problem' to 'waste as a resource'. To this end high levels of cooperation are needed between the waste industry and enterprises engaged in circular economy business models. Collecting high quality waste streams for re-use, remanufacturing and recycling also requires citizen engagement and integrated infrastructure development from the municipal to the EU level. Ultimately, both waste prevention as well as a widespread growth in circular economy activities will require a coherent and holistic approach that takes recovery options into account at every stage of the product life cycle. Co-benefits will include reducing environmental burden as well as creating both high-skilled and low-skilled jobs for an inclusive, green economy. In concrete terms, this report examines five waste streams identified in the EU's Circular Economy Action Plan: municipal waste, packaging waste, food waste, bio-waste and critical raw materials. It looks at the current state of policy development, presents trends and data comparing Member State performance, reviews the state of technological development, and assesses employment opportunities relevant to each waste stream in the overarching context of assessing progress toward the circular economy transition in the EU. Case studies of specific options for collecting and treating waste based on experiences in Denmark, Italy and Slovenia complement the more macro-level analysis of trends. Finally, key policy options are identified, in particular focused on ways to prevent waste, align circular economy and waste management objectives and improve the quality and reliability of indicators toward more robust monitoring.

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AUTHORS

Oakdene Hollins: Peter Lee, Edward Sims, Olivia Bertham, Harry Symington, Nia Bell, Lucie Pfaltzgraff and Pernilla Sjögren.

Wuppertal Institute: Henning Wilts and Meghan O'Brien, with support from Justus Benke.

STOA ADMINISTRATORS RESPONSIBLE

Lieve Van Woensel and Nera Kuljanic
Scientific Foresight Unit (STOA)
Directorate for Impact Assessment and European Added Value
Directorate-General for Parliamentary Research Services
European Parliament, Rue Wiertz 60, B-1047 Brussels
E-mail: lieve.vanwoensel@ep.europa.eu and nera.kuljanic@ep.europa.eu

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List of abbreviations

AD	Anaerobic Digestion
AECOC	Asociación de Fabricantes y Distribuidores
BBI	Bio-Based Industries (a public-private partnership)
BREF	Best Available Reference Document
CBA	Cost Benefit Analysis
CD&E	Construction, Demolition AND Excavation (waste)
CDW	Construction and Demolition Waste
CE	Circular Economy
CHP	Combined Heat and Power
CORDIS	Community Research & Development Information Service (EC repository of EU-funded research projects)
COST	European Cooperation in Science and Technology (funding scheme for networks)
CRM	Critical Raw Material
DG	Directorate General
DIFTAR	Dutch system of differentiated tariffs to improve waste segregation at source
EAP	Environmental Action Programme
EC	European Commission
EEA	European Environment Agency
EfW	Energy from Waste
EIP-RM	European Innovation Partnership on Raw Materials
ELIBAMA	European Li-Ion Battery Advanced Manufacturing
EPR	Extended Producer Responsibility
ERDF	European Regional Development Fund
EU-28MS	The 28 Member States of the European Union
FEVE	European Container Glass Federation
GAIA	Global Alliance for Incineration Alternatives
GHG	Greenhouse Gas
IEEP	Institute of European Environmental Policy
ISWA	The International Solid Waste Association
JRC	Joint Research Centre of the European Commission
$kgCO_2e$	GHG emissions equivalent to one kilogram of carbon dioxide
MBT	Mechanical-Biological Treatment
MRF	Materials Recovery Facility
MS	Member State (of the European Union)
MSW	Municipal Solid Waste
OECD	Organisation for Economic Co-operation and Development
PAYT	Pay As You Throw
PCB	Printed Circuit Board
PGM	Platinum Group Metal
PPWD	Packaging and Packaging Waste Directive
R&D	Research And Development
SIP	Strategic Implementation Plan (of the EIP-RM)
SME	Small to Medium-Sized Enterprise

STEEPED	Methodology for considering technological options in a broader context encompassing Social, Technological, Economic, Environmental, Political/legal, Ethical and Demographic
STOA	Science and Technology Options Assessment
TRL	Technology Readiness Level
UNEP	United Nations Environment Programme
WEEE	Waste Electrical and Electronic Equipment
WFD	Water Framework Directive
WRAP	Waste & Resources Action Programme
WtE	Waste to Energy

Executive summary

Significant progress has been achieved in reducing the impacts of waste generation on the environment and human health. The challenge for the future is both continuing this progress – especially related to the relatively high amounts of untreated waste still landfilled in many Member States – and building on it to move beyond a waste management sector characterised by 'collect and dispose' operations. Two key challenges for the future are: (a) reduce levels of waste generation and (b) align waste management objectives with those of the circular economy.

As regards challenge (a), the environmental benefits of avoiding waste clearly far exceed the environmental impacts of any other waste management options. However, per capita municipal waste generation is still increasing in around one-third of all Member States and while almost all Member States have developed some type of policy toward prevention – two-thirds of policy instruments focus on information and awareness raising – most of these focus on households and neglect other sectors. Expanded and strengthened policies are a key priority for reducing environmental burden and reaching the overarching aims of a resource-efficient economy.

As regards the second challenge (b), the development of a circular economy will require high-quality, secondary raw materials that can be fed back into production processes. In this sense, the waste management sector will have to become a key partner in building new business models that focus both on waste prevention and turning waste into a resource. The Circular Economy Action Plan looks at how to integrate circular thinking into different stages of the life cycle (in particular in production-oriented policy instruments) and provides a much more concrete proposal for changed regulations on waste treatments with specific targets and objectives set for five waste streams: municipal waste, packaging waste, food waste, bio-waste and critical raw materials. How these waste streams could play a role in the transition to a circular economy is the central focus of this study.

Municipal waste makes up less than 10 per cent of total waste generated in the EU (construction followed by mining and quarrying comprise more than 60 per cent of annual waste generation), but it is one of the most polluting waste streams, with high potential for improvement. On average, EU citizens generated 486 kilograms per person in 2012. Member States with higher levels of GDP generally generated above average levels of waste, but also have more advanced waste management processes.

For example, around one-third of municipal waste was sent to landfill in 2012 in the EU. While 6 Member States have already met the landfill target for 2030 (no more than 10 per cent of municipal waste landfilled), half of Member States still have landfill rates over 50 per cent. The challenges for those countries characterised by high levels of landfilling will be to (a) implement waste separation, collection and sorting systems; (b) to build-up the required infrastructures; as well as to (c) develop the processes, technologies and secondary markets for recycling streams that are economically and environmentally viable over the long term. There is a strong correlation between a reduction in landfilling and landfill taxes and bans. At the same time, landfill bans may also have contributed to shifting waste, especially plastic, from landfills to incinerators.

Denmark, Sweden, the Netherlands, Belgium and France each incinerate over 35 per cent of municipal waste generation (with Sweden and Denmark both having a capacity of 100 per cent or more of municipal waste generation). This means that in order to reach the circular economy recycling target of 65 per cent recycling of municipal waste, they will have to divert waste streams from incineration to recycling. The challenges for these countries will be (a) how to align the objectives of greater recycling volumes with the need to honour long-term commercial contracts with incinerator operations; (b) how to respond to the role that waste-to-energy has taken as part of national energy strategies for reducing GHG emissions and also toward increasing energy security (as intended for example in Poland); whilst at the same time (c) focusing on waste prevention. It should be noted that inter-EU trading of waste has emerged to fill incinerator capacities (e.g. around 1.2 million tonnes of the waste incinerated in Denmark, which has a capacity of 4.2 million tonnes, was imported, mainly from the UK and Ireland). Experiences with trading may be built on to develop an EU-wide integrated infrastructure for recycling at the economies of scale needed for high-value, low-volume waste streams (like critical raw materials).

In 2012, 33 per cent of plastic packaging from households and 37 per cent from industry was recycled. Wood packaging is a particularly challenging waste stream. Ireland has the highest level of wood waste recycling, in part due to both an extended producer responsibility scheme and a 'polluter pays' initiative, as well as low current capacities for waste-to-energy.

Household food waste equates to 11 per cent of total municipal waste. Preventing avoidable food waste from being generated could therefore have a major impact on waste collection systems and on the capacity of bio-waste management facilities in Member States. It is estimated that nearly 60 per cent of the 88 million tonnes of food waste generated in the EU-28 in 2012 was avoidable, and that households generate the highest share of food waste (around 53 per cent).

Critical raw materials (CRMs) are a new focus for waste policy. CRMs do not typically generate high volume waste streams, however they are significant when considering issues of value-added and material security, especially as the EU relies heavily on imports of many CRMs. Potential revenues from e-waste recycling are estimated at €2 billion in Europe. Waste electrical and electronic equipment (WEEE) is currently one of the fastest growing waste streams in the EU (growing at 3 to 5 per cent per year). While the potential for re-use, repair and remanufacturing are judged as high, in practice a lack of legislation encouraging and enforcing re-use has led to little progress toward mainstreaming. For example, while the repair of computers and personal and household goods has increased around 14 per cent between 2011 and 2014 in the EU as a whole, it accounted for just 0.3 per cent of non-financial business economy value added in the Czech Republic and France — the highest shares among any of the Member States.

High-level recycling is particularly relevant for retaining critical raw materials contained in WEEE waste streams within the economy. Volume-based targets may inadvertently encourage the uptake of low-quality recycling, or downcycling of e.g. contaminated mixed household waste, if not complemented by additional legislation. While the goal of the circular economy transition is to maximise the 'value' of materials retained within the economy, efforts toward achievement of current targets may lead to investments toward processing high volumes of waste, but with low value. This could also be the case when treating bio-waste, where the production of bio-energy is a high-volume, low-value option and e.g. bio-chemicals a low-volume, high-value option.

This implies that significant investment is required to enable waste segregation, which is the first step in moving away from landfilling and incineration toward recovery and recycling. Technologies for sorting mixed municipal waste do exist, but are not as effective as citizen separation. For example, mechanical biological treatment (MBT) enables recovery of certain metals and other resources and is able to divert some portions of waste to recycling (e.g. 34 per cent of MBT in Italy is recovered for recycling), to composting (e.g. 23 per cent in Italy), and energy (e.g. 10 per cent in Italy). Nevertheless around 24 per cent of MBT treated municipal waste ends up in landfills in Italy. MBT treated waste streams are of lower quality than separate collection, and moreover, citizens may lack incentives to prevent and sort waste if they know MBT is applied. Research has shown that citizen engagement has been key to success stories toward prevention and recovery.

For example, Ljubljana, Slovenia was declared the European Green Capital for 2016 and the first European capital to move towards zero waste. This reflects the trend in Slovenia toward greater shares of recycling, in particular made possible by separate collection of municipal waste. Despite some original citizen opposition – countered by strong awareness campaigns – Slovenia is a country where at least 70 per cent of the respondents sort eight types of waste. Other types of citizen engagement in the circular economy are emerging. In the EU as a whole between around 10 and 40 per cent of respondents to a 2013 survey had already engaged in some form of circular economy practices. The types of activities citizens engage in are quite varied in different Member States: sharing schemes seem quite prevalent in Finland and Latvia, leasing is most popular in Belgium and buying a remanufactured product is by far the most prevalent form of 'alternate' consumption in Germany and the UK.

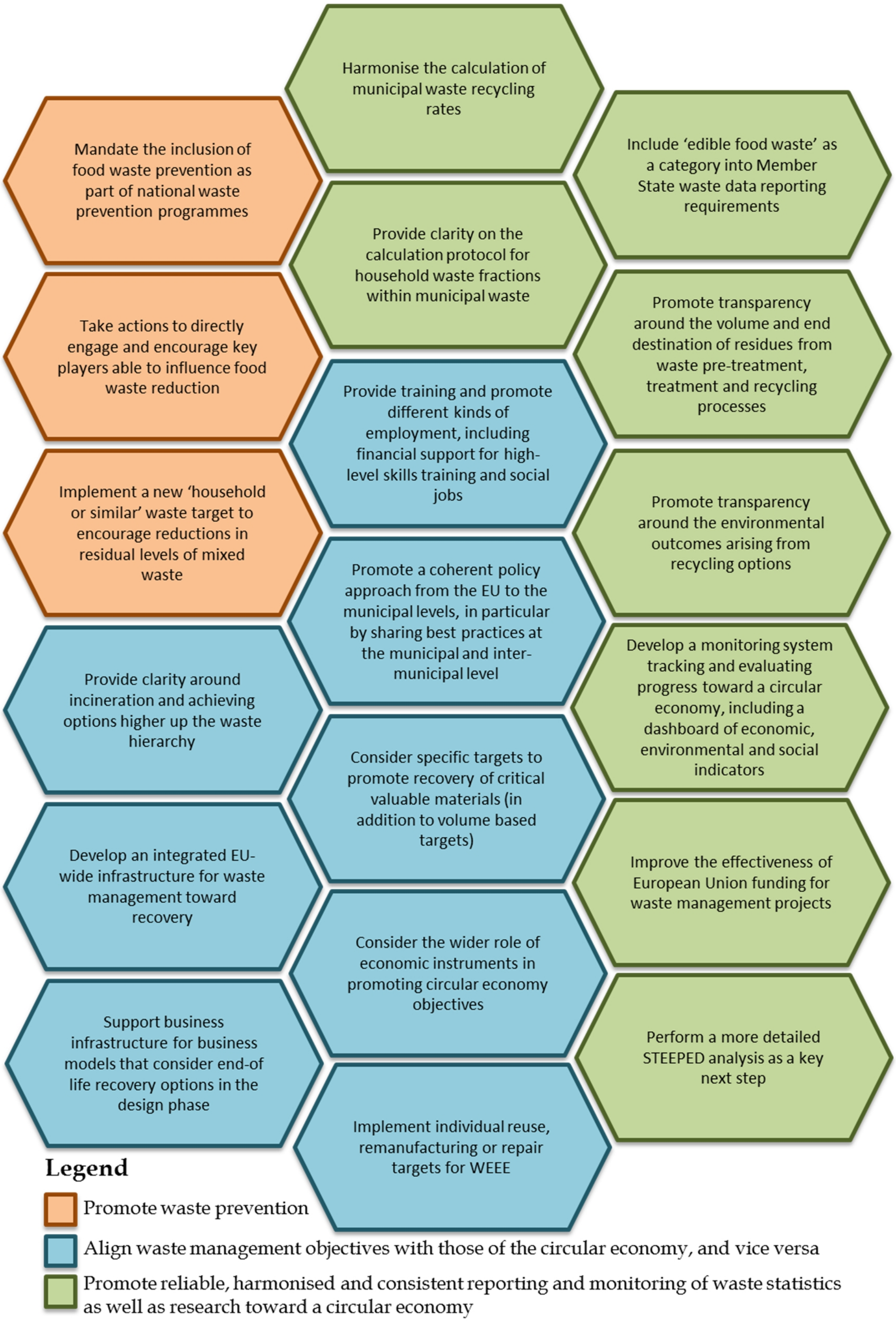
The transition to more circular systems of production and consumption will inevitably impact both the numbers of people employed in the sector – and their skill sets. 'Repair' activities account for nearly half of all people employed in the circular economy, in particular as they are labour intensive. Indeed, thousands of social enterprises across Europe have been active in the repair sector for many years, providing job and training opportunities for disadvantaged workers and giving them a fresh start on the labour market. Flanders is an excellent example of the potential to scale-up re-use with social benefits; the turnover in re-use shops has nearly quadrupled in Flanders between 2001 and 2012, indicating growth in the sector that is a win-win-win for people, business and the environment. Nevertheless, the literature points to jobs in the repair sector that are in decline, in particular due to increasing obstacles and costs to re-use and repair. This trend should be reversed. Overall, it is estimated that the implementation of existing legislation on waste prevention and management could create more than 400 000 new jobs. To avert skill bottlenecks that may delay the development of new value chains or the deployment of new technologies, it is essential to strengthen education and training that focus on short and long run strategies.

High levels of variation within Member States may present additional challenges. For example, Portugal has a variation of share of waste sent to landfill between regions of 86.2 per cent. Narrowing the gap between different regions may not be straightforward, in particular as good practices may be difficult to replicate due to different socio-economic conditions, e.g. technical and economic feasibility of recycling may be easier in urban areas. This implies the need for greater harmonisation in cascading European legislation and best practices down to the municipal and inter-municipal levels. Altogether a circular economy may have a different flavour in every European city and region, depending on geographic, environmental, economic, or social factors. The European Regional Development Fund and the Cohesion Fund could be used more effectively to support circular economy efforts.

More robust regional data would enable stronger monitoring and more targeted direction of such funds. This is indicative of the greater need to develop more reliable, consistent and harmonised data also at the Member State level. Challenge relates both to inconsistency in definitions and measurement methods, including how target attainment is measured. Monitoring of the circular economy is at an even less advanced stage. As a circular economy shall promote sourcing of resource inputs from secondary (recycled) sources, measuring the inputs of primary resource consumption as well is critical. This also reflects the need to measure activities further up the production chain, from the design phase to use, re-use, repair and remanufacturing, which move beyond one-time studies and surveys. Policy makers may provide stronger clarity on definitions as well as support further research toward development of a monitoring system including future modelling assessments taking wider social, environmental and economic indicators into account.

Finally, Figure 0 summarises the key policy options developed within this report. These are generally grouped according to the challenges they address and depict key policy actions toward increasing the sustainability of the EU waste sector for people, business and the environment.

Figure 0: Policy options presented in this report



1. Introduction

This report examines waste management in the European Union (EU) in the context of a circular economy transition. Chapter 1 presents the challenges for waste management, especially related to the high amounts of waste generated in EU Member States. It argues that maximising synergies between waste management and circular economy – in particular in the way waste is defined, collected and managed – are key to raising resource efficiency with co-benefits for job creation, especially for those in need of work, and economic prosperity.

1.1. Waste management – what is the challenge?

The European economy is largely linear by design, resulting in avoidable environmental and human health impacts, inefficient use of natural resources and over-dependency on resources from outside Europe. Moving to a circular economy would alleviate these pressures and concerns, and deliver economic, social and environmental benefits (EEA, 2017). In the past the creation of waste in connection with production and consumption was accepted as a necessary evil. Today, that apparent common sense is increasingly being challenged: circular economy, zero waste, closed-cycle, resource efficiency, waste avoidance, re-use, recycling – all these terms can be attributed to the ideal of achieving a world largely without waste, and instead one with a responsible attitude to resources, materials, products and the environment. However, it will require a comprehensive holistic concept to actually ensure that approaches like avoidance, re-use and recycling are taken into account in every stage of the product life cycle and at the level of materials and energy – with environmental product design applied from the very outset to permit recycling at the end of the product life cycle (Wilts 2016).

Currently, the side effect of an economy with high GDP is large volumes of waste per capita. Thus the decoupling of waste production and related impacts from economic growth is critical to a transition to a circular economy UNEP (2011b). Environmentally sound waste management has been a cornerstone of European policies from the beginning and significant progress has been achieved regarding the reduction of impacts from waste generation to the environment and human health. Extensive technical regulations, focused and massive investments in waste treatment infrastructures like sanitary landfills, waste incineration plants, as well as sorting and recovery facilities for specific waste streams have led to a situation where in many countries waste is now managed in a reliable and environmentally sound way. Of course there is still a lot to be done e.g. with regard to the amount of waste that is still disposed of without any prior treatment (EEA, 2015).

Traditionally, with the exception of certain high value waste streams, the European waste management sector could be described as a ‘collect and dispose’ operation; collecting mixed waste streams from municipal and commercial sources and disposing of the waste to landfill or through incineration. Nevertheless it is becoming more and more obvious that waste management in a circular economy will have to go beyond such an end-of-pipe approach that simply focuses on ‘cleaning up the mess’ after the production and use phase: waste management will have to become an integral part of a circular economy, closely linked to patterns of production and consumption. Circular product design will require feedback from the waste management sector how products or components could be remanufactured, dismantled and recycled. The waste management sector will have to become a crucial partner in new business models that focus on waste prevention and of course the waste management sector will have to ‘turn waste into resources’ (EC, 2015): Instead of predominantly seeing waste as a threat the waste management sector, in close cooperation with industry, will have to produce high-quality secondary raw materials that can be fed back into production processes.

In this sense seeing waste as a resource – where benefits could come from high-quality recycling as well as from less waste – will require nothing less than a fundamental transformation of one of the key technical infrastructures that predetermine a large share of our current industrial metabolism and has been optimised for centuries with the purpose of reducing direct threats to human health and the environment: e.g. the first waste incineration facility in Germany was built in 1896 in the city of Hamburg – not to produce, but following the last great outbreak of cholera. The idea was to get rid of waste in a more reliable way.

Today, waste management will have to expand the perspective and take into account resource requirements linked to our patterns of production and consumption alongside the whole value chain (SRU, 2016). The environmental benefits of avoiding waste clearly far outweigh the environmental impacts of any other waste management option lower down on the waste hierarchy. As an example, the following table highlights the greenhouse gas emissions avoided through waste prevention when compared with recycling.

Table 1: GHG emissions avoided per tonne of different types of waste avoided or recycled (kgCO_2e per tonne)

End fate	Glass	Board	Wrapping paper	Dense plastic	Plastic film	Metals
Avoided	920	1,600	1,510	3,320	2,630	12 000
Recycled	390	1 080	990	1,200	1 080	3,300

Source: European Commission, 2016i

Indirect but clearly increasingly important impacts of resource consumption will have to become a key driver of future waste management. It is clear that waste management policy or the waste management sector are not responsible for the waste generation – that is a decision for companies and households – but they could play a key role in an overall transformation towards a resource efficient circular economy.

1.2. Waste management in the circular economy

This transformation has to go beyond waste management and has to be embedded into a wider framework – the circular economy. The need to transition to a more circular economy is recognised as an essential element in developing a sustainable, low carbon, resource efficient and competitive economy. Using the concepts of circularity helps progression towards a sustainable future.

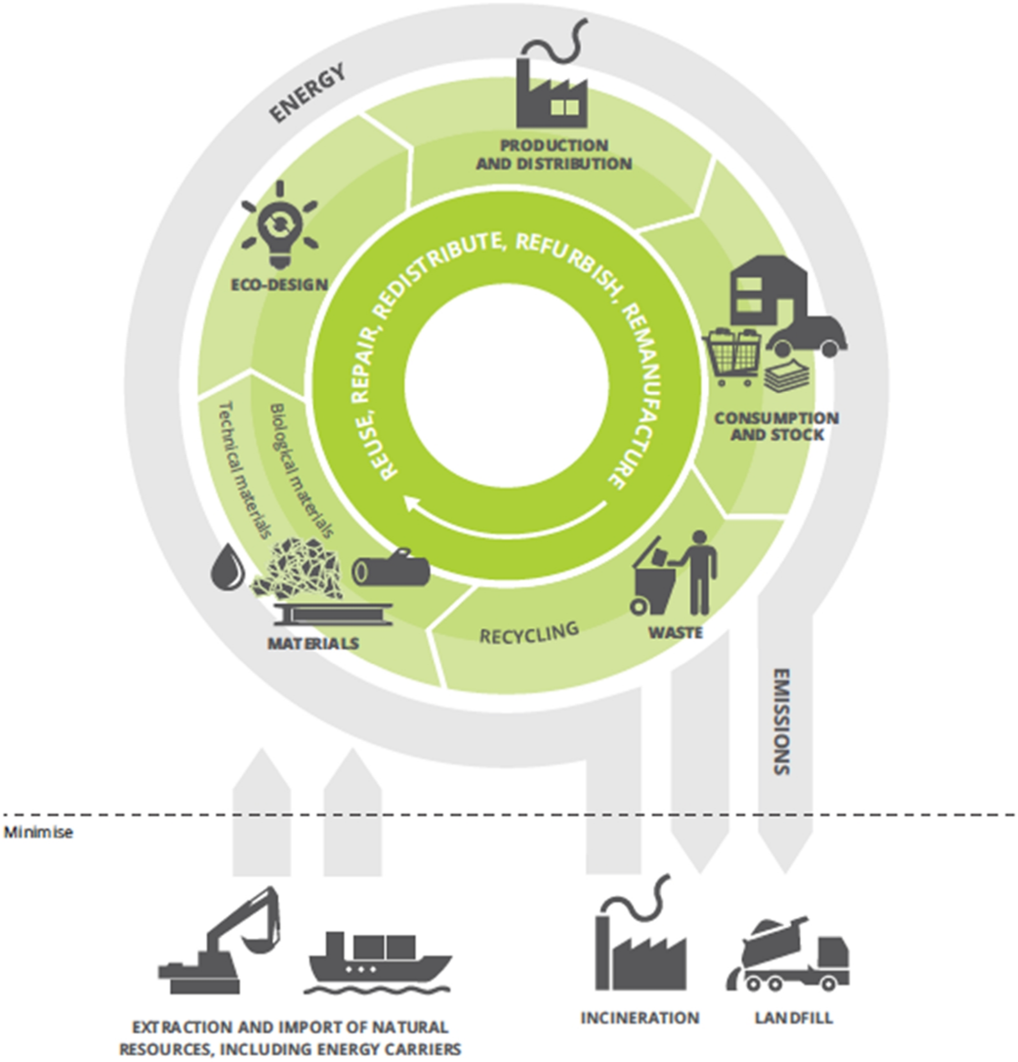
As outlined above, our current modes of production and consumption remain overwhelmingly based on the linear principle. Resources are extracted, processed, used, and ultimately for the most part discarded as waste. At the end of such a cycle, waste is typically disposed of by incineration (thermal utilisation) or landfill. In both cases materials are withdrawn from circulation or destroyed (even if thermal utilisation does at least produce energy). In 2012, the 28 Member States:

- consumed 5 billion tonnes of material of which 80 per cent (4 billion tonnes) came from virgin materials and only 20 per cent (1 billion tonnes) came from secondary raw materials recovered from the waste stream (WRAP, 2015) – giving a recirculation rate of 20 per cent.
- disposed of 2.5 billion tonnes of waste, 42 per cent (1.2 billion tonnes) went to landfill

However, such a linear economic model can only function if limitless resources are available to satisfy endless demand. Global demand is growing steadily, while the availability of both non-renewable and renewable raw materials is finite. A strictly linear economy will inevitably encounter limits.

Central to the circular economy concept is the notion that the value of materials and products is kept as high as possible for as long as possible. This helps to minimise the need for the input of new material and energy, thereby reducing environmental pressure linked to the life-cycle of products, from resource extraction, through production and use to end-of-life. Figure 1 presents a simplified figure of such a circular economy.

Figure 1: The circular economy concept



Source: EEA, 2015

The concept covers all aspects of economic activity, from resource extraction through production, storage and consumption, ending with disposal or ideally recycling. The **reduce, re-use** and **recycle** approach goes a long way towards this concept, although waste avoidance is prioritised (European Commission, 2014). The idea is to close cycles to turn waste back into a resource (in this connection we also speak of 'second-sourcing'). But if this idea is to be put into practice as effectively as possible, another earlier step is needed: to take account of later recycling already at the design stage.

The fundamental idea of the circular economy has given rise to various currents and variants featuring smaller or larger differences in concept, approach and scope. These include the circular economy of the Ellen Mac Arthur Foundation, the blue economy concept, cradle-to-cradle, and zero waste (the differences lie principally in the roles of bio-based cycles and renewable energy).

STOA has an overarching vision: sufficient resources for a world with 10 billion people by 2050. Both minimising the production of waste, and then extracting maximum value from what might have traditionally been considered waste, are key pillars in ensuring there are sufficient resources. This becomes all the more significant against a backdrop of resource scarcity (or a lack of access to resources through geographical and political factors), price volatility and population growth.

1.3. The objectives and scope of this study

Against this background the focus of this study is the current and future role of waste management in the EU's progress towards a more circular economy. The objectives of this study are to:

- provide an overview of the EU policies in place to promote a circular economy transition and manage waste, considering also how Member States are currently performing;
- review different waste treatment options for specific waste streams – with a focus on municipal waste - and analyse current trends as regards Member State performance as well as the state of technologies;
- assess co-benefits and trade-offs for job creation;
- suggest policy options for strengthening waste management toward circular economy objectives.

To this end, this report applies a number of methods. For general analysis it relies on an extensive literature review as well as stakeholder interviews – a list of participants who took part in the interview process can be found in Annex 1. Data analysis is undertaken based, in the most part, on Eurostat statistics, and supplemented by data presented in specific studies and EU projects. Trends are assessed at the macro level of Member States – e.g. comparing Member State performance and the current state of technology development. Case studies also offer a more detailed analysis of particular waste treatment options in specific Member States. Policy options are drawn from conclusions of the analysis as well as recommendations given in key literature sources.

This study focuses on five key waste streams. These waste streams were selected as they are distinguished within the European Commission's proposed Circular Economy Package with specific targets and objectives. They are classified as:

- Municipal waste, e.g. from households
- Packaging waste
- Food waste
- Bio-waste and residues
- Critical raw materials (CRMs)

Chapter 2 describes the current policy framework for the management but also prevention of these waste streams. It also provides more detail on the overarching circular economy policy framework. Current performance and key trends are analysed for each of these waste streams at the EU and Member State level, in addition to progress toward development of a circular economy (Chapter 3). Chapter 4 assesses key waste management technologies while Chapter 5 focuses on employment performance and opportunities, in particular in the circular economy. Chapter 6 presents case studies delving deeper into waste-to-energy incineration (in Denmark), mechanical biological treatment (in Italy) and sorted collection (in Slovenia). The concluding Chapter 7 draws conclusions with regard to potential policy options.

Box 1: Key findings and messages from Chapter 1

- The transition towards a circular economy will be key for Europe´s competitiveness but also long-term sustainability.
- Waste management will have to play a key role in this transition. It needs to become an integral part of a circular economy that contributes to waste prevention and the supply of high-quality secondary resources.
- This report focuses on the priority waste streams indicated in the European Commission´s Circular Economy Action Plan.

2. The current policy framework

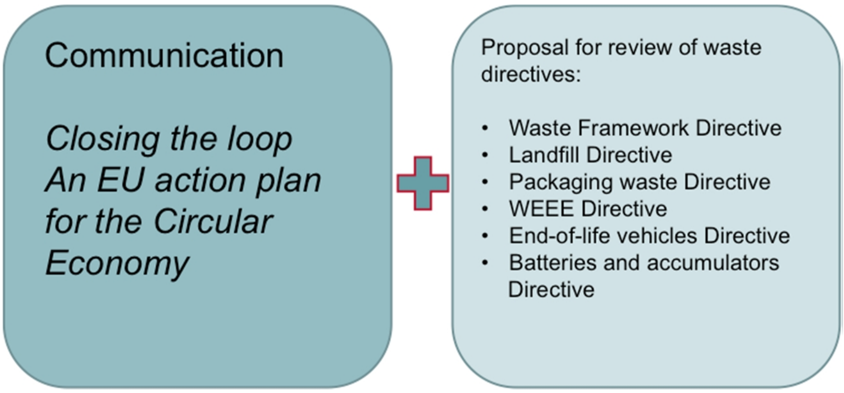
Looking at the potential positive benefits of a circular economy, the key question is: what kind of policy framework would enable and support such a radical transformation from a linear towards a circular system. This question is especially high on the agenda of the European Commission. In 2015 the Commission published its Circular Economy Action Plan, which set the ambitious objective of treating waste as a resource by year 2020 and turning the European economy into a circular economy (European Commission 2015). The objectives are in line with the strategic direction for EU environmental policy outlined by the 7th Environmental Action Programme (EAP, adopted in 2013). In setting the vision for 2050, it mentions a 'circular economy where nothing is wasted and where natural resources are managed sustainably'.

This chapter begins by looking in more detail at the overarching policy framework for a circular economy. It briefly presents policy instruments and then examines the current state of policy for each of the five waste streams identified in the Circular Economy Action Plan. In addition, waste water, as well as the coherence of waste policy from the municipal to national level, are assessed.

2.1. The policy framework for a circular economy

The Circular Economy Action Plan comprises various legislative proposals and measures in the areas of production (product design and production processes), consumption and waste management, as well as concrete targets for creating an ambitious long-term roadmap for waste management and recycling in Europe. As illustrated in Figure 2, the action plan can be divided into two key elements: a communication on how to integrate circular thinking into different stages of the life cycle and a much more specific proposal for changed regulations on waste treatments. Although circular economy of course goes beyond waste management, the European Commission also acknowledges that waste infrastructures are a crucial element for reducing linear patterns of production and consumption.

Figure 2: The key elements of the European Commission´s Circular Economy Action Plan



The key objective of the legislative proposal to amend current waste regulations is to set incentives for the waste sector to no longer consider waste primarily as a threat but as a potential source of future secondary resources. Against this background, the review includes the following key aspects:

- Align definitions and reporting methods;
- Increase targets for municipal waste;
- Increase targets for packaging waste;
- Limit the landfilling of municipal waste;

- New measures to promote prevention, including for food waste, and re-use;
- Minimum conditions for Extended Producer Responsibility;
- Early Warning System for monitoring compliance with the targets;
- Simplify reporting obligations.

In relation to the waste streams and waste prevention covered within this study there are quantitative and qualitative targets, as presented in Box 2.

Box 2: Targets set out in the proposal of relevance to this study

Three quantitative targets:

- A binding landfill target to reduce landfill to a maximum of 10 per cent of **municipal waste** by 2030;
- A target to prepare 65 per cent of **municipal waste** for re-use and recycling by 2030; and
- A target to prepare 75 per cent of packaging waste for re-use and recycling by 2030 (with supplementary targets for specific packaging material).

Four qualitative targets:

- Waste prevention programmes
- To develop a common EU methodology to measure **food waste** and define relevant indicators
- To promote an efficient use of **bio-based resources** through a series of measures, such as guidance and dissemination of best practices of the cascading use of biomass and support for innovation in the bio-economy within the field of clean technology bio-waste and residues.
- To take action to encourage recovery of **critical raw materials**, and prepare a report on best practices and options for further action at the EU level.

The Action Plan comprises a variety of measures to strengthen the implementation of the circular economy in the EU Member States that go beyond traditional waste management policies. As a policy innovation, the circular economy links waste management with production, consumption, and general policy frameworks, e.g. in the field of production oriented policy instruments*:*

- Support for eco-design of products
- Addressing planned obsolescence
- Support for SMEs

The European Commission´s Action Plan not only addresses the production phase but also aims to influence consumer behaviour, especially by providing reliable information for households so that they can benefit from the cost saving potentials of a circular economy, e.g. by:

- Strengthening re-use and remanufacturing
- Green Public Procurement

In addition to policy approaches that directly target activities in the spheres of production or consumption; the overall policy framework will also be of crucial importance for the transition towards a circular economy. The European Commission specifically addresses financing opportunities as a key framework condition.

2.2. Policy instruments in the current waste management sector

One of the key challenges for a circular economy policy framework will be its integration with the existing waste management approaches in the Member States and regions. Considering aspirations established in the 7th and in previous EAP's, the current landscape of policy instruments used to manage waste is complex. Table 2 summarises the various instruments used at EU wide, regional and national levels.

Table 2 Examples of policy instruments used to manage waste

Policy instrument	Examples used to manage waste
Legislation	Directives and regulations used to: • set targets for and reporting requirements for individual waste streams (e.g. recycling targets and landfill reduction targets) • establish extended producer responsibility schemes • establish economic instruments • encourage improved eco-design
Economic incentives	Investment in waste collection infrastructure supported through the Cohesion Fund, funding for R&D and innovation (e.g. Horizon 2020),
Market based instruments	Landfill tax and gate fees, incineration tax and fees, plastic bag taxes; Pay As You Throw (PAYT) schemes
Information requirements	Consumer recycling information on packaging, voluntary reporting of waste production and target setting by companies
Voluntary tools	Awareness raising campaigns for the public, voluntary industry commitments, product design and labelling (e.g. through the EU Ecolabel) provision of good practice information, business led initiatives

European Union directives and regulations have set the context for many of the other transpositional policy instruments to be implemented, and could therefore be considered the most significant drivers in the changes seen in waste management across Europe. The general framework for waste management within the EU is provided by the Council Directive 2008/98/EC on waste (the Waste Framework Directive). Of relevance to all the waste streams covered by this report, the Waste Framework Directive:

- established the waste hierarchy as key to making waste management decisions;
- sets out the basic waste management definitions including for when a by-product is not waste and the end-of-waste status;
- requires Member States to take necessary measures to recover, re-use and recycle waste, which includes the separation, where feasible, of waste streams;
- controls hazardous waste through a ban on the mixing of hazardous waste, with the exception of household waste;
- establishes principles such as polluter pays and extended producer responsibility (EPR)

Details of the main EU directives and regulations currently influencing waste prevention and the management of the five key waste streams forming the focus of this study are shown in Table 3. Key points of the policies in the context of this study follow below.

Table 3: Summary of the main influencing EU directives and regulations relating to waste management and the circular economy

	Waste prevention	Municipal waste	Packaging waste	Food waste	Bio-waste and residues	Critical raw materials
Waste Framework Directive 2008/98/EC	X	X	X	X	X	X
Landfill Directive 99/31/EC		X	X	X	X	X
Packaging and Packaging Waste Directive 94/62/EC	X		X			
The Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU						X
Batteries and accumulators and waste batteries and accumulators Directive 2006/66/EC						X

This is not a comprehensive analysis of all waste management directives. A number of other directives and regulations impact on waste management, such as the Eco-design Directive, Waste Shipment Regulation and the Fertiliser Regulation, but we focus here on those directives considered of most relevance to the proposed circular economy package.

2.3. Waste prevention

Waste prevention has been established as a priority through the Waste Framework Directive and its promotion of the waste hierarchy (with reduction as the top priority). The Waste Framework Directive required Member States to establish waste prevention schemes by December 2013. Flexibility is provided within the Directive regarding the nature of the programmes, however it does require that objectives are set, and that qualitative or quantitative indicators are introduced.

In 2015, the European Environment Agency (EEA) undertook a review of the first 27 waste prevention programmes. The reviewed programmes cover a variety of sectors (see Table 4). General conclusions are that (EEA, 2015):

- all programmes cover the household sector;
- all programmes, except Northern Ireland, cover the public services sector and all programmes, except Bulgaria and Latvia, cover the construction/infrastructure sector;
- most programmes cover private service activities/hospitality, manufacturing, and the sale, retail and transport sectors;
- programmes in France, Germany, Hungary, Ireland, Italy, Lithuania, the Netherlands, Poland, Scotland, Spain and Sweden include the agriculture sector. Agriculture is mainly mentioned in the context of preventing food waste;
- ten programmes, those in the Czech Republic, Estonia, Finland, France, Germany, the Netherlands, Poland, Scotland, Slovakia and Spain, include mining and raw material processing.

Table 4: Scope of the waste prevention programmes by sector

	Austria	Brussels *	Bulgaria	Czech Republic	England *	Estonia	Finland	Flanders*	France	Germany	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Northern Ireland *	Norway	Poland	Portugal	Scotland *	Slovakia	Spain	Sweden	Wales *
Households (27)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Public services (26)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Construction/infrastructure (25)	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Manufacturing (24)	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X
Private service activities/hospitality (23)	X	X		X	X	X	X	X	X	X		X	X		X	X	X	X	X		X	X	X	X	X	X	X
Sale, retail, transport (23)	X		X		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
Agriculture (11)									X	X	X	X	X		X			X			X		X		X	X	
Mining, raw material processing (10)				X		X	X		X	X								X			X		X	X	X		

(Highlighted columns: France, Germany, Netherlands, Poland, Scotland *, Spain) All sectors covered.

Source: EEA, 2015
***Note:* * Refers to region**

Only six countries and regions (France, Germany, the Netherlands, Poland, Scotland and Spain) cover all the listed sectors. Stating that the programme covers a sector does not necessarily mean that specific initiatives or measures on waste prevention are included. For example, the number of waste prevention measures for the agriculture, and mining and raw material processing sectors is very low. Where not covered, the agriculture, and mining and raw material sectors may be dealt with in other policies and by other ministries.

The review revealed that countries and regions use a wide variety of indicators with 17 setting quantified targets, but with limited use of monitoring systems (EEA, 2015). Based on their specific context, countries and regions have chosen different key sectors, waste streams and policy approaches for the implementation of their programmes. Around two-thirds of policy instruments focus mainly on information and awareness-raising, with regulatory and economic instruments accounting for only around one-third.

The EEA reviews of progress in Europe in 2013 and 2014 highlighted a clear need to improve on the implementation of waste prevention measures. The European Court of Auditors (2012) reported similar findings, stating that the EU Waste Framework Directive's targets do not adequately focus on waste prevention, even though prevention is the first management option according to the waste hierarchy.

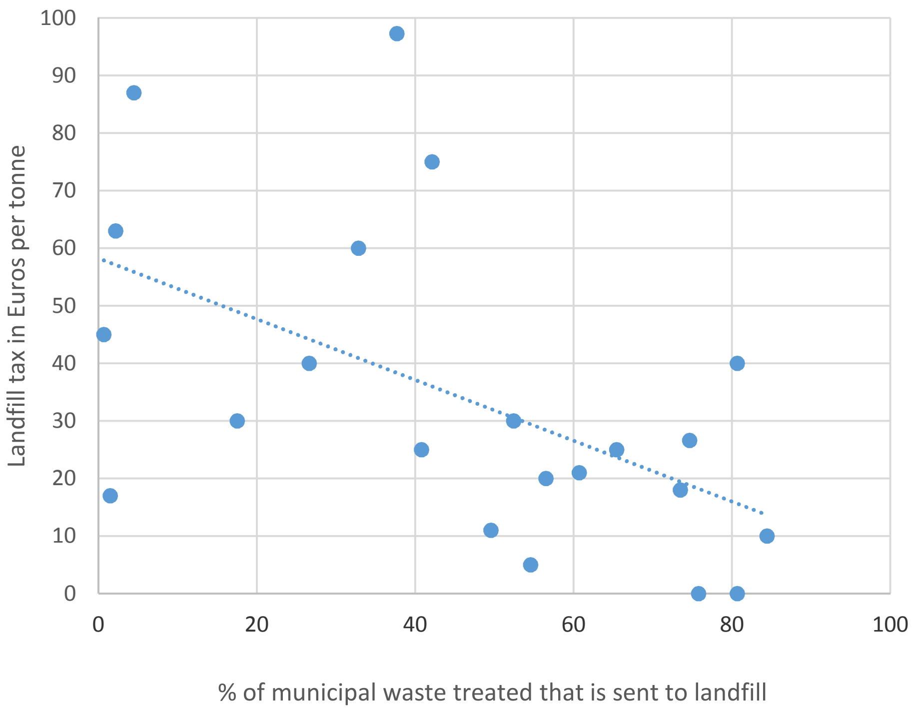
2.4. Municipal waste

As defined within the Landfill Directive, municipal waste means waste from households, as well as other waste which, because of its nature or composition, is similar to waste from households.

The mixed and dispersed nature of municipal waste typically make it difficult to treat. In relation to the waste hierarchy therefore, traditionally the options have been limited to landfilling and, in recent decades, incineration. The Landfill Directive therefore represents the most significant piece of European legislation in relation to municipal waste. The requirement for Member States to set up national strategies to reduce the amount of biodegradable municipal waste going to landfill to tackle the high levels of methane gas being discharged to atmosphere from landfills was noteworthy in this respect. Targets for 5, 8 and 15 year timeframes were set.

Member States were given flexibility in how to achieve these targets. Many of the EU-28 MS introduced a landfill tax as a means of diverting waste from landfill, to meet the requirements of the Landfill Directive, with a few Member States implementing a landfill ban. Considerable variation exists in the value of landfill tax between Member States. Figure 3 shows the correlation between landfill tax and landfilling, with a clear pattern of high levels of landfill corresponding to low landfill tax.

Figure 3: A comparison of landfill gate fees and tax across EU Member States



Source: EEA, 2013

2.5. Packaging and packaging waste

The objective of the European Parliament and Council Directive 94/62/EC on packaging and packaging waste (the Packaging Directive) aims to limit the production of packaging waste and promote the waste hierarchy for packaging waste. The Packaging Directive established targets, and therefore collection schemes, for the recovery of packaging materials. Incineration with energy recovery was permitted and was considered as contributing to the realisation of the targets. By 2009, 25 Member States had developed extended producer responsibility (EPR) schemes (IEEP, 2009).

The Packaging Directive (Annex ii of the directive) also had provisions on packaging prevention with measures aimed at limiting the production of packaging waste. However, these have been difficult to implement due to the absence of clear indicators (European Commission, 2014a). Waste prevention is at the very 'top' of the waste hierarchy but, in the case of packaging, the market share of reusable household packaging is decreasing. This is seen as a trend that may favour the smooth functioning of the EU's internal market for packaging under the EU Treaty governing the free movement of goods and competition, rather than national re-use systems that in some instances pose a problem to the internal market regulations through limiting movement of packaging (the second of the Packaging Directive objectives) (EIMPACK, 2011).

The European Commission report (2014c) stated that the circular economy concept is not considered 'fully developed' within the Packaging Directive as there is no focus on re-use and minimisation, although the conclusion is that the directive has undoubtedly proved to be an effective instrument of European waste policy. The implementation of EPR schemes, coupled with the use of economic instruments (landfill taxes, bans, PAYT schemes) has been a particularly effective approach to meeting the packaging recycling and recovery targets (BIOIS, 2011). However, it is reported that to date legislation has only considered quantitative aspects of recycling and that a more qualitative approach may be required to ensure the increased recycling rates are not met through the downcycling of contaminated mixed household packaging waste (European Commission, 2014a). It might be that close investigation is needed to be certain that the headline figures meet the aspirations of the circular economy. Clearly, this is highly relevant to the 'value' driven concept of the Circular Economy Package.

2.6. Food waste

Actions on food waste are currently managed to enable Member States to meet the targets of the Waste Framework Directive, specifically to make reductions to the volume of biodegradable waste entering landfill, as required by the Landfill Directive. These objectives have been achieved through the development of collection schemes for mixed biodegradable (including food waste) and finding alternative waste management routes, including composting, anaerobic digestion and incineration.

Food waste prevention has been the focus of a number of national initiatives, examples of which are provided in Box 3. However, it is widely acknowledged that more needs to be done to reduce food waste.

Box 3: Examples of voluntary food waste prevention national initiatives

United Kingdom

The voluntary '**Love Food Hate Waste**' campaign in the UK, led by sustainability charity WRAP, equips local authorities and the public with key knowledge and practical advice to reduce food waste at consumer level. The campaign promotes behavioural change across five hotspot areas which typically lead to food waste, including: planning, portions, date labels, leftovers and forgotten foods and storage (WRAP, 2016). It resulted in a 21 per cent reduction in the amount of food being wasted since 2007.

Spain

'**More Food Less Waste**' (2016) was set up by the Spanish Ministry of Agriculture, Food and Environment with EU-wide reduction targets in mind. Another policy driver was the need to reduce Spain's national food waste level, with Spain having been identified as one of the larger Member State contributors to food waste in Europe (Live Well for Life, 2014). The private sector endorsed the strategy, notably through the support of one of its industry representatives, Spanish manufacturing and distribution association AECOC, and, as a result, the major members declared their commitment to the objectives outlined in the waste reduction strategy.

The European Commission has set up a dedicated Expert Working Group on Food Losses and Food Waste with the following task:

'[To] provide advice and expertise to the Commission and Member States to prepare possible policy initiatives and improve the coherent implementation of existing EU legislation, programmes and policies with respect to food waste prevention. Facilities sharing of learning and best practice related to food waste prevention.'

A target for the Working Group is to support the halving of food waste by 2050 through measures that aim to 'prevent food waste in primary production, in processing and manufacturing, in retail and other distribution of food, in restaurants and food services as well as in households'. Delivering this will require Member States to establish food waste prevention measures and to establish uniform methodologies for measurement.

The target to reduce food waste fits with Goal 12 of the United Nations 2030 Agenda for Sustainable Development, to Ensure Sustainable Consumption and Production Patterns. This includes a commitment to halve per capita global food waste.

STOA (2013) reports that a target of halving worldwide food loss was first made at the World Food Summit in 1974 when losses were estimated at 15 per cent. The 1974 target was to halve food loss by 1985. Unfortunately, despite initial efforts to agree common goals, the issue was said to quickly disappear from the political agenda. Attempts to resurrect the initiative in the late 1990s were hampered by a lack of new data.

2.7. Bio-waste and residues

Bio-waste and residues includes not only food waste as discussed above, but also, for example agricultural, forestry, marine and animal derived residues. Whilst historically disposal of some of these waste streams has been considered a challenge, with the aid of new technologies and tackling market barriers in the take up of well-established technologies, these waste streams are being rethought within the context of a more circular economy, with waste streams re-categorised as either feedstock, raw materials or energy.

These waste streams have not been covered specifically within European legislation, except for food waste, in terms of targets for separation and reduction. However, it is covered through the broad requirement to divert biodegradable waste from landfill, and so is impacted by the relevant policies and requirements, such as landfill taxes. The European Environment Agency (2013) reported that although significant progress had been achieved in the recycling of technical nutrients the same could not be said for biological nutrients

However, this area has become a focus for research and development (R&D). The bio-economy is a theme within the European Commission's Research and Innovation programme. The EU is providing R&D funding for the emerging EU bio-economy sector through the Bio-Based Industries (BBI) public-private partnership. The BBI's funding calls for proposals aim to accelerate 'the development of (new) sustainable value chains from biomass feedstock supply via efficient processing, to acceptance and application of bio-based products in the end-markets' (BBI, 2016). In other words, it will create realistic secondary markets and value chains, help reach critical mass and high technology readiness level (TRL), de-risk investment and pool resources. For the period 2014-2020, the total number of Horizon 2020 funds allocated to this initiative is €3.7 billion, 25 per cent (€975 million) being provided by Horizon 2020, and 75 per cent (€2.7 billion) provided by industry. This includes €90 million of funding for calls for proposals related to bio-waste valorisation included in two flagship calls for funding proposals (European Commission, 2016c).

In April 2016 six 'model regions' were announced to lead the way towards sustainable chemistry within the EU. The objective of this focus was to channel EU efforts in promoting green chemistry with the aim of boosting cooperation between the chemicals sector and other sectors including agriculture, forestry and waste management (European Commission, 2016d).

The EU's proposed Circular Economy Package aims to promote an efficient use of bio-based resources, so will build on the work already underway.

2.8. Critical raw materials

Critical raw materials (CRMs) are a new focus for waste policy. CRM's do not typically generate high volume waste streams, however they are significant when considering issues of material security, since the EU relies heavily on imports of many CRM's. They are therefore of value and importance to the EU economy, to EU industrial jobs, and to sustained economic growth within the EU.

The European Commission report on critical raw materials (European Commission, 2014b) reports that, historically, the indispensable role of metals, minerals, rocks and biotic materials has had a low profile. However, more recently, securing reliable, sustainable and undistorted access to crucial non-energy raw materials has been of growing concern in economies such as those of the EU, USA and Japan.

The concentration of high value and 'critical' (in terms of supply security) materials in waste electrical and electronic equipment (WEEE) and certain types of end-of-life batteries makes them a particular target for increased recovery efforts. The EUs Raw Materials Initiative (EU RMI) aims to tackle the challenges of high dependency on imported materials and the security of supply of such materials. Using Horizon 2020 funds, the European Commission set up a stakeholder platform, the European Innovation Partnership on Raw Materials (EIP-RM), with specific targets for 2020 including: 'improving framework conditions for enhanced efficiency in material use and in waste prevention, re-use and recycling, and raw materials efficient product design'.

The action areas related to CRM waste management within the EIP-RM programme are:

- Product design for optimised use of (critical) raw materials and increased quality of recycling.
- Optimised waste flows for increased recycling.
- Prevention of illegal shipments of waste.
- Optimised material recovery.

The 2012/19/EU Waste Electrical and Electronic Equipment Directive and the 2006/66/EC Batteries and Accumulators and Waste Batteries and Accumulators Directive include requirements to assist the re-use and repair of equipment. This includes:

- WEEE Directive: calls for funding proposals to make sure that producers do not prevent, through specific design features of manufacturing processes, WEEE from being re-used;
- WEEE Directive: Member States shall take the necessary measures to ensure that producers provide information free of charge about preparation for re-use and treatment in respect of each type of new EEE;
- Batteries Directive: Member States shall ensure that manufacturers design appliances in such a way that waste batteries and accumulators can be readily removed

2.9. Wastewater

Wastewater is managed through the Council Directive on Urban Waste Water Treatment (91/271/EEC), and through other directives that manage the quality of water in the natural environmental such as the Bathing Water Directive, the EU Water Framework Directive, Ground Water Directive and through steps taken to protect certain sites under the Habitats Directive.

Wastewater is not often considered within the context of the circular economy. Clearly the implications in relation to negative impacts upon Europe's flora and fauna from poor water quality following emissions from waste water treatment plants to surface and underground water bodies must be considered. The treatment of sludge from wastewater treatment plants is captured within the Waste Framework Directive and the Fertiliser Directive. It is included in the bio-waste and residues sections as 'common sludge'. There may be scope, in the same way that other waste streams need to be reconsidered in terms of the potential circular economy value that they may bring, that similar approaches could be taken for sludge from waste treatment plants, however this is beyond the scope of this study.

2.10. Transposition of EU legislation

The transposition of EU legislation varies significantly from Member State to Member State. A European Topic Centre on Sustainable Consumption and Production (ETC/SCP) study in 2014 reviewed how EU waste management legislation was implemented in Italy, Poland and Spain in 2013. Table 5 provides a summary of the policy interventions, highlighting the activity hotspots. For example, there is a high level of activity in Spain at regional and inter-municipal level; whilst in Italy and Poland it is more evenly distributed. Although a sample size of three means that conclusions should be made with a level of caution, it does reaffirm the call by the EEA (2013) for example, for greater harmonisation in cascading European legislation and best practice down to municipality and inter-municipal level.

Table 5: Summary of the institutional framework (policy interventions) of municipal waste management in 3 Member States, 2013

	Italy	Poland	Spain
National level	4	5	5
Regions	6	5	14
Provinces	6	2	0
Municipalities	5	6	5
Inter-municipal	8	4	8
Private stakeholders	3	3	3

2.11. Regional support

Regional policy targets all regions and cities in the European Union to support job creation, business competitiveness, economic growth, sustainable development, and improve citizens' quality of life. Local and regional authorities have an important role in launching and accelerating the transition to a circular economy, whether by leading by example, setting clear framework conditions or directly supporting local and regional stakeholders. A recent policy brief by the ESPON 2020 Cooperation Programme highlights that a circular economy may have a different flavour in every European city and region, depending on geographic, environmental, economic or social factors: 'The industrial profile of a city or region plays an important role, with, for example, service and resource-intensive sectors each calling for different types of support' (ESPON, 2016). The diversity of territorial contexts translates into different needs and opportunities that circular economic approaches should address.

Local and regional authorities can offer support to relevant stakeholders by providing targeted funding, access to knowledge and information, as well as networking opportunities. Financial support for a circular economy can take different forms, such as grants, loans, tax incentives or investment guarantees, either offered directly by the public sector or channelled via other actors, e.g. business associations or business development agencies. The European Court of Auditors (2012) reported that the European Regional Development Fund (ERDF) and the Cohesion Fund[1] allocated €4.6 billion to waste management infrastructure projects between 2000 and 2006 and a further €6.2 billion between 2007 and 2013.

Unfortunately, a general conclusion from the study by the European Court of Auditors (2012) was that the effectiveness of this EU funding was not fully maximised due to the weak implementation of supporting measures, such as domestic legislation and policy. In addition, the poor quality of the data was cited as a major barrier to accurately measuring the effectiveness of the funding in terms of its impact on meeting waste policy targets.

Going forward, the European Commission (2016h) will invest €5.5 billion through the European Regional Development Fund and the Cohesion Fund over the 2014-2020 period in projects to improve waste management with expected results on waste management projects allocated against the following targets:

- Bulgaria: 285 000 tonnes less waste to landfill (European Commission, 2014c);
- Czech Republic: Increase in waste recycling capacity of 700 000 tonnes (European Commission, 2014d);
- Cyprus: Increase in solid waste recycling to 50 per cent (European Commission, 2014e);
- Greece: Increase in recycling of 650 000 tonnes (European Commission, 2014f);
- Hungary: Increase in solid waste recycling of 60 000 tonnes (European Commission, 2014g);
- Portugal: Preparation for re-use and recycling of at least 50 per cent of urban waste, by increasing the additional capacity of waste recycling by 91 000 tonnes/year and reduction of biodegradable municipal waste disposed to landfill to less than 35 per cent (European Commission, 2014h);
- Romania: Increase (by 2023) in the recycling rate of household and similar waste to 50 per cent, and a reduction in biodegradable waste disposed to landfill to 1.53 million tonnes (European Commission, 2014i).

Box 4: Key findings and messages from Chapter 2

- The current policy framework focuses on the sound management of specific waste streams; the key challenge for the transition towards a circular economy will be closer interlinkages between the waste management sector and up-stream sectors.
- The European Commission´s Circular Economy Action Plan has outlined first important steps in this direction that will now have to be implemented.
- Other aspects like waste prevention or the spatial context of the circular economy will require further efforts in order to contribute to the circular economy at their full potential.

[1] The Cohesion Fund is one of three funding streams supported through regional policy and is aimed at Member States whose gross national income per inhabitant is less than 90 per cent of the EU average.

3. Monitoring current performance: key trends and indicators

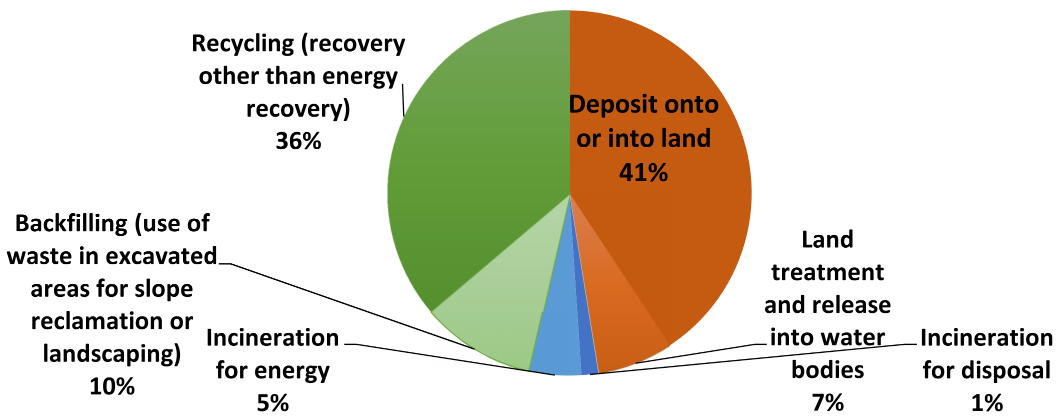
Chapter 3 begins by presenting waste generation and treatment trends in the EU in general and for the five specific waste streams that are the focus of this report in detail. It reports on progress and compares Member State (MS) performance toward reaching targets in the Circular Economy Package. Key trends for which data are available are then presented for more upstream processes related to enterprise and citizen activities toward re-use, repair and remanufacturing. Finally, challenges related to data gaps, inconsistencies and reporting methods, with implications for the overarching aims of the circular economy transition, are discussed. It should be noted that charts and tables present a snapshot of key available data to compare MS performance and present trends, but are not meant to provide a comprehensive overview of all available data.

3.1. Waste generation, treatment and trends in the EU-28

Approximately 2.6 billion tonnes of waste was generated in the EU-28 in 2014.[2] This is the highest amount of waste ever recorded. Construction contributed the highest share in 2014 (33.5 per cent) followed by mining and quarrying (29.8 per cent), manufacturing (9.8 per cent), households (8.1 per cent) and energy (3.7 per cent); the remaining 15 per cent was waste generated from other economic activities, mainly including waste and water services (8.8 per cent) and services (3.8 per cent). Almost two-thirds of waste generation was mineral waste, mostly connected to mining and quarrying activities (such as in Bulgaria, Sweden, Finland and Romania) and to construction and demolition activities (such as in Luxembourg). The level of overall waste excluding mineral wastes fell by 2.6 per cent between 2004 and 2014 to reach on average 1.8 tonnes per inhabitant in 2014 (compared to more than 5 tonnes per inhabitant on average including mineral wastes). Further trends for specific waste streams are presented below.

As regards treatment, the highest share of waste in the EU-28 is disposed of through landfilling, raising environmental and economic concerns related to pollution, land take and lost resources. Figure 4 depicts relative shares of waste treatment methods used in the EU-28 Member States in 2014 (orange depicts deposits, blue – incineration, and green – recovery). It shows that around 46 per cent of wastes are recovered in some form in the EU, contributing to a circular use of resources.

Figure 4: Waste treatment methods used for waste generated in the EU-28 in 2014



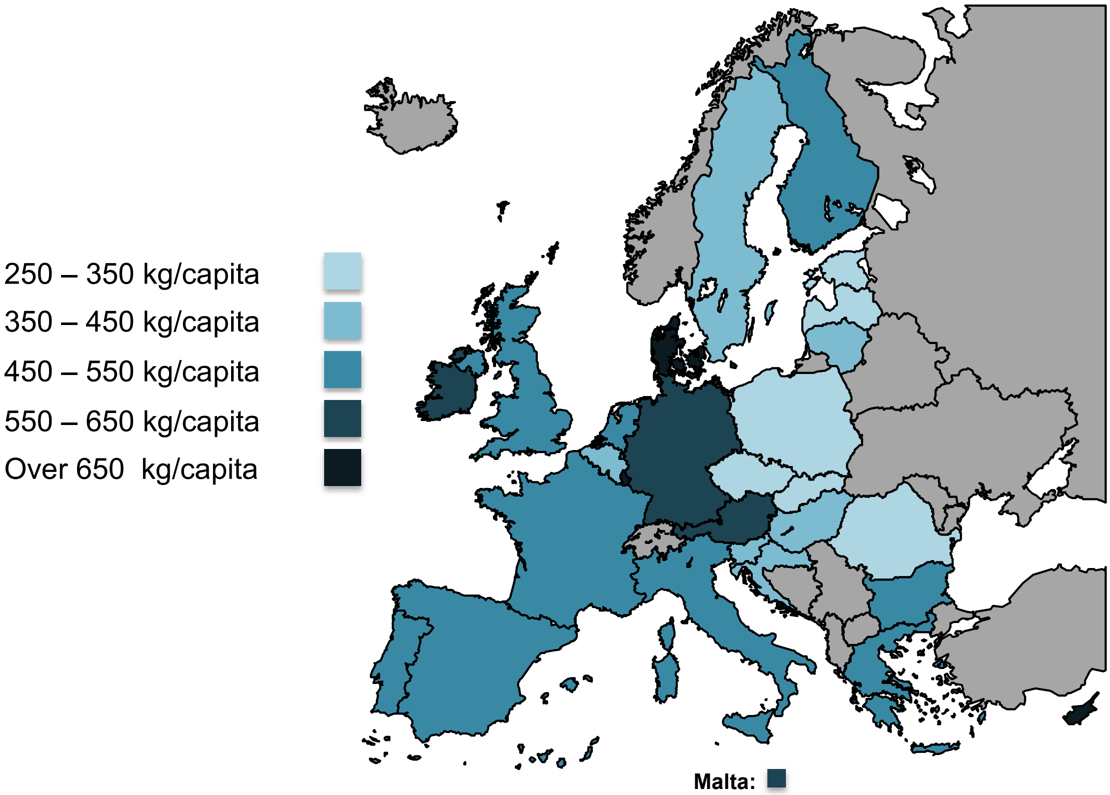
Source: Eurostat (env_wastrt; accessed June 2017)

[2] All data presented in this introductory section are based on Eurostat 'waste statistics'; http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics; accessed June 2017.

3.1.1. Municipal waste

Municipal waste is a key policy area with wide reaching impacts. The 'Best Practice' report on waste management produced by the European Commission (European Commission, 2016b) states that '…municipal solid waste represents only 10 per cent of total waste generated in Europe and yet it is one of the most polluting categories of waste, and the category with the highest potential for environmental improvement through better management'. Municipal waste frequently has a mixed composition which makes it challenging to treat.

Figure 5: Municipal waste generation per capita in 2012

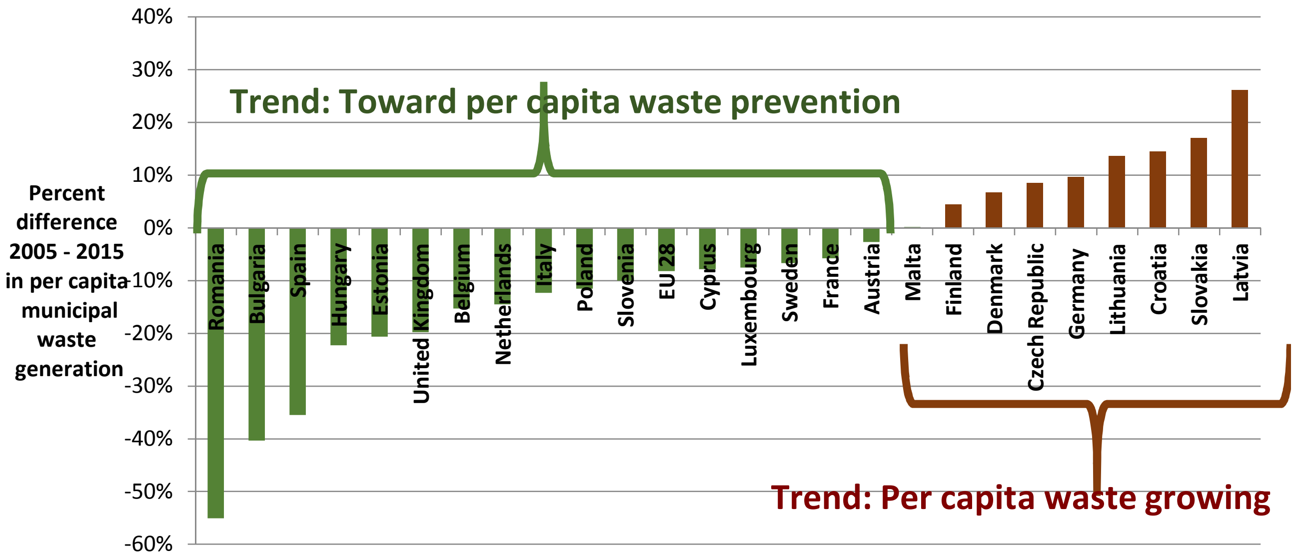


Source: Eurostat (env_wasmun, accessed June 2017). Note: 2012 is presented as most recent date with data available for all 28 Member States (also throughout this chapter). Data is available in Eurostat up to 2015, with gaps for 3 Member States.

Figure 5 shows a comparison of the municipal waste produced per capita in the EU-28. On average, Europeans generated 486 kg/capita in 2012. Denmark has the highest level of per capita waste generation in the EU (791 kg per capita), reporting close to three-times Romania's figure (251 kg per capita and the lowest level with in the EU). It should be noted, however, that variations in the definition of municipal waste used across EU-28 MSs and how it is collected (e.g. household waste collected together with waste from commerce, trade and administration) means that such comparisons are made with caution (see also Section 3.3). Cyprus, Malta and Greece have high levels of waste per capita primarily due to tourism. In general, EU Member States with higher GDP produce significantly more waste per capita than those with lower GDP.

As regards trends, in general municipal waste generation in per capita terms is being reduced (it sank from around 515 kg per capita in 2005 to 476 kg per capita in 2015, or 8%). Per capita waste generation is still growing in around one-third of EU MS, whereas it is declining in two-thirds (see Figure 6). This may reflect both the successes and challenges of increased waste prevention in the EU.

Figure 6: Percentage changes in per capita municipal waste generation in the EU-28MS between 2005 and 2015



Source: Eurostat (env_wasmun, accessed June 2017). Note: Ireland, Greece and Portugal are not depicted due to data gaps. Ireland reduced per capita waste generation (-25% between 2012 and 2005), Portugal remained almost the same (0.2% between 2014 and 2005) and Greece increased per capita waste generation (+13% between 2012 and 2005).

The EU's proposed Circular Economy Package has targets for:

- the reduction of municipal waste to be sent to landfill;
- a ban on the landfilling of separately collected waste; and
- the amount of municipal waste to be re-used or recycled.

For that reason, trends in each are examined in further detail in the sub-sections below.

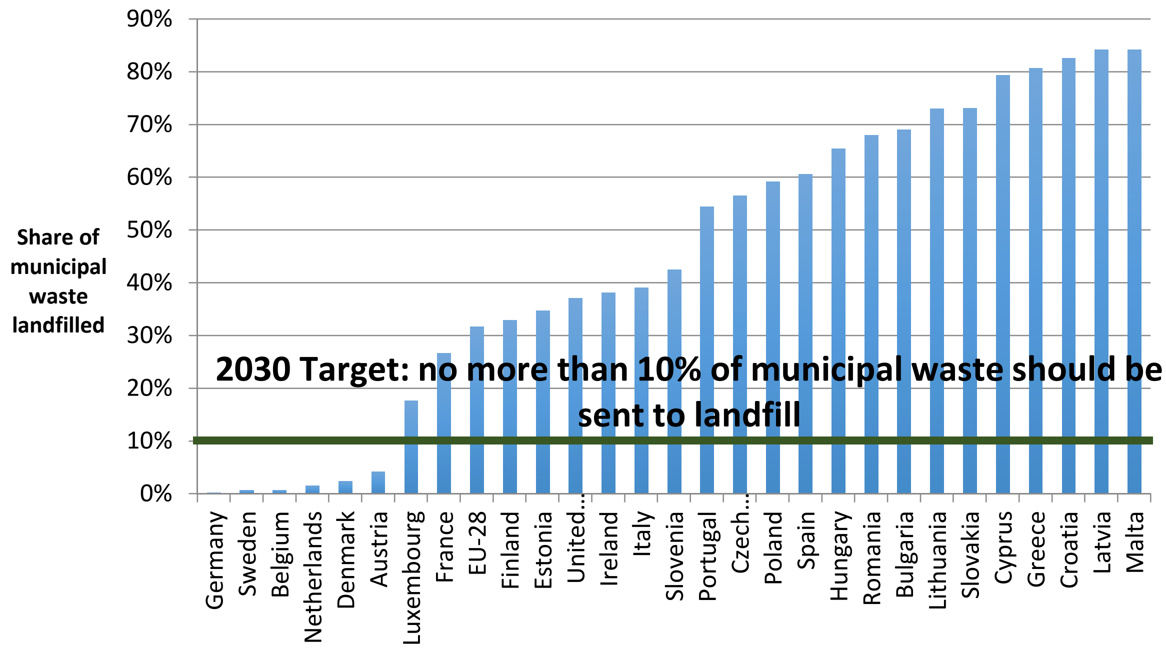
3.1.1.1 Landfilling of municipal waste

In 2012, 77 million tonnes of municipal waste were sent to landfill across the EU-28, equating to 32 per cent of the total municipal waste generated. Whilst 6 Member States have already met the 2030 landfill target, Figure 7 shows that the target will be challenging for as many as half of Member States who currently have landfill rates of over 50 per cent.

Those that have met the target have waste management systems that include policy mechanisms such as the landfill tax or landfill bans which represent good practice in the transposition of European policy. However, the landfill taxes and bans are accompanied by a suite of other policy interventions focusing on infrastructure, collection systems, secondary markets and materials, and behaviour change. Box 5 provides an overview of key elements of the suite of policies implemented in the Netherlands, Belgium and Estonia to successfully reduce levels of landfilling.

ETC/SCP (2014) reports that economic incentives, such as 'Pay As You Throw' (PAYT) schemes, are well established in some Member States and can have a significant impact on people's behaviour. Where households pay a fee unrelated to the amount of mixed waste produced, rather than dependent on participation in separate collection schemes, there is no financial incentive for households to sort their waste. This is borne out by Spain which has one of the highest rate of landfill (over 60 per cent) and has no national landfill tax. Article 16 of the Spanish Waste Act allows waste authorities in different regions to apply economic incentives, such as taxes on municipal waste. The region of Catalonia introduced a tax on landfilling municipal waste in 2004; however, little regional data is recorded in Eurostat, so it is unfortunately not possible to compare Catalonia to other regions in detail (ETC/SCP, 2013e).

Figure 7: The percentage of municipal waste landfilled in EU-28 in 2012



Source: Eurostat (env_wasmun, accessed June 2017).

However, significant investment is required to enable waste segregation, which is the first step in moving up the waste hierarchy away from landfilling and incineration. In 2012, 68.5 million tonnes of mixed waste classified as 'household or similar' in Eurostat was landfilled, accounting for 89 per cent of the total of landfilled municipal waste. This currently represents a significant barrier to realising the proposed target of no more than 10 per cent sent to landfill. Box 6 provides examples of towns that have implemented waste segregation at source.

A criticism of both the landfill tax and a more extreme landfill ban is that waste is often only moved up one level in the waste hierarchy. An example of this can be seen in Figure 8 where nine countries with a landfill ban on plastics are highlighted.

Figure 8 shows that on average, the countries with a ban send 32 per cent of plastic waste to recovery, 66 per cent to incineration and 2 per cent to disposal. In comparison, the countries that do not have a ban send, on average, 24 per cent plastic waste to recycling, 22 per cent to incineration and 54 per cent to disposal. The striking finding is that the level of plastic waste recycling is only 8 per cent higher in the countries with a ban, whilst the level of incineration is 44 per cent higher than the Member States with no ban. Hence, the outcome of the landfill ban has been primarily to shift plastic waste from landfill to incineration.

Box 5: Examples of policies implemented by Member States that have effectively reduced landfilling of municipal waste

The Netherlands: An ECT/SCP (2013b) report outlines the national strategy for landfill adopted in the Netherlands. This includes:

- a landfill ban covering 35 waste categories introduced in 1995;
- a landfill tax introduced in 1995, considerably reducing the amounts of MSW landfilled;
- in 2002, a steep increase in the tax level which continued to increase marginally the following years;
- a sharp increase in 2010, making the landfill tax in the Netherlands the highest in Europe; and
- by 2012, repeal of the tax as the low level of landfilling rendered it an administrative burden.

The Dutch Environment Ministry supports the segregation of vegetable, garden and fruit waste at source (Dutch Waste Management Association, 2011). The Dutch implemented DIFTAR, a system based on differentiated tariffs. This has proved to provide the right incentive to improve waste segregation at source. Digestate produced as a result of the methanisation and composting of separately collected bio-waste is then sold as a fertilizer (Saveyn and Eder, 2014)

Belgium: Belgium has one of the highest landfill taxes and landfill tax increases in Europe, combined with a landfill ban (ECT/SCP, 2013c). Despite a high GDP, it generates less than the EU-28 average of waste per capita. Belgium can be regarded as a frontrunner with national and regional policies in place well before EU policies were introduced (GAIA, 2012):

- The first Waste Decree, regulating the development of regional waste plans, was approved in Flanders in 1981. New regional plans are developed every 4-5 years and set targets for overall residential waste generation, separate collection, and residual waste after source separation and home composting.
- The first waste plan for vegetable, fruit and garden waste was developed in the period 1991-1995 and led to the creation of the Flemish compost organisation, VLACO.
- Landfill and incinerator restrictions came into force in 1998 and 2000, banning the landfilling of unsorted waste, separated waste suitable for recovery, combustible waste, and all pharmaceuticals, and banning the incineration of separated recyclables and unsorted waste.
- PAYT was introduced, as was the use of graduated taxes; i.e. most expensive is the collection of residual waste, followed by organic waste and then plastic bottles, metal packaging and drink cartons. Collection of paper and cardboard, glass bottles and textiles is free.
- All but three of the 308 municipalities in Flanders collected source-separated materials by 2009.
- In 2010, approximately 34 per cent of the Flemish population (2 million) was composting at home.

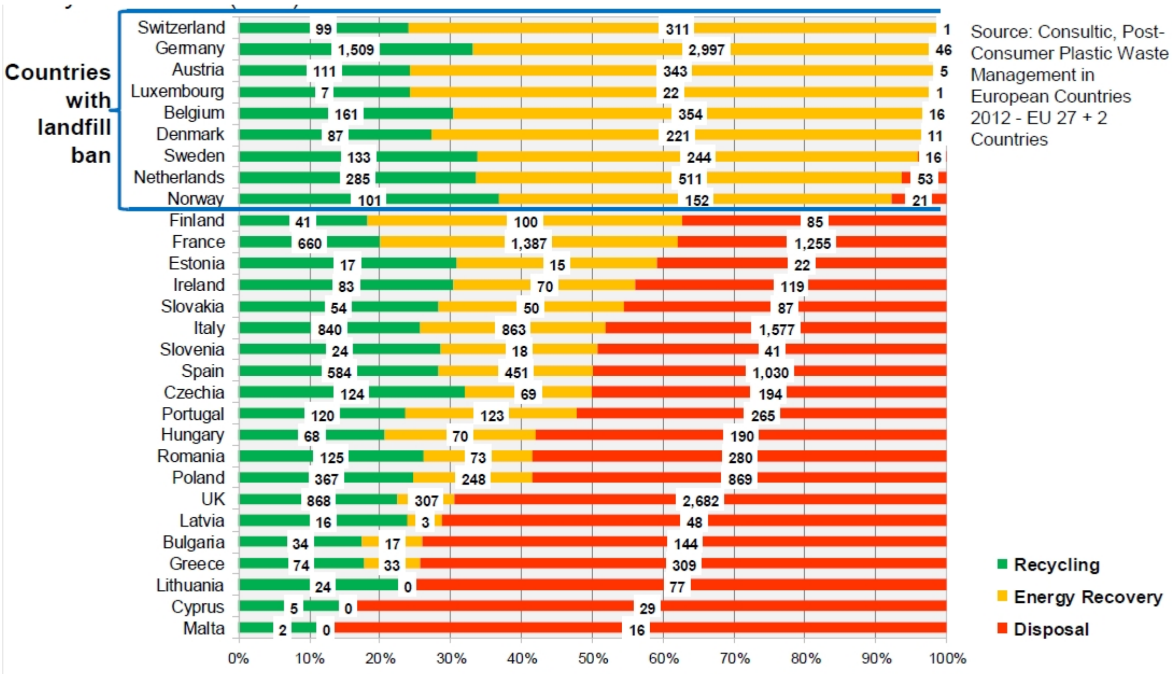
Estonia: The 2008 National Waste Management Plan in Estonia focused heavily on the diversion of biodegradable waste from landfill in line with the Waste Framework Directive. Estonia banned landfilling of untreated waste in 2009, has a landfill tax of €30 per tonne and operates a permit scheme limiting the amount of waste that can be landfilled in each municipality with heavy penalties for breaching these limits (ECT/SCP, 2013d).

Box 6: Reducing mixed waste streams by incentivising separate collection

The town of Vrhnika in Slovenia used a pay-as-you-throw scheme to encourage the public to separate their MSW at source and cut collection costs significantly. The municipality of Vrhnika was able to lower the amount of residual waste collected from 201 kg per capita in 2004 to 80 kg per capita in 2011 (76.2 per cent separate collection), ending the town's sole reliance on landfill in under ten years. In Ljubljana, source segregation of municipal waste, combined with better planned waste collection and an efficient communication campaign on waste prevention (including food waste), led to an increase in waste recovery from 16 to 145 kg per person between 2004 and 2014 (see the Case Study in Section 6.3). The municipality aims to generate only 70 kg of residual waste per capita by 2021 (Zero Waste Europe, 2014b and 2015).

Mandatory segregation of bio-waste has been implemented in Scotland and Wales. The latter has introduced 'mandatory recycling & re-use credits for the collection of source segregated dry recyclate, bio-waste and bulky waste' (Wales Environment Link, 2011).

Figure 8: Treatment of plastics waste, comparison of EU-27 (plus Norway and Switzerland) with and without landfill ban (2012)



Source: PlasticsEurope, 2016

Table 6 provides a summary of the recyclable materials and bio-waste collected separately and then landfilled in 2012, a practice to be banned by 2030 under the targets of the proposed EU Circular Economy Package. 5.9 million tonnes were landfilled, with the two bio-wastes and plastic waste being the significant waste streams in terms of volume. Compared to other waste streams, a high percentage of textiles are landfilled. France sends more separately collected waste by weight to landfill than any other Member State, with 1.2 million tonnes of recyclable material and over 0.5 million tonnes of 'animal & mixed food waste' and vegetal waste. One possible reason for this is the relative cost of each waste treatment option in France. An ADEME report (2015) states that, in 2012, the average net cost to landfill residual municipal waste was €180 per tonne compared with €203 per tonne to incinerate residual municipal waste; €343 per tonne to treat recyclable waste (except glass); and €62 per tonne to treat glass. With the exception of glass, this can be seen to work counter to the waste hierarchy, providing a financial incentive to landfill waste.

Table 6: A breakdown of recyclable material and bio-waste sent to landfill in 2012 by material

Material	Total waste treatment (k tonnes)	Landfill / disposal (k tonnes)	% landfilled	Significant contributors (tonnes)
Metal wastes, ferrous	69 160	80	0.12	Bulgaria 17 128; Germany 14 529
Metal wastes, non-ferrous	7 940	80	1.01	Belgium 43 490; Cyprus 13 198
Metal wastes, mixed	9 200	30	0.33	Spain 17 820; France 4 222
Glass wastes	15 490	230	1.48	Germany 48 934; Italy 46 087
Paper and cardboard wastes	38 800	180	0.46	Cyprus 83 306; Bulgaria 63 758
Rubber wastes	2 410	20	0.83	Spain 7 744; Bulgaria 5 404
Plastic wastes	12 730	1 440	11.31	France 930 640; Greece 79 824

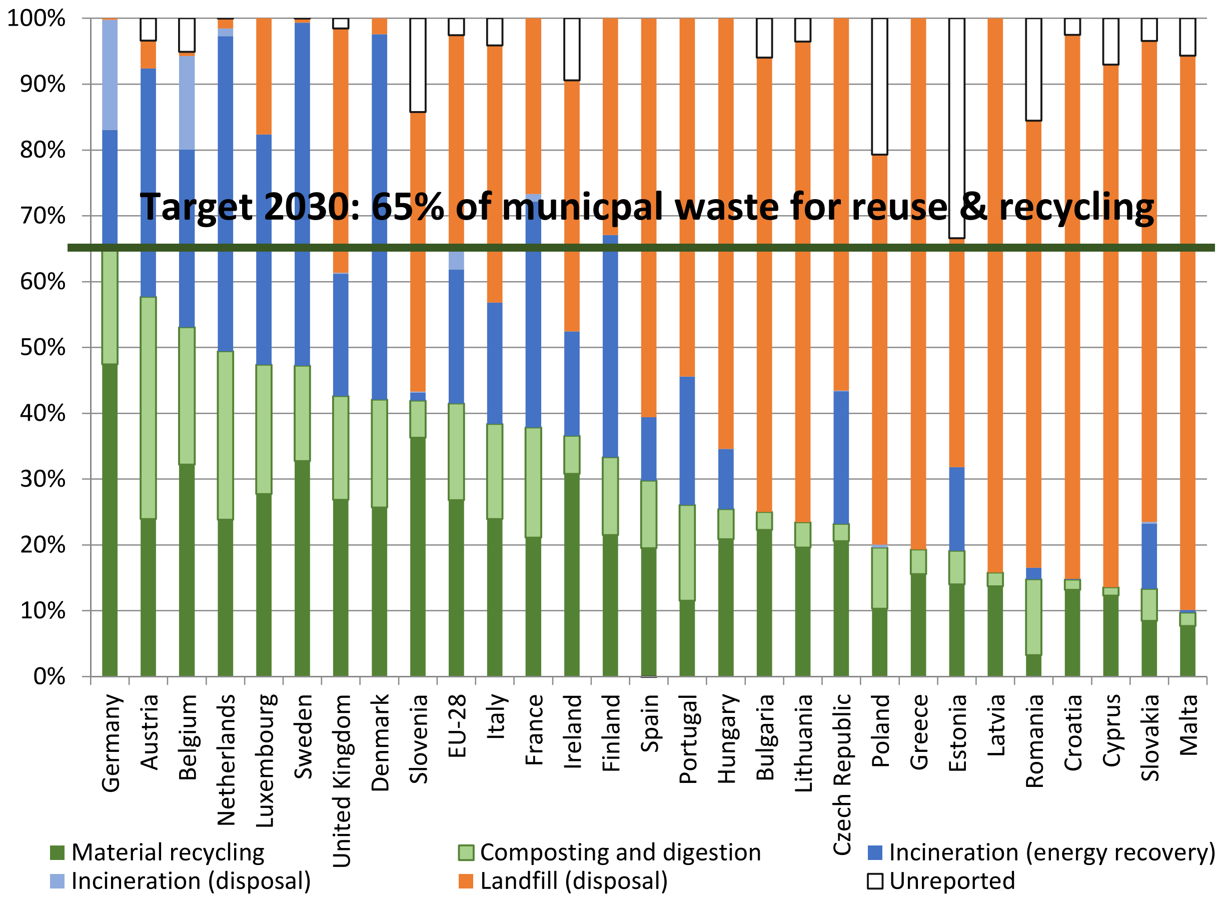
Material	Total waste treatment (k tonnes)	Landfill / disposal (k tonnes)	% landfilled	Significant contributors (tonnes)
Wood wastes	51 110	490	0.96	France 274 289; Greece 79 824
Textile wastes	2 370	150	6.33	Spain 35 326; Czech Rep 27 598
Total recyclable material	209 210	2 700	1.29	France 1 218 038; Cyprus 214 224
Animal and mixed food waste	26 520	1 950	7.4	Romania 1 567 481; France 285 416
Vegetal waste	45 390	1 250	2.8	Romania 295 070; France 258 085

Source: Eurostat (env_wastrt; accessed 2016)

3.1.1.2 Recycling of municipal waste

The proposed EU circular economy package has set a target to prepare 65 per cent of municipal waste for re-use and recycling by 2030. In total, around 42 per cent of total EU-28 MS municipal waste was recycled through material recycling, composting and digestion. From Figure 9 it can be seen that, based on 2012 data, Germany already meets the target.

Figure 9: Treatment of municipal waste in the EU-28 in 2012



Source: Eurostat (env_wasmun, accessed June 2017). Note, the share is based on per cent of each municipal waste disposal and recycling option calculated as a share of municipal waste generation. Not all countries reported disposal and recycling statistics that added up to 100% of waste generated. For this reason, unreported shares are depicted as it is unknown how this waste was disposed of and/or recycled.

The challenge in meeting the recycling target depends on the current context of municipal waste collection and treatment:

- Countries with high volumes of landfilling will need to divert waste from landfill. The challenges will be to implement waste separation, collection and sorting systems and infrastructure, as well as the processes, technologies and secondary markets for recycling streams. Countries in this bracket include the many of those listed on the right side of Figure 9.
- Countries that incinerate high volumes of waste will need to divert waste from incineration, not landfill. In many cases these countries already have advanced waste separation and sorting infrastructures. Their challenge will be (a) how to align the objectives of greater recycling volumes with the need to honour long term commercial contracts with incinerator operations and ensure return on investment, (b) respond to the role that waste to energy has taken as part of national energy strategies, (c) whilst at the same time focusing on waste prevention. They will also need the processes, technologies and secondary markets for recycling streams. Countries in this bracket include e.g. Belgium, Netherlands, Sweden and Denmark.

It can be seen that the interplay between recycling and incineration is key in many Member States, and that any discussion of moving up the waste hierarchy needs to be taken with an understanding of the capital and legal commitments already made towards incineration

3.1.1.3 Incineration of municipal waste

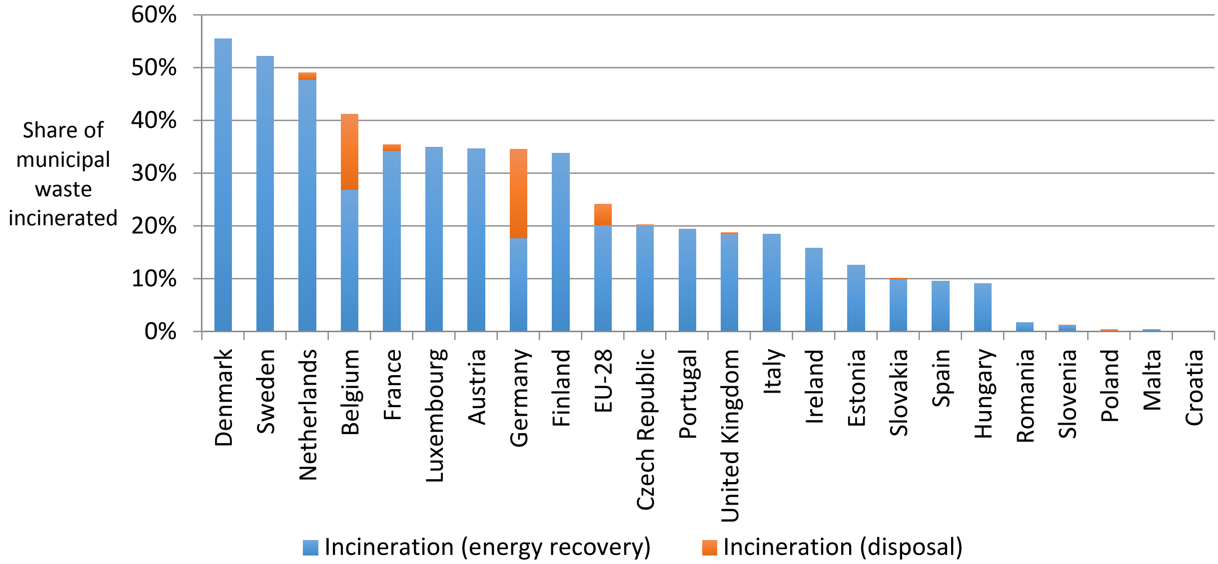
Figure 10 provides a breakdown of the municipal waste sent to incineration[3] in the EU-28. This shows that Denmark, Sweden, Netherlands, Belgium and France each incinerate over 35 per cent of municipal waste and need to switch from incineration to hit the 65 per cent recycling target. **Figure 10** also shows that 16.7 per cent of municipal waste in Germany was incinerated without energy recovery, accounting for 8.3 million of the 9 million tonnes treated in this way across the whole of the EU-28. However, the EEA (2013b) reports that this does not necessarily reflect the actual amount of municipal waste incinerated since it is reported to include 'treatment for disposal', mostly referring to waste that has already undergone mechanical biological treatment.

Current plans will see an increase in incineration in some countries. Poland is investing heavily in building EfW/CHP infrastructure in many of its cities (Table 7) to reduce its dependency on both landfilling of waste (currently over 59 per cent of municipal waste is landfilled) and importation of energy and fuel. England is in a similar position to Poland, with the Waste Infrastructure Delivery Programme (WIDP) funding an increase in EfW capacity of over 5 million tonnes between 2013 and 2020 (Local Partnerships, 2014).

For all EU-28 Member States the existence of secondary markets, the 'value' of waste, is critical in increasing the volumes of waste streams recycled. Where secondary markets exist, raising recycling targets is an easier aspiration. PlasticsEurope (2016) reports, for example, that between 2006 and 2012, Denmark reduced its overall percentage of waste plastic sent to incineration by 12 per cent and increased recycling of waste plastic by 12 per cent. These markets are, in many cases, relatively young and evolving and can be vulnerable to the economic pressures and challenges that all raw material markets face. Fluctuations in oil price, for example, can impact on recycled plastics markets, where recycled material might be a substitute for virgin, fossil fuel based raw material unless low oil prices make fossil fuels a commercially better choice.

[3] The terms incineration, energy from waste (EfW), waste to energy (WtE) and combined heat and power (CHP) are used interchangeably here.

Figure 10: The percentage of municipal waste incinerated in EU-28 in 2012



Source: Eurostat (env_wasmun, accessed June 2017).

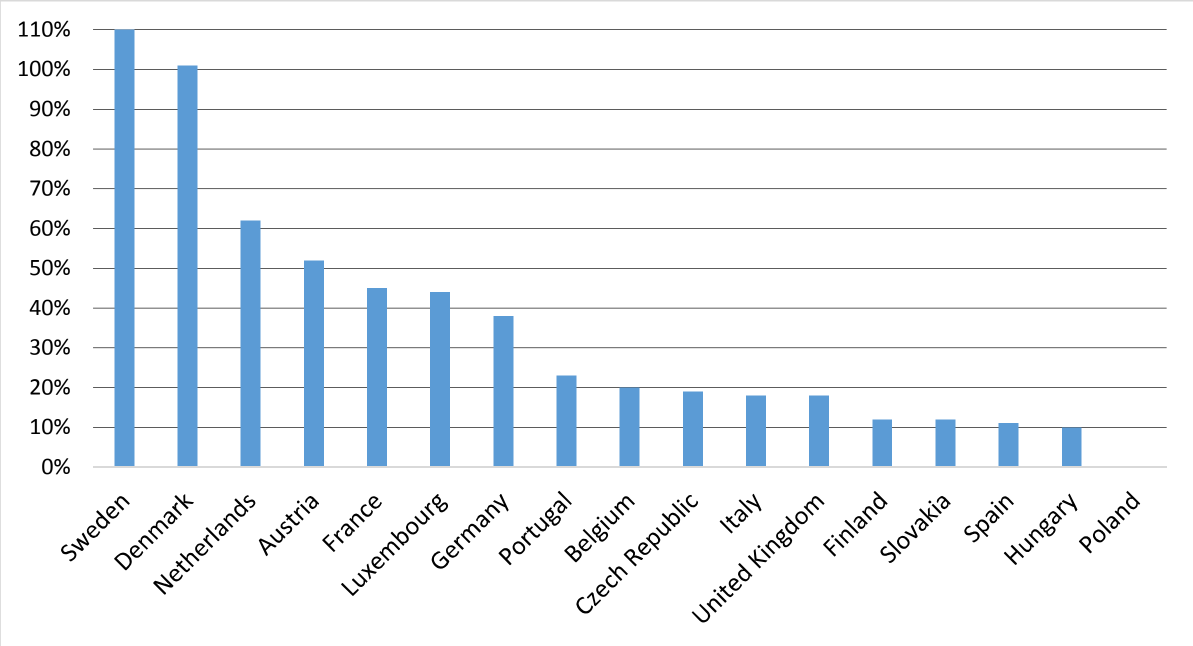
Table 7: Examples of recent waste infrastructure development in Poland

Member State	Technology	Capacity (k tonnes)	Waste type	Commissioned
Poland (Poznan)	EfW	210	Mixed - household	Due mid 2016
Poland (Bialystok)	CHP	120	Mixed - household	Jan-16
Poland (Konin)	CHP	100	Mixed - household	?
Poland (Bydgoszcz)	EfW	180	Mixed - household	Nov-15
Poland (Krakow)	EfW	220	Mixed - household	Nov-15
Poland (Szczecin)	EfW	150	Mixed - household	Due mid 2016

Source: Local Partnerships, 2014

Figure 11 shows the relative incineration capacities in the EU-28 in 2010. High capacities demonstrate how well this technology is established, especially in Member States with high GDP. When waste is incinerated its volume reduces by 90 per cent and its weight by 80 per cent, thus from one tonne of waste there will be around 200 kg of bottom ash left (Kleis and Dalager, 2004). From a landfill diversion perspective, it can therefore be considered a volume minimisation technology. In terms of the recycling and landfill diversion targets, if a Member State met the 2030 target for municipal waste of 65 per cent preparation for re-use and recycling, it could, in theory, send the remainder to incineration, where the solid waste (bottom ash) that would finally be landfilled would only equate to 7 per cent of the total waste and, hence, would meet the 10 per cent landfill target.

Figure 11: Incineration capacity as a percentage of total municipal solid waste in Europe in 2010



Data source: Municipal solid waste management capacities in Europe, desk-based study, June 2014

Incineration overcapacity is a concern for local authorities locked into long-term contracts with the need to feed plants with high volumes of waste. This can lead to actions that seem counter intuitive from an environmental perspective, such as the transportation of waste long distances for incineration. Recycling & Waste World (2015) reports that this is often the case in regions where waste is incinerated to provide district heating. For example, Denmark has an incineration capacity of 4.2 million tonnes of waste and, in 2014, 1.2 million tonnes of waste incinerated in Denmark were imported, primarily from the UK (around 180 000 tonnes) and Ireland (around 100 000 tonnes). Denmark rationalises the import of waste for incineration: in terms of GHG emissions, the import of waste for incineration is more advantageous with regard to the energy gained compared to its landfilling in its country of origin, as calculated for a scenario based in 2050. The incineration of imported waste would account for savings of 700 kg CO_{2e}. and the equivalent of 16 GJ of primary energy per tonne of imported waste. This figure accounts for the displacement of the use of coal, for example, if waste is used to generate energy (Cimpan et al., 2015).

The UK currently exports approximately half of its domestic municipal waste but is planning to develop incinerator plants domestically. Due to the high capital costs associated with the construction of incinerators, once incineration is available, it can create a lock-in effect and divert investment away from higher value applications for recyclates, undermining waste prevention strategies (Wilts & von Gries, 2015). Additionally, overcapacity can lead to financial risks both for local governments and private businesses (GAIA, 2013). Separate development of waste incineration facilities within EU Member States would also undermine potential efforts toward an integrated EU waste and recycling system taking advantage of capacities already developed.

As part of the Energy Union Framework Strategy (adopted on 25 February 2015 (COM(2015) 80 final), which announced a 'Communication on waste to energy' as part of its Roadmap, the European Commission has an ongoing initiative entitled 'Exploiting the potential of waste to energy under the energy union framework strategy and the circular economy'. The main problems that this initiative is looking to address are:

- lack of synergies between the waste-to-energy (WtE) situation and EU policies;
- making existing WtE processes more energy efficient;

- unevenly spread WtE (over) capacity;
- untapped potential from waste-derived fuels; and
- lack of clarity with respect to the waste hierarchy

Rather than imposing sanctions, such as banning the incineration of recyclable materials, the European Commission has acknowledged that this is an issue that impacts on a number of EU-level policies. The policies in question include circular economy policy; energy union strategy; climate change policy; and renewable energy policies. As part of the Roadmap it is stated that an impact assessment is not considered necessary and that it is not envisaged that legislation will be modified, nor new legislation or policy fields developed. The purpose of the Roadmap is to identify the 'potential' for synergies between the policies.

3.1.1.4 Municipal waste challenges for Member States

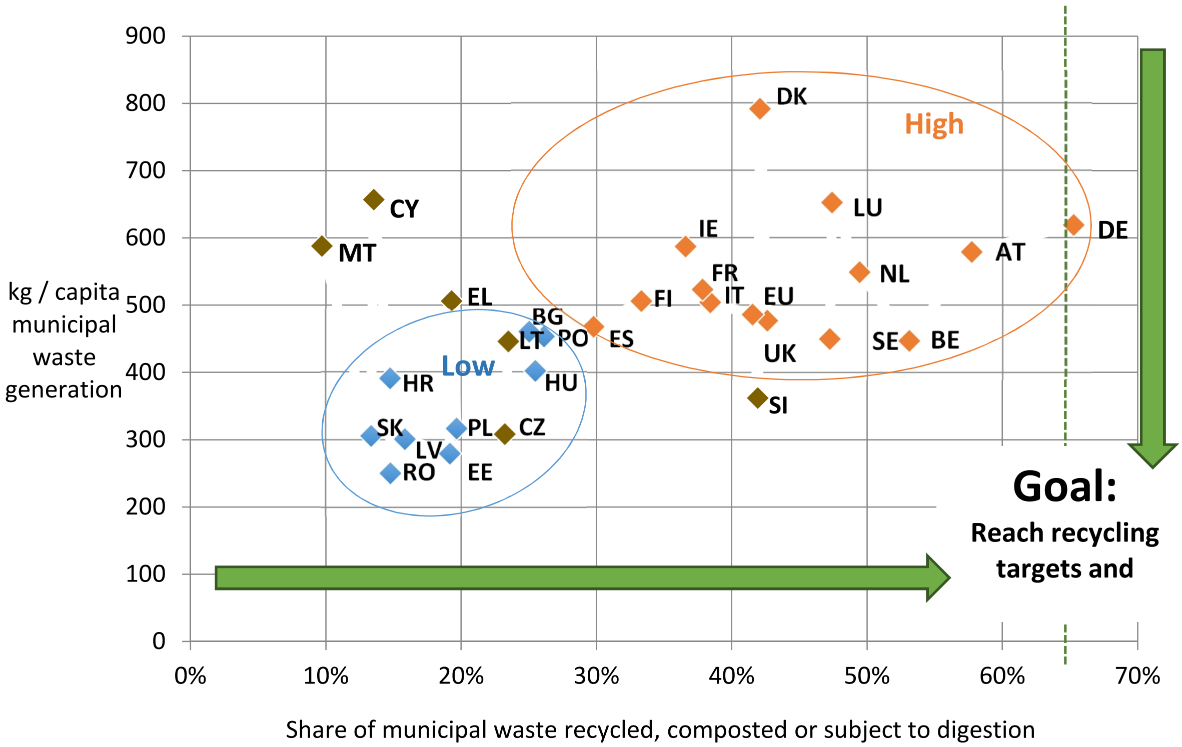
High level waste management statistics hide the wide variability and challenges between the EU-28, and indeed, within individual countries. The challenges can broadly be seen in 3 categories related to the performance and socio-economic conditions[4] of Member States:

1. Those countries, predominantly with higher levels of GDP, with high levels of waste per capita, but with relatively advanced waste management processes → challenge is to reduce waste generation, in particular through waste prevention (including lowering absolute levels of consumption) and increase efforts toward a circular economy
2. Those countries, predominantly with lower levels of GDP, with lower levels of waste per capita, but with poorly developed waste management processes and facilities → challenge is to develop waste management and treatment capacities economically and environmentally viable over the long term
3. Those countries with moderate GDP per capita characterised by an emerging waste treatment and recycling capacity → challenge is to learn from what works and accelerate, replicate and mainstream successful practices across their economies

Figure 12 shows that Member States sit across a wide spectrum of waste generation and waste management performance. In the figure, those counties falling into the categories 1 and 2 above have been encircled to demonstrate the strong grouping of GDP and waste production and management characteristics. In this case, it assumes that a high recycling rate serves as a proxy for advanced waste management processes. Figure 12 reiterates that countries with high levels of recycling, such as Germany, have only met part of the challenge. Namely, there is also a need to reduce the high levels of waste generation.

[4] Depicted for the sake of transparency and simplicity in terms of GDP, noting that vast differences exist within countries and are not captured by this indicator alone

Figure 12: Country performance in waste generation and recycling and the link with GDP in 2012



Source: Eurostat (env_wasmun, accessed June 2017). Note: Orange distinguishes countries in grouping 1 above with relatively high GDP; Blue refers to countries in grouping 2 above with relatively low GDP; brown depicts countries in grouping 3 above

3.1.2. Packaging and packaging waste

In 2012, 79 million tonnes of packaging waste were generated by the EU-28. On average, 65 per cent of packaging waste was recycled across the EU-28 in 2012, which means a 10 per cent increase over 18 years is required to meet the overall proposed 2030 target. As in all aspects of waste management, performance varies significantly between Member States ranging from a recovery rate of 80 per cent in Belgium (the only MS to have reached the target), to 41 per cent in Poland (see also Table 13 in Section 3.2.1 for a country breakdown below).

Table 8 shows the 2012 performance of the EU-28 on average against the proposed packaging recycling targets. Wood packaging is a particularly challenging waste stream, in terms of meeting the 2030 target, with a near doubling of the 2012 recycling rate being required. Ireland has the highest level of wood waste recycling and overall second highest recycling. Ireland operates both an EPR scheme and a 'polluter pays' initiative. Repak, the operator of the packaging compliance scheme in Ireland, reports that a factor in the high recycling rate for wood is the low level of EfW capacity in Ireland.[5] The 'polluter pays' principle applies to the use of a 'pay-by-weight' scheme for household waste collection. This was used in 30 per cent of households in 2015 but was rolled out to all households on 1 July 2016. Repak's 2015 annual report states that 'Collectors will have to end the practice of charging a flat fee per collection by introducing a charging system that promotes greater segregation of waste, improves recycling and allows householders to save on their bills'.

[5] Repak, personal communication, 16 August 2016.

Table 8: Packaging recycling achievements per Member State (MS) in per cent, 2012

Material	Proposed target	EU-28 average	Range between MS	Top performing MS	Poorly performing MS
Glass	85%	72%	100% - 21%	Belgium (100%), Luxembourg (95%)	Malta (21%), Cyprus (32%)
Metallic	85%	72%	99% - 13%	Cyprus (99%), Belgium (97%)	Croatia (13%), Greece (38%)
Paper & cardboard	85%	84%	99% - 53%	Finland (99%), Croatia (96%)	Poland (53%), Portugal (66%)
Wood	75%	38%	82% - 0%	Ireland (82%), Portugal (70%)	Croatia (0%), Malta (1%)
Plastic	55% (2025 target)	36%	58% - 22%	Czech Republic (58%), Slovakia (57%)	Poland (22%), Latvia (24%)
Total	75%	65%	80% - 41%	Belgium (80%), Ireland (74%)	Poland (41%), Malta (47%)

Source: European Commission, 2015d

Table 8 also shows that plastic packaging is an issue with a need for a 19 per cent increase in the overall recycling rate to meet the 2025 target. The Czech Republic and Slovakia have both met the 2030 plastics target and hence potentially represent exemplary cases. In less than ten years, the Czech Republic increased its recycling rate from under 10 per cent to 70 per cent for general packaging recycling following an update of national legislation to establish a recycling network across the country (Recycling International, 2015). Since 1997, the not-for-profit packaging company EKO-KOM has operated a nationwide system providing collection of packaging waste following the Packaging Act. It acts as a Producer Responsibility Organisation, set up through the legislation to meet recovery and recycling obligations. The organisation 'ensures that waste from used packaging is separated by the consumer, collected and subsequently undergoes final separation [followed by recovery] as a reusable material'.

Plastic packaging waste accounts for over 62 per cent of all plastic waste, households account for 63 per cent of plastic packaging waste and industry for 37 per cent (EPRO, 2012). In 2012, 33 per cent of plastic packaging from households and 37 per cent from industry was recycled. This suggests that more effort is needed from the municipal sector.

The high cost of processing plastics due to the high labour intensity means that it is often exported to countries where labour prices are lower. In 2012, 25.2 million tonnes of plastic waste were generated in Europe and 6.3 million tonnes were collected for recycling of which 2.0 to 3.5 million tonnes were exported legally, mostly for recycling in Asia, especially China.

Official plastic export figures might be an underestimate. Plastic Recyclers Europe (2013) states that 'Member States reporting of illegal waste shipment is very incomplete and thus it is not possible to be precise about quantities'. It is estimated that 3.2 million tonnes of post-consumer plastic are collected for recycling and therefore, with a conversion efficiency of 60 per cent, the recycling output is 1.9 million tonnes. This represents just 4 per cent of the overall demand for plastics in Europe.

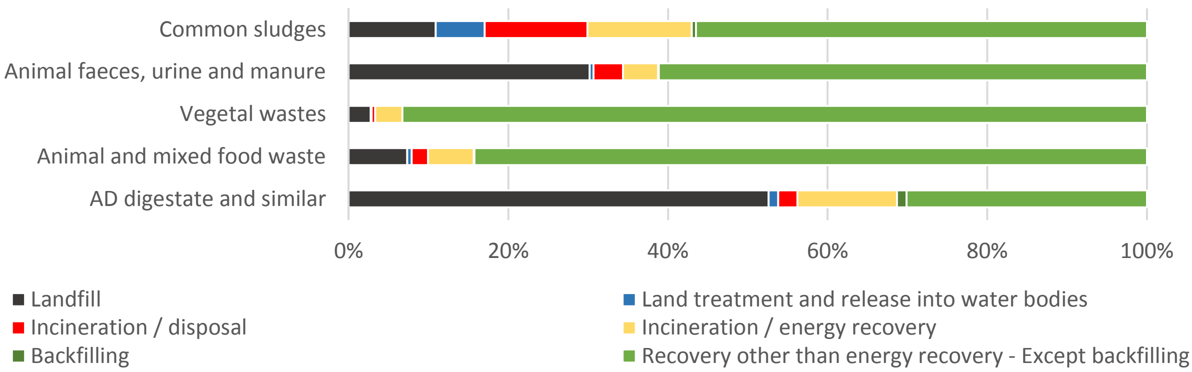
The European Commission (2011d) reported that, in 2008, the volume of plastic carrier bags produced in Europe was 3.4 million tonnes. Member States that have policies in place to reduce plastic carrier bag use include Belgium, Denmark, France, Germany, Italy, Ireland, and England, Scotland, and Wales in the UK. The plastic bag levy in operation in Ireland is one of the oldest schemes. The levy, originally set at €0.15, was introduced in Ireland in 2002 and immediately resulted in the number of bags being used, reducing from 328 bags per capita per year to 21, and in 2014 to 14 (Environ, 2016).

3.1.3. Bio-waste and residues

In 2012, 100 million tonnes of segregated bio-waste was treated within the EU-28. Figure 13 shows the five main types of bio-waste recorded on Eurostat and the treatment routes taken. Vegetal wastes and animal and mixed food waste account for over two-thirds of the waste and over 80 per cent of both waste streams are recovered in ways other than for energy recovery. Food waste is described in more detail in the next section.

The data also show that 52 per cent or 1.3 million tonnes of all anaerobic digestion (AD) digestate is landfilled. Digestate is the output, alongside methane enriched biogas, arising from the AD process. From a circular economy perspective, the landfilling of digestate means that no material recovery is taking place, a practice that would go against the objectives of a circular model. Germany, the Netherlands, Belgium and Spain are the four largest producers of digestate with a total of 1.33 million tonnes, and account for 0.98 million of the 1.3 million tonnes that was reportedly going to landfill. Italy, the fifth largest producer of digestate with 260 000 tonnes, recovers 60 per cent of its digestate and only landfills 28 per cent. Poland, Hungary and Austria appear to perform even better, with recovery rates above 95 per cent.

Figure 13: Treatment of selected waste biomass streams in EU-28 in 2012



Source: Eurostat (env_wastrt, accessed 2016)

If it has the correct physical and chemical properties, digestate can be used as fertilizer. However, due to its actual or perceived poor quality, markets for digestate are limited. In the UK, digestate values range from GBP13 paid by the operator for disposal to GBP3 paid by consumers (WRAP, 2014)[6]. Another estimate mentions a price of GBP5-10 per m^3 depending on the NPK[7] value attained. In Italy and in Germany, composted digestate is sold at €50-100 per tonne, accessing higher value applications as a soil improver on golf courses.[8] This is because the AD digestate is composted to allow for stabilisation, pathogen removal and improved nutrient content. In the UK, 11 kg of contaminant is allowed per tonne of digestate. This negatively affects the quality of the digestate, limiting its use.

[6] These estimates are based on only five UK respondents, therefore can only be used as an indication.

[7] indicates the nitrogen (N), phosphorus (P) and potassium (K) content of fertilisers

[8] David Newman, International Solid Waste Association, 26 April 2016

The EUs proposed circular economy package has a proposal to 'promote an efficient use of bio-based resources through a series of measures, such as guidance and dissemination of best practices of the cascading use of biomass and support to innovation in the bio-economy within the field of clean technology'. Proposed amendments to the 2003 Fertiliser Regulations have been made to address the issue of digestate quality. The European Parliament (2016) reports that 'the proposal modernises the conformity assessment and market surveillance in line with the "new legislative framework" for product legislation, covers a wider range of fertiliser products (including those manufactured from secondary materials), and sets limits for the presence of heavy metals and contaminants in fertiliser products'.

3.1.4. Food waste

The Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS) project estimates 88 million tonnes of food waste was generated in the EU-28 in 2012 (FUSIONS, 2016). Table 9 shows that households represent the most significant proportion of waste production in the value chain, accounting for 46.5 million tonnes or 53 per cent of the total food waste generated. An estimated 51 million tonnes of that waste was avoidable, of which, 28 million tonnes or 55 per cent came from households.

Table 9: Estimates of food waste in EU-28 in 2012

Value chain stage	Food waste (million tonnes) ± 95% confidence interval	% avoidable	Preventable waste (million tonnes)
Primary production	9.1 ± 1.5	50	4.6
Processing	16.9 ± 12.7	50	8.5
Wholesale and retail	4.6 ± 1.2	83	3.8
Food service	10.5 ± 1.5	59	6.2
Household	46.5 ± 4.4	60	27.9
Total	87.6	58	51.0

Source: FUSIONS, 2016

The FUSIONS study flags up the high levels of uncertainty in the estimates of the percentage of edible food waste. Table 9 shows that at the processing stage an estimated 50 per cent of food waste is edible, higher than previous studies which had indicated food waste at the processing stage is largely unavoidable. Edible food waste generation also varies between the different food categories, analysis of which can support more effective waste prevention strategies. Evidence suggests a much higher percentage of household waste is avoidable, possibly as high as 80 per cent of household food waste, equating to 37.2 million tonnes of preventable waste (JRC, 2015).

The impact of food waste goes well beyond simply being an environmental issue (where it has far-reaching consequences related to especially climate change (due to agriculture's large carbon footprint), biodiversity loss related to land take, and water scarcity and pollution), since it also has consequences from economic, societal and ethical perspectives. The FUSIONS project reports that an estimated 51 million tonnes of edible food is wasted each year in the EU-28 and most of this is generated in households (27.9 million tonnes). FUSIONS estimates that edible food waste costs householders in the EU-28 €98 billion per year. Conversely, STOA (2013) reports that consumers are not aware of their wasteful lifestyles since they do not experience any of their consequences, i.e. their consumption behaviour neither leads to a shortage of food, nor to major economic disadvantages to the individual.

Additionally, the risk of food waste is increasing due to the growth in the share of 'luxury' groceries such as delicate, often imported and easily perishable good with a short shelf life.

Household food waste equates to 11 per cent of total municipal waste. Preventing avoidable food waste from being generated could therefore have a major impact on waste collection systems and the capacity of bio-waste management facilities required in Member States. Whilst data on food waste is poor and heavily reliant on one-off 'snapshot' studies such as the FUSIONS project, it can be stated with some confidence that the Member States with high GDP generate the vast majority of the food waste. For example, STOA (2013) reports that several studies reveal that the wastage of food tends to augment with rising prosperity and even in the countries with a low to medium average income the upper classes are living wastefully regarding food.

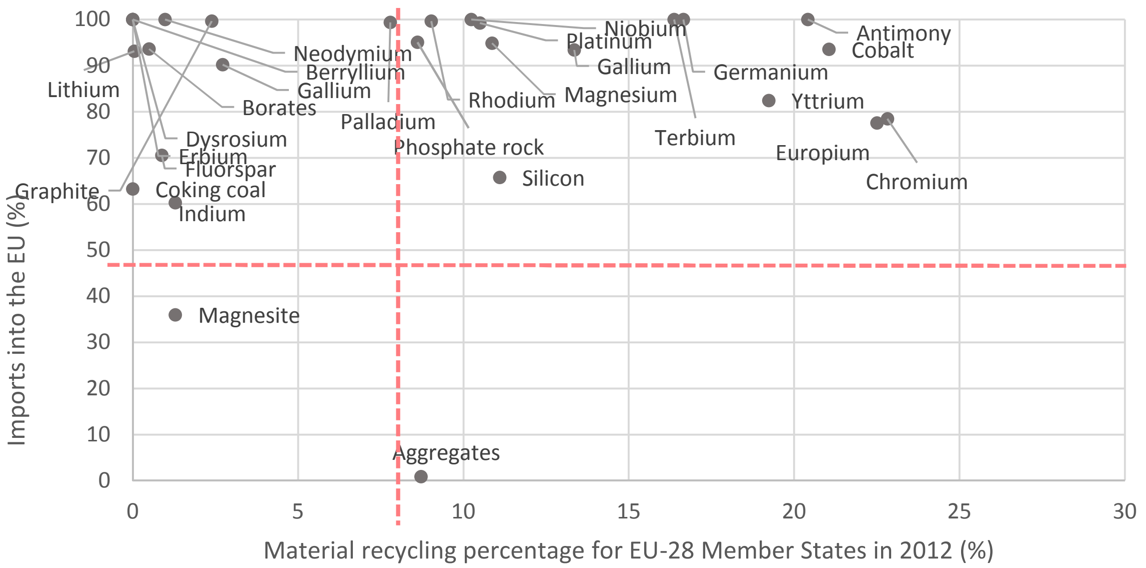
3.1.5. Critical raw materials

The commitment regarding CRMs in the proposed EU circular economy package does not set targets, but requires the EU-28 Member States to take action to encourage the recovery of CRMs, and to prepare a report on best practices and options for further action at the EU level. There are however targets for certain waste streams, namely batteries and waste from electrical and electronic equipment (WEEE).

A summary of priority CRMs in the EU from the perspective of material security and circularity can be found in Annex 3. There is an extreme variation in the reliance on imported materials included in Europe's priority list of CRMs, from aggregates (over 2.4 billion tonnes, with over 99 per cent supplied domestically) to rhodium (17 tonnes, with over 99 per cent imported).

Figure 14 plots the import dependency against the recycling rate of 28 CRMs. The materials in the top left quadrant are high potential materials, i.e. those materials with a high import dependency and a low recycling rate. The percentage of material currently sent to landfill and tailings in the EU can be considered an opportunity to increase recirculation. However, realistically, not all of this currently landfilled material is in a viable form suitable for recirculation, either because of its form when it was imported (primary material, secondary material or product) to the EU, or because of its form when it was landfilled. The economics and viability of material recovery depend on the complexity of the waste stream from which it is being recovered and its concentration.

Figure 14: Assessment of the opportunities for material recirculation for CRMs in 2012



Source: Own compilation based on BIO by Deloitte, 2015

The main applications of the materials in Figure 14 are grouped into four categories in Table 10: batteries, electronic and electrical products, other manufactured products including alloys, catalytic convertors and glass, and industrial processes and construction.

Table 10: CRMs grouped by main application. Yellow shaded materials are those identified above as 'high-potential'

Batteries	Electronic and electrical products	Other manufactured products including alloys and glass	Industrial processes and construction
Lithium††	Indium	Beryllium	Fluorspar
Graphite	Gallium	Borates	Coking coal
Cobalt†	Rare earth elements*	Antimony	Aggregates
	Germanium	Chromium	Phosphate rock
	Silicon	Niobium	Magnesite
	PGMs (Platinum, palladium and rhodium)		
		Magnesium	

* Rare earth elements (REEs) include neodymium, dysprosium, terbium, europium, yttrium and erbium.

† Cobalt is also used in aeronautic super-alloys, an application from which it is predominantly recovered and re-used in house by the OEMs involved.

††Lithium is also used in ceramics and glass manufacture, in lubricating greases, pharmaceuticals and polymer production. These dispersive applications aren't amenable to increasing lithium recirculation.

Eurostat does not currently capture data on CRMs but it can be interrogated for information on the treatment of end-of-life batteries and WEEE in general, and these are discussed in more detail below. As with all waste streams, there are cultural, physical (infrastructure and technology) and financial challenges to increasing CRM recovery from WEEE and end-of-life batteries in the EU.

There is neither evidence within the action areas of the European Innovation Partnership on Raw Materials nor in the list of EU-funded projects and reports on the CORDIS database of any concerted effort to explore expanding re-use and remanufacturing treatment of WEEE and end-of-life batteries as a means to minimise the EU's reliance on imported CRMs. There was, however, a strengthening of the provisions for re-use in the WEEE Directive. The remanufacturing of servers and other types of electronic equipment (typically high value and or specialist, i.e. medical, equipment where the pace of technological change has slowed) is already common. The current and potential for remanufacturing activity in other product groups should be an area for further investigation. Second-life industrial battery use in renewable energy storage, if found to be suitable, could extend the in-use life of high-CRM products as well as reduce demand for the CRMs themselves.

Finally, while weight-based recycling targets for WEEE is a key first step, in particular to reduce the amount of total waste sent to landfill, from a resource efficiency perspective, such targets may miss the aim of recovering the most resource intensive and critical raw materials (Bahn-Walkowiak et al 2014). For instance, palladium comprises only about 0.005% of the weight of a mobile phone, but causes 5% of the total material requirements (Chancerel and Rotter 2009). This implies that more specific targets are needed to promote the recovery of critical, valuable materials from end-of-life products.

3.1.5.1 Batteries

The target for scrap battery collection is a 45 per cent collection rate by 2016. By 2014, 7 Member States had met the target (Slovakia, Luxembourg, Sweden Belgium, Austria, Finland and Bulgaria) whereas 4 Member States remained far from the goal with around a 20 per cent collection rate (Cyprus, Croatia, Malta and Estonia) and 4 Member States had no reported data available for 2014. Slovakia and Luxembourg have the highest collection rates and both have introduced EPR schemes. The European Portable Battery Association (EPBA, 2013) reports that 'Slovakia introduced the Product Fee Act, in 2001, subjecting separately sold batteries to fees of the Recycling Fund on 100 per cent of batteries placed on the market less the amount of batteries collected by producers themselves or collected on their behalf'. The Recycling Fund is a non-state body run by a government-appointed Board of Directors. In Luxembourg, from 2010, producers have been responsible for financing net costs of collection, treatment and recycling, and public information campaigns. Interestingly, the performance of the Member States with low GDP is dispersed, highlighting the mixed nature of national legislation in this area, i.e. it is a relatively new policy area and performance does not therefore correlate with the date of joining the EU.

3.1.5.2 Waste from electrical and electronic equipment

Waste from electrical and electronic equipment (WEEE) is one of the most important sources of complex waste. Potential revenues from e-waste recycling are estimated at €2 billion in Europe (D'Adamo, 2016). WEEE contains high levels of CRMs that are predominantly from a single source, imported from China. WEEE also contains precious metals including gold, silver and platinum group metals. The magnets of hard disk drives also contain the rare-earth element neodymium at viable concentrations for recovery (European Parliament, 2015c). Silicon, indium, gallium, and germanium are used in the semiconductors found in electronic circuits as well as in light emitting diodes. Indium, in the form of indium tin oxide, is the market-leading transparent anode material used in photovoltaics, touchscreens and other electronic displays. WEEE is a major source of CRM loss, since less than 1 per cent of CRMs contained in the waste stream in the EU are recycled, of which the majority is pre-consumer recycling (European Parliament, 2015c).

According to Eurostat data, WEEE is currently one of the fastest growing waste streams in the EU, growing at 3-5 per cent per year. In 2012, over 9 million tonnes of products were put on the market but Eurostat reports that only 0.8 per cent (71 000 tonnes) was re-used. Member States are obliged to report to the European Commission on the achievement of the targets for WEEE collection, re-use, recycling and/or recovery. Table 11 shows that nine of the EU-28 Member States had already reached the 2016 WEEE Directive target of collecting more than 45 per cent of electrical and electronic equipment (EEE) placed on the market.

Table 11: Re-use and recycling of WEEE in EU-28 in 2012

	Products put on the market	Waste collected		Re-use		Recovery	
Member States	**Tonnes**	**Tonnes**	**%**	**Tonnes**	**%**	**Tonnes**	**%**
Belgium	329 598	116 458	35	4 068	1.23	98 669	29.94
Bulgaria	53 144	38 431	72	292	0.55	32 587	61.32
Czech Republic	168 840	53 685	32	0	0.00	43 297	25.64
Denmark	141 925	76 200	54	0	0.00	70 692	49.81
Germany	1 776 492	690 711	39	11 845	0.67	653 372	36.78
Estonia	15 044	5 465	36	0	0.00	4 912	32.65
Ireland	84 964	41 177	48	360	0.42	35 012	41.21
Greece	135 264	37 235	28	0	0.00	33 578	24.82
Spain	573 980	157 994	28	351	0.06	143 413	24.99
France	1 602 702	470 556	29	9 568	0.60	394 298	24.60
Croatia	39 505	16 187	41	0	0.00	15 406	39.00

Member States	Products put on the market	Waste collected		Re-use		Recovery	
	Tonnes	Tonnes	%	Tonnes	%	Tonnes	%
Italy	892 910	497 378	56	-	-	401 730	44.99
Cyprus	12 852	2 514	20	42	0.33	2 176	16.93
Latvia	16 818	4 694	28	37	0.22	3 924	23.33
Lithuania	28 337	14 259	50	0	0.00	11 108	39.20
Luxembourg	12 386	5 010	40	0	0.00	4 664	37.66
Hungary	84 176	44 262	53	0	0.00	36 593	43.47
Malta	13 516	1 506	11	0	0.00	1 129	8.35
Netherlands	324 717	123 684	38	475	0.15	118 036	36.35
Austria	158 261	77 402	49	1 248	0.79	69 561	43.95
Poland	481 225	175 295	36	791	0.16	134 729	28.00
Portugal	117 001	43 695	37	33	0.03	38 518	32.92
Romania	130 548	23 083	18	0	0.00	20 296	15.55
Slovenia	28 310	9 430	33	30	0.11	8 184	28.91
Slovakia	47 886	22 671	47	0	0.00	20 261	42.31
Finland	137 756	52 972	38	557	0.40	48 441	35.16
Sweden	219 160	168 612	77	0	0.00	154 746	70.61
United Kingdom	1 426 175	503 611	35	41 630	2.92	0	0.00

Source: Eurostat (env_waselee; accessed 2016)

Sweden, with 77 per cent, is the Member State with the highest collection rate, already meeting the 2019 target of 65 per cent. Sweden introduced an extended producer responsibility scheme for WEEE in 2001. El-Kretsen manages the 'Elretur' nationwide collection and recycling system. Collection points, such as recycling centres, are managed and funded by the local authorities and there are over 1 000 collection points throughout Sweden. In some places the 'drop off' schemes are complemented with kerbside collection (Elretur nd). Table 11 shows that the UK is the highest-ranked Member State in terms of re-use, but this is still modest at just 2.9 per cent. A WRAP study (2011) reported that within collected household WEEE in the UK, 12 per cent was found to be in full working order. Even partially working WEEE, where just a battery or a few components could be salvaged, might have the potential for remanufacturing. A lack of legislation encouraging and enforcing re-use, along with insufficient quantities of good quality equipment, have been identified as major barriers to remanufacturing and refurbishing (Kissling, 2013). WRAP (2015) highlights the benefits from re-use with the example of an iPhone, which retains around 48 per cent of its original value when re-used but just 0.24 per cent as recyclate.

In terms of the overall material and energy recovery rate of the collected material, Sweden is an exemplar. Table 12 shows that, in 2008, material recovery ranged from 85 per cent to 98 per cent in the five categories of WEEE studied. The analysis of 'various electronics' highlights the very small quantities of CRMs (silver, gold and palladium) present and reaffirms the dispersed nature of this waste stream.

Table 12: Material and energy recovery in the Swedish WEEE treatment system in 2008

Equipment	Recycling rate	Energy recovery
White goods	94.8% (Iron 72.5%, Aluminium 20.7%, Copper 1.0%, Nickel 0.5%)	5.2%
Refrigerators and freezers	90% (Iron 76%, Plastic 9%, Aluminium 2%, Copper 2%, Freon 1%)	9%
Various electronics	85.1% (Iron 35.39%, Glass plate 32.9%, plastic 9.71%, Copper 3.61%, Aluminium 3.49%, Silver 0.01%, Gold 0.0005%, Palladium 0.0002%	14.9%
Fluorescent tubes	98% (Glass 85%, Aluminium 10%, Fluorescent powder 3%)	2%
Low-energy bulbs	85% (Glass 60%, Aluminium 20%, Fluorescent powder 5%)	15%

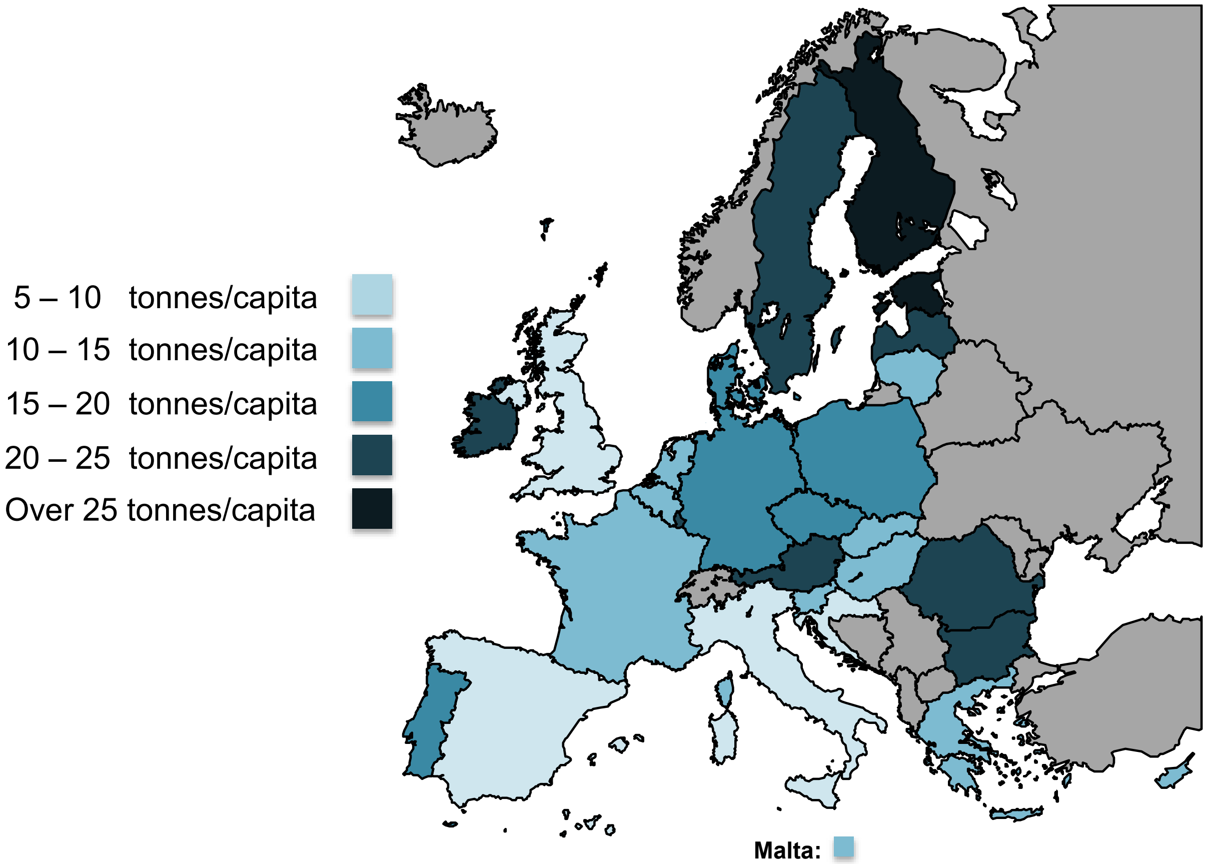
Source: Eurostat (elretur nd, accessed 2016)

WEEE is a very complex material to track, and hence the reliability of the Eurostat data should be treated with caution. Factors such as differences in the proportion of large household appliances making up the WEEE waste stream (e.g. 75 per cent in Bulgaria compared to nearer 50 per cent in other Member States) have a large influence on the overall recycling rates reported. The data in Eurostat on WEEE recycling is also likely to be underestimated due to the exclusion of 'non-obligated WEEE', i.e. that which is received by a treatment facility or exporter not related to a WEEE scheme. In the case of the light iron content of large household appliances, metal treatment facilities, rather than WEEE treatment facilities, are often responsible for recycling. In a 2013 report, WRAP estimated that including non-obligated WEEE recycling in total WEEE recycling figures would increase the UK's effective WEEE recycling rate from 30-35 per cent to over 45 per cent, and thus meet the target set by the WEEE Directive for 2016 (WRAP, 2013).

3.2. Toward a circular economy

One of the major aims of the circular economy is decoupling resource use and environmental impact from economic activities. For this reason, measuring and monitoring resource efficiency and waste reduction, in particular by tracking material flows, is a key priority (EASAC, 2016). This implies that not only measuring the resource outputs in terms of waste and recycling, but also the resource inputs, e.g. in terms of material footprints, is a crucial aspect of a monitoring system. This is because a circular economy shall reduce the total amount of primary resource inputs, thereby mitigating environmental impacts and pressures associated with resource extraction, by making greater use of those resources within the economy. Figure 15 depicts the material consumption of EU countries in terms of the 'domestic material consumption' indicator. However, as this does not take upstream resource flows into account it should be used a proxy indicator for material footprints, calculated instead with e.g. the 'raw material consumption' (RMC) indicator. Overall, material footprints in the EU are decreasing (e.g. RMC decreased from around 17 tonnes per capita in 2005 to nearly 14 tonnes per capita in 2014). Large differences between Member States exist, as depicted in Figure 15, with Finland, Estonia and Romania having the largest material footprints and Italy, Spain and the United Kingdom the lowest in per capita terms.

Figure 15: Material footprints in 2015 using DMC as a proxy indicator for RMC, tonnes per capita



Source: Eurostat (env_ac_rme, accessed June 2017)

While material flow indicators are thus critical to monitoring progress toward a circular economy transition, EASAC (2016) point out that '"However, such basic concepts do not capture the environmental impact of resources extraction and use, or the objective of more efficiently using goods, including repairing and reusing'. This emphasises the need for a system of monitoring indicators, e.g. as part of a dashboard or comprehensive reporting framework. In its ongoing work the European Eco-Innovation Observatory has proposed such a dashboard of indicators for monitoring the circular economy across multiple scales (see Figure 16). In addition, the EASAC (2016) report notes that "owing to the linkages between the circular economy, human well-being and sustainable development, the indicators for monitoring progress towards a more circular economy can be included in the wider debate on developing alternatives to gross domestic product (GDP), where the Commission's circular economy indicators, "Beyond GDP", sustainable development indicators and environmental pressure index actions are involved'.

Presenting all indicators related to a circular economy would be beyond the scope of this report. Section 3.2.1 summarises progress in Member States toward reaching the proposed targets, focusing on more of a 'downstream' approach, in other words focused still on waste and recycling as outputs of the economic system. Section 3.2.2 presents some trends and data related to upstream processes—in particular based on some of the proposed EIO indicators related to societal behaviour and business operations, arguing that better data for monitoring and targets for steering development of circular economy aims are needed.

Figure 16: Monitoring progress toward a circular economy: toward a dashboard of EU Indicators

Sustainable resource management

- The circular economy is a key pathway for sustainable development: The EC states 'This (circular economy) action plan will be instrumental in reaching Sustainable Development Goals'. Specifically it shall contribute to lowering resource demands, thereby increasing resource security and lowering pressures on the environment domestically and abroad.
- This set of indicators examines the performance of EU Member States toward transforming their economies toward circularity (macro level indicators), such as material footprints, municipal waste generation per capita and progress toward circular economy targets.

Societal behaviour

- Citizen engagement, behaviour change and social norms are integral to the success of a circular economy transition. This means that people participate in new forms of consumption (e.g. sharing, product-service systems, willingness to pay more for durability), re-use (requiring changed mindsets regarding repair and refurbishment), and disposal (seperating waste streams and bringing 'waste' to remanufacturing/recycling/sorting sites).
- This set of indicators presents levels of citizen engagement and participation in the circular economy (bottom-up indicators), such as turnover of repair activities, participation in alternative forms of consumption.

Business operations

- Businnesses are the engine behind the circular economy transition. They foster circularity across the life-cycle of material use, beginning with how and what materials are sourced (quality, environmental and health standards). The design stage is particularly crucial to enabling re-use / re-manufacturing / recycling and raising the durability of goods for keeping within the economy longer. Remanufacturing and recycling are key business operations critical to scaling up the circular economy.
- This set of indicators depicts eco-innovation activities toward changing and adapting business models according to the principles of a circular economy (bottom-up indicators), such as innovation to increase product durability companies engaged in remanufacturing activities and innovation to facilitate recycling.

Source: Eco-Innovation Observatory, forthcoming. Indicators and data available soon at www.eco-innovation.eu

3.2.1. Toward reaching downstream targets

The objectives and targets set within the proposed EU Circular Economy Package will provide varying degrees of challenge to Member States. Table 13 shows performance, based on 2012 data, against the targets set for 2030 within the proposed Circular Economy Package. Encouragingly, each of the 2030 performance targets has already been reached by at least one Member State. Additionally, 10 of the Member States have already achieved the 2030 target for paper & cardboard packaging. It can be seen however, that the targets for municipal waste and wood packaging are particularly challenging for many Member States, with over 50 per cent of the Member States being more than 20 per cent away from the 2030 targets. The same table, but with details of actual performance can be found in Annex 5.

Table 13: Performance of the EU-28 in 2012 against the proposed EU Circular Economy Package 2030 targets

Member State	Municipal solid waste		Packaging materials					
	<10% Landfill	>65% Recycle	Glass >85%	Metallic >85%	Paper & cardboard >85%	Wood >75%	Plastic >55%	Total >75%
Austria								
Belgium								
Bulgaria								
Croatia								

Cyprus	Red	Red	Red	Green	Green	Red	Amber	Amber
Czech Republic	Amber	Red	Amber	Amber	Green	Red	Green	Amber
Denmark	Amber	Red	Amber	Red	Amber	Red	Red	Amber
Estonia	Red	Red	Amber	Amber	Amber	Amber	Red	Amber
Finland	Red	Red	Amber	Green	Green	Red	Red	Amber
France	Red	Red	Amber	Amber	Green	Red	Red	Amber
Germany	Amber	Green	Amber	Green	Green	Red	Amber	Amber
Greece	Red	Red	Red	Red	Amber	Red	Red	Amber
Hungary	Red	Red	Red	Amber	Amber	Red	Red	Red
Ireland	Red	Red	Green	Amber	Amber	Green	Amber	Amber
Italy	Amber	Red	Amber	Amber	Amber	Red	Amber	Amber
Latvia	Red	Red	Red	Red	Amber	Red	Red	Red
Lithuania	Red	Red	Amber	Amber	Amber	Red	Amber	Amber
Luxembourg	Red	Amber	Green	Amber	Amber	Red	Amber	Amber
Malta	Red	Red	Red	Red	Amber	Red	Red	Red
Netherlands	Green	Amber	Amber	Green	Green	Red	Amber	Amber
Poland	Amber	Red	Red	Red	Red	Red	Red	Red
Portugal	Red	Red	Red	Amber	Amber	Amber	Red	Amber
Romania	Red	Red	Amber	Red	Amber	Red	Amber	Amber
Slovakia	Red	Red	Amber	Amber	Amber	Red	Green	Amber
Slovenia	Amber	Amber	Green	Red	Amber	Red	Green	Amber
Spain	Red	Red	Red	Amber	Amber	Amber	Amber	Amber
Sweden	Red	Amber	Green	Amber	Amber	Red	Red	Amber
UK	Amber	Red	Amber	Red	Green	Red	Red	Amber

Source: Eurostat; Colour coding index: Green = target already reached; Amber = within 20 per cent of target; Red = missing target by more than 20 Per cent.

The proposed EU Circular Economy Package targets will clearly be easier to achieve for those countries with more advanced waste management processes. Factors that currently hold back some Member States from achieving the targets are (BiPRO, 2013; CMS, 2013):

- A lack of modern infrastructure;
- High dependency on landfill, with recycling rates being either too low or non-existent;
- Administrative and institutional failings;
- A lack of political will, and lack of domestic legislation and policy;
- A lack of awareness of waste management outside urban centres; and,
- Inefficient source separation of municipal waste.

The variations shown between Member States in are further accentuated by variations within a Member State. As an example, Table 14 provides a summary of the regional variation in the percentage of waste going to landfill in 10 Member States. Portugal stands out, with a variation between regions of 86.2 per cent. Narrowing the gap between different regions may not be easy. A report by the ETC/SCP (2013) on the regional variation in recycling in Portugal stressed that 'The differences between regions are significant and show that there are lessons to be learned between the various Portuguese regions. On the other hand, it should be mentioned that there are limitations in how good practices among regions can be transferred. For example, in urban regions such as Lisboa, it is technically and economically more feasible to establish and maintain higher levels of recycling than it is in rural areas'. This conclusion is likely to be applicable to many of the Member States that show a significant variation across regions, and would apply to all types of waste management. However, the Member States (such as the Netherlands and Belgium) that currently perform well across all regions may be able to provide some best practice case studies for rural areas in other Member States.

Table 14: Regional waste treatment variation by Member State – Summary table

Member State	No. of regions (NUTS 2)[9]	% of waste sent to landfill		
		Min	Max	Range
Poland	17	32.7%	72.0%	39.3%
Netherlands	12	1.1%	1.7%	0.6%
Belgium	11	0.0%	1.9%	1.9%
Austria	9	1.7%	13.3%	11.6%
Romania	9	39.5%	94.9%	55.4%
Portugal	8	1.4%	87.6%	86.2%
Hungary	7	50.1%	94.4%	44.3%
Slovakia	4	32.4%	85.0%	52.6%
Croatia	2	81.8%	83.3%	1.5%
Slovenia	2	40.7%	44.1%	3.4%

Data source: Eurostat (2012); Municipal waste generated by NUTS 2 regions. Colour coding index: Green = target already reached; Amber = within 20 per cent of target; Red = missing target by more than 20 per cent.

Finally, many of the targets set out in the proposed EU Circular Economy Package are 'volume' based, whilst the goal of the circular economy concept is to maximise the 'value' of materials retained within the economy. This leads to the consequence that the resulting waste management practices, and the capital investments that are made, may not support the achievement of circular economy goals for retaining the value of resources within the economy.

3.2.2. Focusing on upstream processes: Re-use, repair, remanufacturing

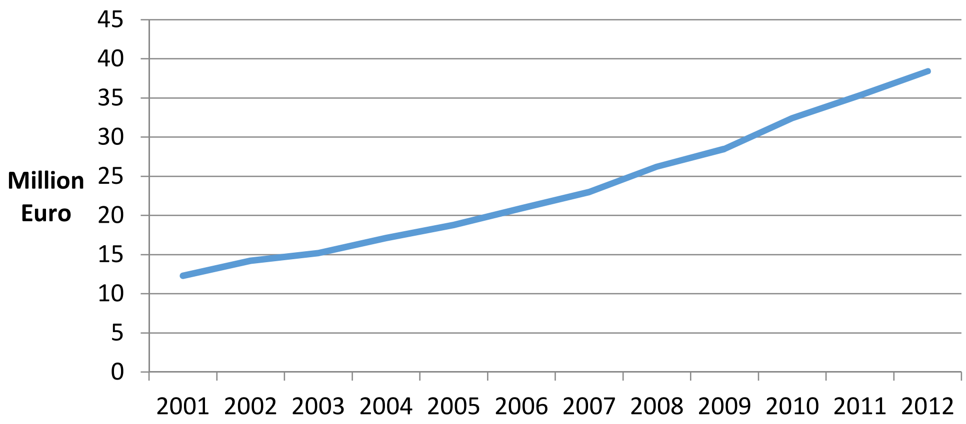
Before recycling, extending the lifetime of valuable resources through re-use, repair, refurbishing or remanufacture is critical to achieving policy aims for waste prevention. In this case overcoming infrastructural lock-in is one of the key policy challenges, especially if the demand for waste streams for energy generation and recycling competes with prioritising re-use and waste avoidance. This section presents some of the bottom-up trends happening across the EU toward innovation in the context of a circular economy.

As regards re-use, limited data is available, and that is of a more case-study nature. For example, Flanders is one of the most active regions for promoting re-use activities, in particular due to a strong network of re-use activities (also providing jobs for vulnerable target groups) and structural embedding in the Flemish waste policy framework. As such it represents a strong case study for transformation toward the circular economy. Indeed, turnover in re-use shops has nearly quadrupled in Flanders between 2001 and 2012. This is depicted in Figure 17 as a proxy until more data on re-use activities

[9] NUTS 2 is the Nomenclature of Territorial Units for Statistics, is a standard used for referencing the subdivisions of Member States for statistical purposes.

across the EU are available, and to demonstrate the growth potential of the re-use sector as a win-win-win for people, the environment and business.

Figure 17: Re-use shops in Flanders, turnover 2001-2012

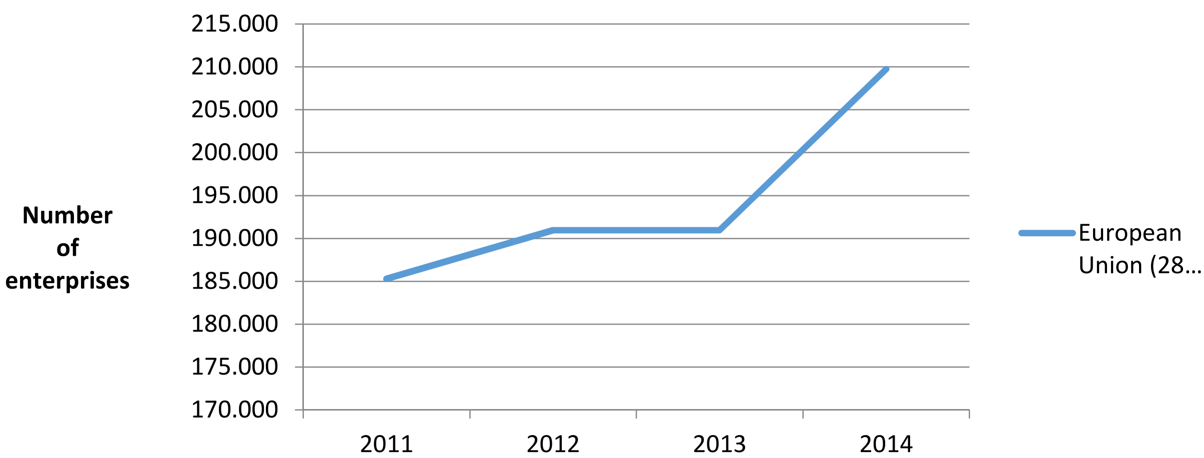


Source: reproduced based on data provided in OVAM, 2015

As regards repair activities, Eurostat reports on the repair of computers and personal and household goods. Trends for the EU as a whole are depicted in Figure 18, showing growth of around 14 per cent between 2011 and 2014. Despite this growth, it should be noted that even in those countries with the largest repair activities, contribution to the non-financial business economy is low. For example, it accounted for just 0.3 per cent of non-financial business economy value added in the Czech Republic and France — the highest shares among any of the Member States.

Wilts et al. (2014) find that repair and second hand products have become more of a niche phenomenon in rich Western economies, targeting low-income populations. This is due to increasing product complexity, shorter innovation cycles, and conscious degradation of product quality (planned obsolescence), which rapidly lowers the value of products and has helped lead to a subtle throwaway mentality: it is assumed that as waste is somehow recycled, re-use and repair are too time-consuming to bother with. Overcoming this societal stigma in addition to the vested interests in generating waste to feed waste incineration and recycling infrastructures will require innovative policy tools (see for example Box 7 on promoting re-use through tax breaks in Sweden and Box 8 on promoting industrial symbiosis in the UK).

Figure 18: Repair of computers, personal and household goods in the EU-28, 2011-2014



Source: Eurostat (sbs_na_1a_se_r2; accessed May 2017)

Box 7: Reduced taxes for repair of household commodities in Sweden

At the beginning of 2017 a new tax law was implemented in Sweden to reduce value added tax (VAT) rates on repairs to bicycles, clothes and shoes from 25% to 12%. It also enables half of the labour costs to repairs on appliances, like fridges, ovens, dishwashers and washing machines, to be claimed back from income taxes. In this way, Sweden aims to promote repair activities to reduce waste generation and lower emissions.

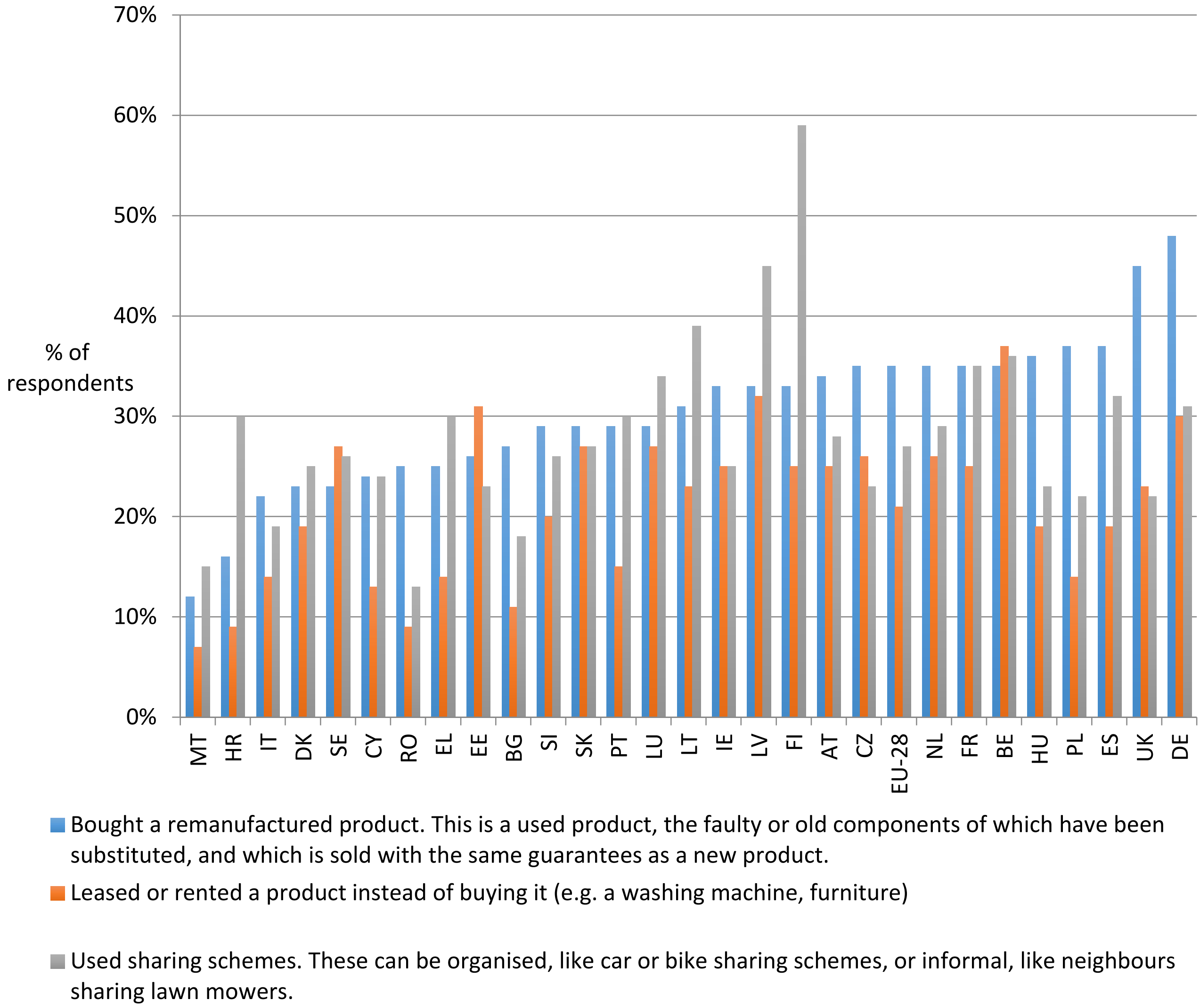
Source and more information: Government Offices of Sweden 2016; www.recyclingpoint.info/sweden-repair-your-goods-to-pay-less-taxes/?lang=en

Box 8: The National Industrial Symbiosis Programme in the UK connects companies to optimise resource use and re-use while saving costs

Industrial symbiosis engages different organisations in a network to foster eco-innovation and long-term culture change. It provides mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes (Lombardi and Laybourn, 2012). Over five years (2005-10) the UK Government invested £27.7 in the NISP programme, which not only achieved material and energy savings, but also managed to leverage around 5 times as much private investment as the initial public investment, generated £1 of extra sales, and saved £1 of business costs with a public investment of less than £0.1, and returned to the UK Treasury more than three times the initial public investment (see also UNEP, 2017).

The circular economy will depend on citizens willing to engage in 'alternative forms' of consumption. Figure 19 shows the between around 10 and 40 per cent of respondents to a 2013 survey had already engaged in some form of circular economy practices, such as buying remanufactured products, leasing or sharing. It shows that the types of activities citizens engage in are also quite different in different Member States. For example, sharing schemes seem quite prevalent in Finland and Latvia, leasing is most popular in Belgium and buying a remanufactured product is by far the most prevalent forms of 'alternate' consumption in Germany and the UK.

Figure 19: Share of EU citizens who have chosen alternatives to buying new products (remanufactured products, leasing, and sharing schemes), 2013

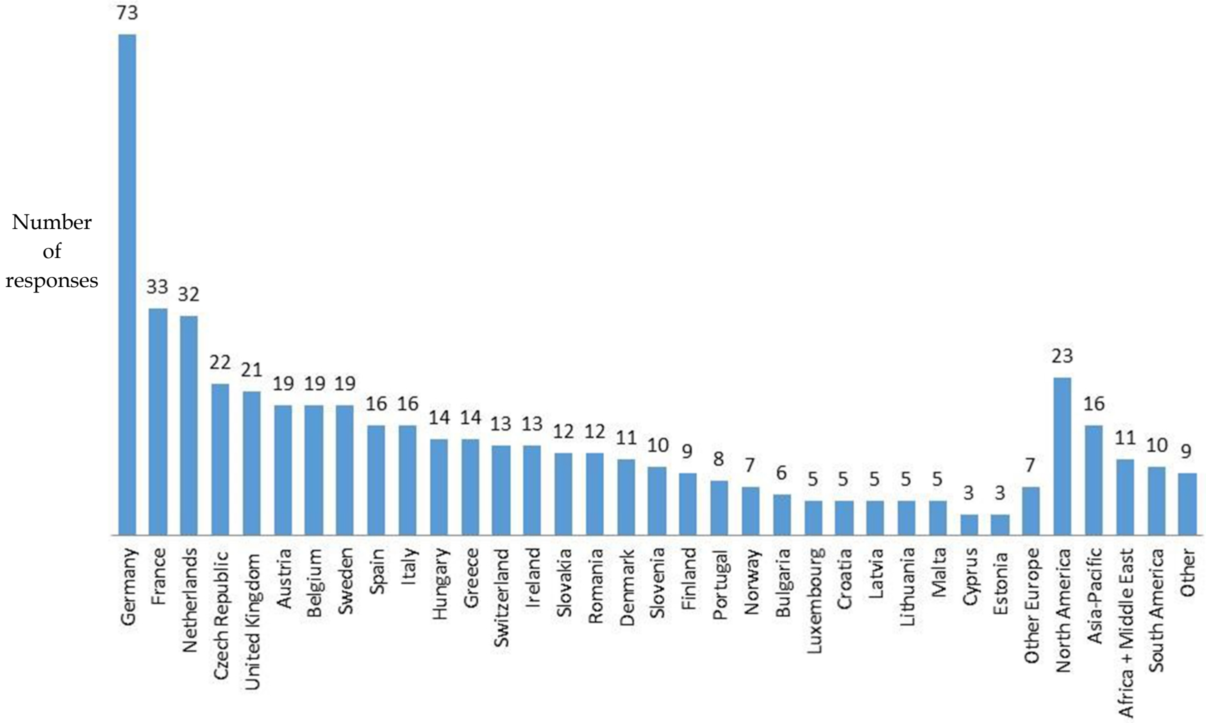


Source: Eurobarometer 388 (Survey in 2013; study published in 2014; EU, 2014).Question: 'There are emerging alternatives to buying new products. Have you ever done any of the following?' (multiple answers possible)

Trends in remanufacturing at the citizen level in Germany reflect the leading position of remanufacturing activities by German enterprises in the world. Figure 20 shows that 14 per cent of total respondents to a remanufacturing survey reported that their firm is active in Germany. In particular the sectors aerospace, automotive, heavy duty and off-road equipment and electronic and electrical equipment and machinery and medical equipment saw high levels of remanufacturing (Parker et al., 2015).

Altogether, despite some positive emerging trends in both downstream and upstream processes, the challenges of effective waste prevention are significant. A particular challenge is overcoming vested interests in waste generation and this will require a systemic, integrated and holistic approach to circular economy that goes current resource efficiency or waste prevention programmes. In this respect support for re-use, repair and remanufacturing are vital components of waste prevention in need of monitoring, modelling and policy support

Figure 20: Geographical distribution of remanufacturing activity, comparing EU and world activities, 2015



Source: Parker et al., 2015

3.3. Key challenges related to data, monitoring and interpretation

The issue of waste data quality and comparability between Member States is a fundamental challenge. This includes not just the quality of the data itself, but also the very definitions of waste streams and the measuring methodologies that can significantly impact the volumes recorded. The current situation hinders a true assessment of the issue of waste management and potentially limits the full understanding of progress in moving towards a more circular economy. Box 9 presents challenges related to the definition of municipal waste whereas challenges related to the definition of food waste and remanufacturing are presented in Annex 2.

The issue of poor data quality is well recognised. Significant further work is required around this issue to support fair and effective comparisons between Member States and to ensure a level playing field concerning how Member States reach the targets. There are inherent difficulties in gathering good quality waste data, and whilst there is always a point at which the benefits of improving data quality is outweighed by cost, there are still steps that could be taken to improve data quality. Some of the key issues relevant to the waste streams discussed in this report and how they might impact progress towards greater circularity are highlighted here.

Box 9: Significant inconsistency in the definition of municipal waste contributes to data uncertainty

The EEA (2013) reports on the 'significant inconsistency' in the definition of municipal waste used by Member States. Significant variations arise from:

- The inclusion of bulky or garden waste in municipal waste data resulting in higher municipal waste per capita figures than a country that excludes these waste fractions;
- Whether countries include only waste from households, or include similar waste types coming from other sources, such as commercial activities and offices. The European Commission reports (European Commission, 2016i) that non-household waste can range from 10 to 40 per cent of total municipal waste; and
- Some countries include separately collected packaging from households, whereas other countries do not.

The ETC/SCP (2014) reports that at a regional level, it is not always possible to provide information on all generated municipal waste. Reasons for this include:

- Part of the waste is not collected, for example it is disposed of by the households, e.g. home composting, burning or fly-tipping, etc.
- Municipal waste is sent out of the region, making data on end treatment more difficult to obtain.

Critiques of the 2012 Eurostat dataset on municipal waste identified many data gaps. The intention of the European Commission's report **Guidance on Municipal Waste Data Collection** was to improve the consistency and accuracy of the dataset across EU-28 (European Commission, 2012). In 2013, the EEA stated that the communication of the guidance report would improve the quality of the dataset (EEA, 2013). Its effectiveness, anticipated in the 2016 data, is yet to be assessed.

3.3.1. Measuring municipal waste recycling targets

In 2011, a Commission Decision was made (European Commission, 2011) that Member States can select one of four different calculation methods to report compliance with the Waste Framework Directive's municipal waste target of 50 per cent re-use and recycling by 2020. The four methods are shown in Table 15.

Table 15: Reporting methods for compliance with Article 11(2) of the Waste Framework Directive

	Measurement method	Member States using method
1	Recycling rate of paper, metal, plastic and glass waste from households	MT
2	Recycling rate of paper, metal, plastic, glass household waste and other single types of household waste or of similar waste from other origins	AT, CY, CZ, GR, HU, IT, LT, PL, PT, SE, SK
3	Recycling rate of household waste	BG, LU, UK
4	Recycling rate of total waste municipal waste	DE, ES, FI, LV, SI

Source: EEA, 2013

The EEA (2013) reports that, if using method 2, and based on typical waste composition, the 50 per cent 2020 recycling target could be met with an overall recycling rate of municipal waste nearer 25 per cent. Furthermore, household waste accounts for between 60 per cent and 90 per cent of municipal waste across the EU-28 (European Commission, 2016b), and hence compliance using method 3 can be achieved with an actual recycling rate of between 30 per cent and 45 per cent of total municipal waste.

The two major consequences of having various methods of calculating this are:

- The actual benefits and overall impact of meeting the recycling targets will be much lower than planned; and,
- National infrastructure investment and building programmes will be designed to achieve these targets and will result in a long-term impact well beyond the 2020 target date. Should targets be incorrect, these projects will be extremely costly and problematic to reverse in the short to medium-term.

Illustrating this issue, Egiseau (2013) reported that although Romania had not decided on which of the four methods to use, the first method was being favoured since this would be easier and less costly to implement than the other three calculation methods. Paper and cardboard, glass, metals and plastic together represent 31 per cent of the weight composition of household waste in Romania and so the 50 per cent target could be achieved by recycling only 15.5 per cent of the total household waste. As a consequence of this, Romania is placing more emphasis on diverting waste from landfill and less on recycling. This is evident from the planned infrastructure build between 2014 and 2020. The intention is to invest €37.9 million on increasing sorting plant capacity by 330,700 tonnes, €82.7 million on increasing MBT plant capacity by 483,880 tonnes and €1 013 million on increasing incineration plant capacity by 1,340,160 tonnes.

3.3.2. Measuring packaging waste recycling rates

Plastic Recyclers Europe (2013) questions the manner in which the Packaging Directive targets for plastic packaging have been calculated as:

- The targets are based on the amount of plastic waste collected **rather** than the amount of plastic finally recycled.
- The Packaging Directive does not provide a definition to estimate the quantity of packaging put on the market, or an approach to calculating the recovery and recycling rates in detail, to ensure data comparability.

Member States currently use different methods for calculating national recycling rates, which makes comparison difficult. In the worst case, the calculations are said to be based on waste which is collected or sorted, but which might not actually get recycled. Plastic Recyclers Europe (2016) report that the non-ferrous metals, steel, paper and plastics recyclers industries are in favour of a harmonised EU-28 method to measure recycling rates at input into the 'final recycling process' rather than the total material collected. The European Container Glass Federation (FEVE, 2016) is in agreement regarding the need for accurate and harmonised calculation methodologies. The Extended Producer Responsibility Alliance (Expra, 2014) questions how, under such circumstances, conclusions can be drawn that Member States have met recycling targets.

The implication of changing the step within the collection and recycling at which recycling volumes are measured will make current recycling rates look less positive, and make the recycling targets harder to achieve, but would provide a more realistic picture of recycling and of monitoring progress towards circularity.

3.3.3. Clarity in accounting for residual waste

From a circular economy perspective, the process losses, or residue from treatment facilities, represents 'leakage', unless it is further processed into secondary raw materials. Residual municipal waste can be hidden from view through statistical definitions. Residue from incinerators, or to a lesser degree, from

MBT processes are frequently landfilled, but no longer defined (so not captured) as municipal waste. Achieving a target of zero municipal waste to landfill through the incineration of waste is therefore deceptive, as the secondary residue, which can be substantial, is typically landfilled (Zero Waste Europe, 2015a). Whilst the calculation of targets this way fits within current legislative reporting requirements, it does not support circular economy objectives of higher material recirculation rates. Through achieving landfill bans and reduction targets through incineration, long-term investment decisions have been made that do not progress Europe towards circular economy ideals.

3.3.4. Ensuring higher recirculation

Member States typically report recycling rates as the volumes input to the treatment process or collected, but this does not represent the quantity of material that will eventually be re-circulated back into the economy. Not all of the material sent for processing is recovered. The volumes of material retained is called the yield rate. This can vary, for example:

- Composting has a 41 per cent yield rate, i.e. 41 per cent of input material is processed into compost;
- Anaerobic digestion results in 35 per cent digestate and 10 per cent biogas; and
- Plastic recycling has up to a 60 per cent yield.

Low yield rates are a particular issue for recyclates destined for high quality secondary markets where the purity of the material is of paramount importance, such as for food grade polymers. From a practical perspective, accurately measuring the yield losses from treatment processes represents a significant challenge. This can be especially problematic for waste that is exported for treatment, for example WEEE. The 2012 Guidance Report describes how residue should be allocated by treatment method (European Commission, 2012).

An issue to be considered is that the targets should not inadvertently encourage the uptake of low quality recycling that lowers the value of resources at the expense of high quality recycling or remanufacturing. In low quality recycling, yield rates are typically higher due to a higher tolerance of impurities, and hence the recycling rate from such processes would be higher than in the case of high quality recycling. However, this might be at the expense of reducing value of resources in the longer terms and not facilitating closed loop recycling. It can therefore be easier to hit volume-based recycling targets when low grade secondary markets are used. On the other hand, if only a small fraction of the material is sent to high quality secondary markets and the remainder is residue sent to disposal then this is unlikely to represent the best environmental option for the whole waste stream. Further work is needed to understand this dynamic more completely. This could be the case when treating bio-waste where the production of bio-energy is a high volume, low value option and bio-chemicals a low volume, high value option.

With respect to the proposed EU Circular Economy Package, FEVE states that 'the targets and calculation method should be functional to the objective of driving progress in waste collection systems and infrastructure for more and better quality recycled glass'. In 2014, of the 73 per cent of glass recycled in the EU-28, 82 per cent was processed into new glass containers. The UK falls well below this 82 per cent with over one-third of glass being used as an aggregate substitute with negligible environmental benefit. To tackle this, the UK Government has introduced a split target scheme to encourage the closed loop recycling of glass through encouraging higher percentages of remelt and less use of glass as aggregate.

Box 10: Key findings and messages from Chapter 3

- The highest share of waste in the EU-28 is disposed of through landfilling (41 per cent) with non-energetic recovery and recycling comprising 36 per cent. Half of the Member States currently landfill more than 50 per cent of their municipal waste, while 6 Member States have met the 2030 target of no more than 10 per cent of municipal waste landfilled. Only Germany has met municipal waste recycling targets.
- Municipal waste comprises around 10 per cent of total waste (construction minerals are the highest share in terms of volume). Nevertheless, this report focuses on municipal waste as it is one of the most polluting streams and has high potential for improvement through better management and integration of circular economy practices.
- Around 476 kg per capita of municipal waste were generated in the EU-28 in 2015, with around two-thirds of Member States reducing their levels of per capita municipal waste generation over the last decade.
- In general, countries with higher levels of GDP also have high levels of municipal waste generation, as well as relatively advanced waste management processes with higher shares of recycling, composting and digestion. Those with lower levels of GDP typically generate less municipal waste per capita, but also landfill much higher shares.
- Food waste comprises around 11 per cent of municipal waste and it has been estimated that edible food waste costs EU consumers €98 billion per year.
- Waste from electrical and electronic equipment are one of the fastest growing waste streams in the EU (growing at 3 to 5 per cent annually). It contains precious metals and critical raw materials, making it key for expanding circular economy principles focused on value retention.
- Monitoring of the circular economy is at a less advanced stage. As a circular economy shall promote sourcing of resource inputs from secondary (recycled) sources, also measuring the inputs of primary resource consumption is critical. This also reflects the need to measure activities further up the production chain, from the design phase to use, re-use, repair and remanufacturing. Data is available at a more case study level and through one-time studies. For example, specific reports reveal the strong growth of e.g. re-use shops in Flanders and the prevalence of remanufacturing in Germany when compared to other Member States.
- Data quality and comparability is a fundamental challenge to monitoring waste and circular economy performance; this relates both to inconsistency in definitions and measurement methods, including how target attainment is measured. There is a risk that low-quality recycling (that is high volume) takes precedent over high-quality recycling (which is low volume, but associated with higher environmental and economic benefits) if monitoring indicators and targets are not better distinguished.

4. Technologies for waste management

This section provides a review of the established and emerging waste management treatment technologies relevant to the recovery of the material streams that this study focuses on. Technologies that represent best environmental practice in the field of waste management are already set out in European legislation and in European reference documents such as the **Best Available Reference Documents** (BREFs) for waste incineration and waste treatment. The waste treatment BREF is currently under revision from its current 2006 edition.

The following technologies primarily focus on the processes of segregating waste streams from mixed or commingled streams to enable the further use of the resulting secondary materials—in other words this chapter focuses on the outputs end of the economy and the state of technological processes to recover valuable resources for secondary use. The recycling technologies for processing technical materials are well established and well cited with the closed loop recycling of glass, aluminium and steel being case in points. However, plastic does represent an issue, and is covered here.

The selection of technologies presented here does not aim to give a full picture of technological developments in the waste management sector but presents technologies that have the potential to strongly influence waste management performance in Europe. The key environmental impacts of the various waste management technologies are included in Annex 7.

4.1. Municipal waste

4.1.1. Mechanical biological treatment (MBT)

MBT in summary:

A pre-treatment technology for tackling mixed waste with the mechanical phase separating out the technical materials and the biological phase, such as anaerobic digestion (AD) or composting, the organic fraction

Likely role in achieving circular economy objectives: MBT can contribute to ensuring the achievement of the targets in the Landfill Directive. It can contribute significantly to the reduction of greenhouse gas emissions from landfills; also the production of refuse derived fuels can substitute carbon intensive energy carriers. However, it cannot secure sufficient recycling to achieve the 2020 recycling target of 50 per cent set by the Waste Framework Directive (ETC/SCP, 2014), and the resulting quality of the organic output is low.

MBT has three main outputs: recyclables, low quality soil and refuse derived fuel (RDF), which is a dry mix of materials suitable for incineration (Zero Waste Europe, 2014c).

The mechanical sorting technologies can include (Plastics ZERO, 2012 and Waste Management World, 2008):

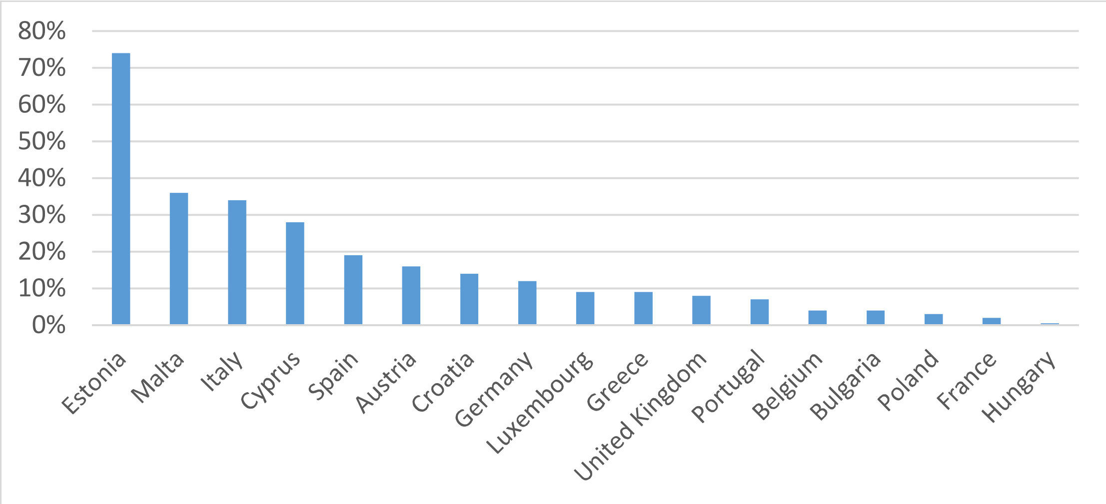
- Drum screens (separation based on particle size).
- Flotation tanks (separation based on density).
- Eddy current separator (metal separation based on the exposition of a changing magnetic field).
- Induction sorting (separation using x ray and infrared sensors positioned under a conveyor belt) using Near Infrared Sensors (NIR) (separation based on material characteristic incident emissions of materials following NIR light application) and x ray technology (separation based on material density).
- Manual sorting.

MBT extracts about 3-7 per cent of input as dry recyclables and, although the organic fraction of mixed waste is stabilised, it is seldom of sufficient quality to be used as fertiliser or soil improver, and it is therefore usually landfilled or used for re-cultivation of landfills (ETC/SCP, 2014). Zero Waste Europe (2014c) reports that the city of Barcelona moved from MBT to the separate collection of bio-waste in 2010 to achieve good quality compost that could be used as a soil improver.

In the Hanover MBT plant in Germany, 195 000 tonnes of residual waste are processed annually and only 3 per cent is recovered for recycling (ferrous metals) with the majority (83 000 tonnes) sent to thermal treatment and 49 000 tonnes to landfill (Vielhaber, 2015). Mass loss/process water accounts for 21 per cent of the process input and this is the reason MBT is regarded as a volume minimisation process; removing moisture to increase the calorific value of the waste fraction being sent to thermal treatment.

Figure 21 shows that Estonia has the highest MBT capacity as a percentage of overall municipal waste. Estonia introduced its first plant in 2007 and in 2013 had four plants with a theoretical capacity of 300 000 tonnes. The major driver for investment was the aforementioned national policies to divert biodegradable municipal waste from landfill (ETC/SCP, 2013d).

Figure 21: MBT capacity as a percentage of total municipal solid waste in Europe in 2010



Data source: Municipal solid waste management capacities in Europe, desk-based study, June 2014

4.1.2. Thermal treatment and advanced thermal treatment

Conventional energy from waste (EfW) provides direct incineration of combustible non-hazardous waste. In a conventional EfW installation the energy generated is either converted into heat (which specifically happens in North European countries with a high heat demand), into heat and electric power (CHP), or electricity only (Coolsweep, 2015).

Figure 22 provides a breakdown of the thermal treatment methods with the respective energy efficiencies. A plant that achieves 'R1 status' for energy efficiency can officially be classed as an energy recovery site rather than a waste disposal site. Coolsweep (2015) reports that currently 66 per cent of European incinerators reach the R1 efficiency status.

The major barrier to EfW in some countries is public opinion. Coolsweep (2015) reports that 'in countries where Waste to Energy is less well known the public often has outmoded pre-conceptions about the industry, based on emissions in the past'.

Thermal treatment in summary:

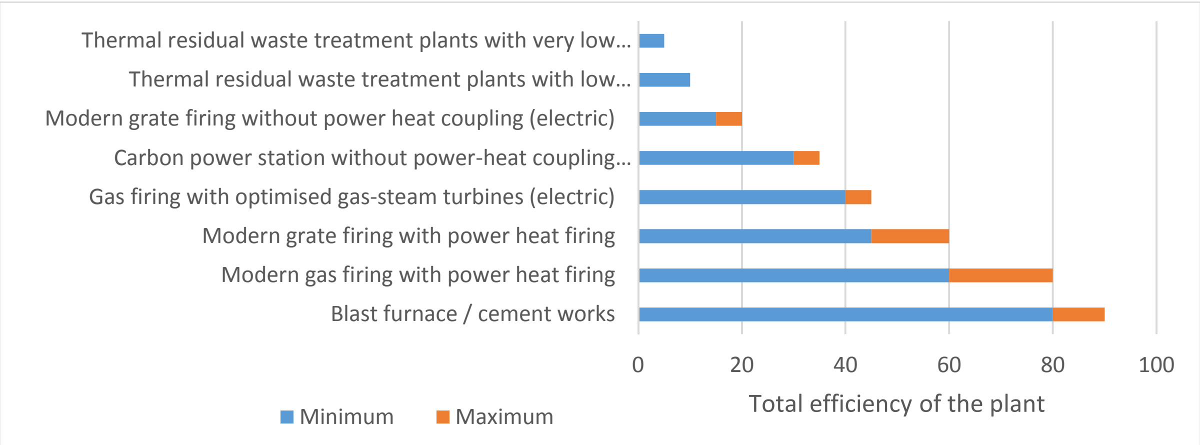
Thermal treatment is a very broad group of technologies ranging from incineration to the more advanced, but less proven, technologies such as plasma gasification.

Likely role in achieving circular economy objectives: The waste hierarchy clearly states that recycling should be preferred over waste incineration and deviations from the waste hierarchy must be justified on a case-by-case basis by a 'life-cycle analysis' demonstrating that observing the hierarchy for a specific waste stream would be technologically feasible and lead to higher socio-economic and environmental benefits. Incineration of certain hazardous waste, for example when containing substances of very high concern (SVHC) listed in Annex XIV to REACH can be more suitable than recycling when, in this case, the SVHC cannot be removed or continued use cannot be authorised under REACH because it cannot be demonstrated that the recycled material containing the SVHC can be used safely or that the benefits of continued use outweigh the remaining risks.

EWB (2015) predicts that European Waste to Energy (WtE) plant capacity will rise to around 116 million tonnes in 2019. Much of this new capacity will be in the UK and Ireland where EWB predicts an increase of 12.6 million tonnes, and it is predicted that much of this will be advanced conversion technologies: gasification, pyrolysis and plasma gasification. However, Energos, one of the major providers of gasification technology, due to build four plants in the UK, went into administration in July 2016, citing cash flow and contractual issues (Bioenergy News, 2016). In Europe, WtE for district heating represents 50 TWh per year and the Heat Road Map Europe 2050 suggests that the potential is 200 TWh per year by 2050.

A recent communication by the European Commission (2017) has highlighted the need to balance incineration capacities. If additional incineration capacity is indeed needed Member States should take into account the right capacity of the plant over its lifespan to avoid circumventing the waste hierarchy in the future and to avoid re-diversion of feedstock supply from material to energy users.

Figure 22: Comparison of the efficiencies of different thermal methods of waste treatment



Source: Scula Agraria del Parco di Monza, 2006

Two other forms of thermal treatment are available; pyrolysis and gasification. The two technologies generate products which can generate energy, solid residue (char) and synthetic gas (syngas) on the same level as fuel (Defra, 2013). Both these thermal treatment options require glass- and metal-free waste streams. Hence, it is recommended to pre-treat the MSW to separate out such materials.

Pyrolysis operates in absence of oxygen and produces bio-char, gas and oil (Defra, 2013). Fast catalytic pyrolysis has recently been developed which yields bio-oil containing aromatic and aliphatic hydrocarbons (rather than slow conventional and irreversible pyrolysis which produces mainly bio-char) (Bardhan et al., 2015). The advantage of pyrolysis lies in the number of operational variables which can be optimised. Single or multi-feedstocks optimisation is possible, and the influence of process parameters is currently being researched for the production of phosphorus-rich fertilizer when using municipal waste as a feedstock.

Gasification produces syngas together with char in the presence of oxygen. It includes traditional fixed and fluidised bed gasifiers and an entrained suspension gasifier which presents the advantage of being able to treat a great number of lignocellulosic feedstocks following size-reduction. Syngas can then be upgraded to produce hydrocarbons through Fisher-Tropsch synthesis. This allows the use of existing processing and transport infrastructure for the hydrocarbons produced, giving an advantage to gasification over pyrolysis (Bardhan et al., 2015).

FEAD (2016) states that the Commission should be cautious of calling gasification and pyrolysis 'mainstream technologies', especially for mixed municipal waste. The Coolsweep (2015) report states that pyrolysis, plasma gasification and gasification could all gain relative market share but there are still concerns about these technologies. For gasification, the need for a certain degree of pre-treatment makes it costly when compared with energy from waste (EfW) and the benefits have yet to be defined at a commercial scale.

In 2015 the European Commission, in cooperation with the Joint Research Centre (JRC), initiated a study 'Towards a better exploitation of the technical potential of waste-to-energy' (Saveyn et al., 2016). The study describes the state-of-play of incineration and other waste management options for different wastes in the EU and provides an assessment of proven and emerging techniques for increased energy recovery in waste-to-energy processes. Techniques for improving energy recovery were discussed for each of the five main categories of waste-to-energy processes: combustion plants, waste incineration plants, cement and lime kilns, anaerobic digestion plants and others. Using the technical options available today, and without taking into account any possible changes to the types and amounts of waste currently sent for energy recovery, this value could be increased by more than a quarter.

4.1.3. Bottom ash recovery

Bottom ash can contain toxins such as heavy metals, especially if animal by-products have been mixed with general waste and incinerated together. The same issue occurs for sewage sludge which is incinerated. Technologies are available to tackle these issues. Ash can be purified, to remove heavy metals and extract phosphorous, but the technique uses sulfuric acid, a compound presenting problems in itself due to its hazardous character and its disposal (Cohen, 2009).

Phosphorus can be recovered from incinerated waste. In Sweden and in Japan, municipal waste has been found to contain a similar amount of phosphorus as sewage sludge due to a high fraction of food waste, but also to a high content of paper, wood and textiles (Kalmykova and Karlfeldt Fedje, 2013). Technologies to extract phosphorus from fly ash are available. They include electro-kinetic, thermos-chemical, bioleaching and accumulation, wet chemical methods (e.g. acid leaching) and 'acid-base leaching with subsequent precipitation' (Kalmykova and Karlfeldt Fedje, 2013). Most of these methods require long processing times and are not deemed particularly efficient. The exception is the wet chemical method, which has shown promising results for phosphorus extraction using two alternative approaches: the 'two-step acid-base leaching' technique and 'acid dissolution-alkali precipitation' technique (Kalmykova and Karlfeldt Fedje, 2013).

4.2. Packaging and packaging waste

4.2.1. Lightweight packaging plants

Lightweight packaging plant in summary:

Lightweight packaging plants can sort and classify different types of packaging waste that has been collected as commingled recycling streams.

Likely role in achieving circular economy objectives: Lightweight packaging plants are effective in separating mixed packaging waste streams, such as those collected through part segregated municipal waste collection processes with yield rates of between 60-95 per cent depending on the material type. They can therefore contribute to the achievement of recovery and recycling targets.

Lightweight packaging plants have progressed from manual sorting systems to state of the art automated systems that detect and sort different material types. Table 16 shows the sorting technologies and recovery yields of a state-of-the-art lightweight packaging plant. This shows that the recovery yield for ferrous metals is particularly good at over 95 per cent but for other products yield rates can be as low as 60 per cent.

Table 16: Material recovery in state-of-the-art lightweight packaging plants

Product	Sorting technology	Recovery yield (%)	Reprocessing route
Ferrous metals	Magnetic separation	>95%	Steel industry
Non-ferrous metals (Al)	Eddy current	60-90% (typically 80%)	Pyrolysis and Al industry
Beverage cartons	Near Infra-red	90%	Paper industry
Plastic foils >A4	Air separation, Near Infra-red, foil grabber	>70%	Mechanical recycling
Hard plastics (PE, PP, PS, PET)[10]	Near infra-red	70-90%	Mechanical recycling
Mixed plastics	Near infra-red	>80%	Mechanical recycling or energy recovery
Residues	-	-	Energy recovery

Source: European Commission (2016i)

4.2.2. Plastic sorting plants

The EEA (2011) highlights that the sorting of plastics at the preliminary stage is the most significant activity in the recycling loop. It is not economically viable to source-segregate plastics and the recycling process therefore requires separating each type and grade of polymer at a pre-treatment stage. This is typically a manual process, but automated technologies are being developed. A summary of the developing technologies is provided in Table 17.

[10] PE = polyethylene, PP = polypropylene, PS = polystyrene, PET = polyethylene terephthalate. Also, HDPE = high density polyethylene.

Plastic sorting plants in summary:

Automated technologies exist and are being developed to sort different types and grade of plastic polymer. This process allows for the recovery and recycling of different plastic types.

Likely role in achieving circular economy objectives: Plastic sorting plants facilitate the recovery and re-use of plastics and can therefore contribute to the achievement of recovery and recycling targets.

Table 17: Sensor technologies used for sorting complex plastics

Plastic type	Technology applied for automated sorting	Performance
Food grade recycled PET flakes	TOMRA AUTOSORT sensor (UV VIS spectroscopy for colour detection, NIR spectroscopy for polymer contamination detection, metal sensor for metal contamination detection)	Effective sorting > 2 mm particle size. Contamination levels reached: < 10 ppm PVC, < 3 ppm metallic particles, < 200 ppm polymers (coloured or uncoloured)
Food and non-food PE	TOMRA Extended wavelength scanner differentiates two different grades of the same polymer: the homo- (food) and co-polymer (non-food) of PE	>99 % purity
Opaque PET	NIR fingerprint spectroscopy	On-going implementation
Black plastics	Pigment addition (marker technology) to allow for UV VIS or NIR spectroscopy detection	On-going research
	Steinert Hyper Spectral imaging	PP/PE recycled granules reaching €900 instead of €200 due to increased purity
Plastics in WEEE	8 to 80 mm particle size sorting followed by far UV spectroscopy	Ongoing research
Plastic films	NRT's NIR spectroscopy and controlled ejection pattern coupled with high speed cameras	Recovery rate similar to plastic containers
HDPE bottles	Image recognition of particular packaging shape or brand to allow implementation of effective EPR scheme	On-going research Likely packaging deformation hinders access to ~ 100 % detection rates
Food-contact and non-food contact PET mixture	Food-contact approved Polymark chemical marker technology Machine readable fluorescent inks	On-going research Substitute for current NIR technology detection of multiple markers as 'binary code' is still to be developed

Adapted from: Waste Management World, 2015b, 2016a and 2016b, WRAP 2011 and 2014b

4.2.3. Plastic recycling

The EEA (2011) reports that a greater variety of technologies are needed to recycle plastic than any other waste types. Reasons include:

- differences in the purity of post-producer and post-consumer waste;
- varying treatment needs for different types of plastic.

Plastic recycling in summary:

Following segregation, a great variety of technologies are used to recycle plastics. PET and HDPE are significant markets recycling into, for example plastic bottles, polyester yarn, strapping, engineered resins for the automotive sector etc. Recent advances in technologies and the introduction of standards has facilitated food grade re-use opportunities.

Likely role in achieving circular economy objectives: Price is a key determinant in the demand for recycled plastics (and therefore for the viability of the recycling operations), as it is frequently used as a substitute for virgin fossil fuel based products. Higher oil prices therefore support the development of secondary markets in plastic and therefore the economic viability of plastic sorting plants. Conversely, the industry is vulnerable to falling oil prices. There is innovation in the field of plastics recovery and recycling enabling a wider spectrum of plastic types to be recycled. However, the move towards more complex multi-layer and multi-material products in the food packaging sector which extend product shelf life have the negative impact of being a barrier to recycling.

Plastic Recyclers Europe (2013) reports that mechanical recycling (grinding, shredding, washing, drying and melting) is considered 'almost always' the method used to recycle plastic. The yield or efficiency of this process varies from plastic to plastic, but the average is around 60 per cent.

Technological advances in the removal of contaminants has enhanced the value of recycled plastic, enabling recovered plastic to be converted into food-grade polymers including two significant markets of recycled PET bottles and HDPE milk bottles.

Chemical recycling technologies exist, especially for plastics made of several monomers. This allows the recovery of virgin quality monomers and create 'infinite' loops[11] through:

- depolymerisation to monomers of condensation polymers (PET, polylactic acid, nylon) via hydrolysis, methanolysis, glycolysis, aminolysis;
- fast, mild and selective catalytic cracking of polyolefins (PP and PE or mixed, low-quality or multi-material plastic streams);
- pyrolysis to hydrocarbon wax or oil to be included in subsequent oil refining operations.

Chemical plastic recycling is not yet a cost-effective strategy on a large scale and is typically used where the end value of the product is higher. As an example, the German recycler APK146 has developed a chemical process that is able to extract certain additives such as starch and certain colour pigments, which if allowed to accumulate over time impacts monomer purity and recycled plastic performance. There is a great deal of innovation in the field of plastics recovery and recycling. As an example, the Enval process uses microwave induced pyrolysis applied to plastic-aluminium

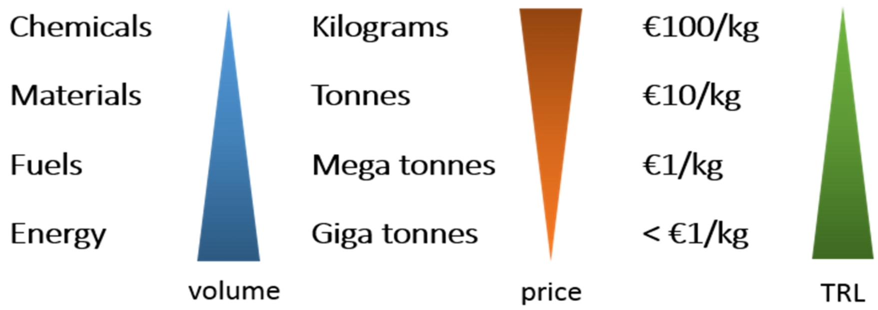
[11] This is in comparison to melt recycling which through repeated melting could lead to problems related to reduced length of polymers and therefore lower value products might result.

laminates from which high quality aluminium can be recovered alongside gas and condensed oils (World Economic Forum, 2016).

4.3. Bio-waste and residues (including food waste)

Once collected, there are several approaches to management of and extracting value from bio-waste including energy from waste (not considered here), anaerobic digestion and valorisation. The approach taken depends on, amongst other factors, the volumes and purity of bio-waste streams to be disposed of and the technology readiness level (TRL) of the various options. The 'value' of waste is a key element of the circular economy concept. In terms of financial value, the different approaches to treating bio-waste have significantly different outcomes. **Figure 23** demonstrates the interplay between the range of outputs from the treatment of bio-waste and the various factors of volume, price and TRL. This diagram does not consider the environmental impacts of the various options, for example the varying degrees of residue that would arise from each technology or the primary materials being substituted/displaced. A STOA (2013b) study on the recycling of agricultural, forestry and food wastes concluded that 'any policy recommendations targeted at the development of biorefinery pathways must be underpinned by clear evidence that the relevant bio-based pathways contribute towards meeting climate change mitigation targets by delivering GHG benefits or other defined environmental benefits compared to the traditional products they replace'.

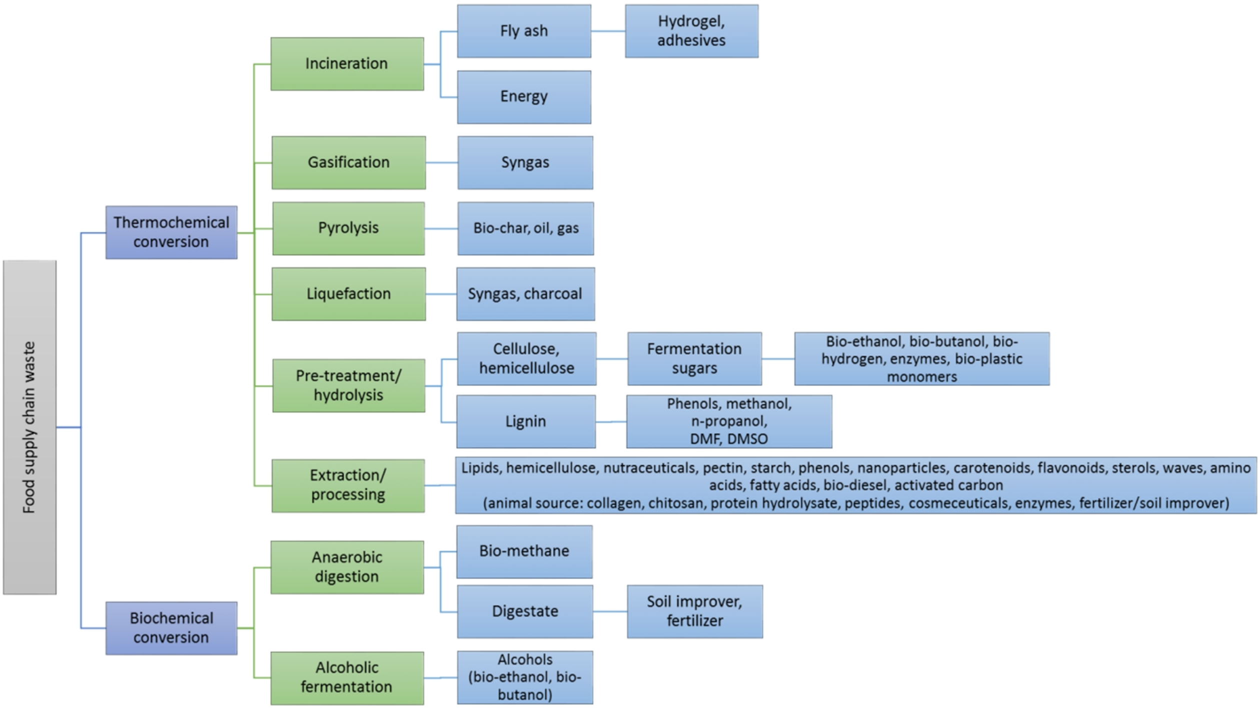
Figure 23: Biorefining value pyramid



Adapted from: 'Building a high value Bioeconomy - Opportunities from waste' (UK HM Government)

A non-exhaustive summary of the compounds accessible from bio-waste is presented in **Figure 24**, alongside the technologies used for their production and their applications.

Figure 24: Products accessible from food supply chain waste



Adapted from: Ravidran et. al., 2016 and Hodásová et. al., 2015

4.3.1. Anaerobic digestion (AD) and composting

Anaerobic digestion and composting in summary:

Composting (requiring oxygen) and anaerobic digestion (in the absence of oxygen) rely on the segregation of organic wastes and their degradation to a stabilised material, digestate, that can, if of the right quality, be used as a fertilizer or soil improver. In the anaerobic process, a methane and carbon dioxide rich biogas is produced that can be used for combustion in transport or energy production.

Likely role in achieving circular economy objectives: Composting (domestic and industrial) and anaerobic digestion are not new technologies. However they are included in this review as their wider adoption is seen as playing a critical role in diverting bio-wastes from landfill and in improving the circularity of biological nutrients. 60 million tonnes of bio-waste generated across Europe could be potentially recycled through AD and composting. This would represent a saving of 1 million tonnes of nitrogen and 20 million tonnes of organic carbon, currently lost as a result of landfilling organic waste (European Compost Network, 2015). The European Commission (2016g) reports that, currently, the EU recycles only 5 per cent of its bio-waste. It is estimated that if more were recycled it could replace up to 30 per cent of the non-organic fertiliser used. The EU imports approximately 6 million tonnes of phosphates per year, so a 30 per cent reduction equates to 1.8 million tonnes.

Composting (also called aerobic digestion) is the oldest method used to manage organic waste. Industrial composting is used for pre-sorted garden and food waste either outdoors, or in a controlled indoor composting facility. It can be defined as 'aerobic biological degradation of organic matter to a stabilised material [which] no longer consumes oxygen nor can generate toxic material' (O'Callaghan et. al., 2016).

Anaerobic digestion (AD) processes organic matter in an environment with little or very low oxygen levels. It utilises a naturally occurring bacterial process to produce digestate and a methane and carbon dioxide rich biogas which can be used as transportation fuel or electricity with heat generation. The digestate can be used in place of synthetic fertilizers following pasteurisation. Two different process conditions can be used: mesophilic (20–40 °C, one to two months to completion) and thermophilic digestion (50–65 °C, below one month to completion). This technology is currently used to treat bio-waste, but also the increasing volumes of sewage sludge and manure (O'Callaghan et. al., 2016).

In Scotland for example, in compliance with the Waste (Scotland) Regulations 2012, businesses generating over 5 kg of food waste per week must present the waste for collection. AD and composting are seen as flexible technologies: they take a wide variety of feedstock types and can cope with high water content. The possibility of smaller scale plants can allow for on-site recycling of nutrients (if used on-farm or at a commercial site, for example) avoiding the high transportation costs that might be associated with incineration.

Table 18 shows the best practice treatment and end fates for three bio-waste streams. This shows that AD is preferable to composting of food waste, but below animal feed, however cannot be used to treat either green cuttings or woody waste.

Producing high grade end-products from bio-waste from separate collection can result in high levels of process yield losses. In the case of composting, the overall yield is 41 per cent, with 'process loss being substantial, likely to equate to loss of water vapour. For AD, the bio-gas generation accounts for 10 per cent of the intake bio-waste and the finished refined digestate 35 per cent (Scuola Agraria del Parco di Monza, 2006).

Table 18: Waste management prioritisation for organic waste streams

Treatment/end fate	Wet organic waste (e.g. food waste)	Green cuttings	Woody waste
Animal feed	1 (if applicable)	NA	NA
Anaerobic digestion	2	NA	NA
Composting/mulching	3	1	2
Combustion with energy recovery	4	2	1

Source: European Commission (2016i)
1 = Ranked first and 4 = ranked last

However, AD is not without its challenges that limit the wider adoption of these approaches. These include:

- a lack of markets for the digestate produced resulting from poor public perception;
- the lack of recognition of AD and composting, especially regarding nutrients recirculation;
- the purity of segregated food waste streams including separation from garden or park waste;
- the capital investment needed in the land and technologies.

4.3.2. Valorisation of bio-waste

Waste valorisation in summary:

Waste valorisation is the process of converting the organic component of waste into more valuable products including chemicals, materials and fuels.

Likely role in achieving circular economy objectives: many of the technologies for waste valorisation are emerging so are not currently used on a large scale. They are more appropriate for homogenous, commercial waste streams rather than municipal organic waste. However, waste valorisation is considered to extract considerably more value from waste streams than AD and composting which are high volume but low value and positioned near the bottom of the bio-refining value pyramid (shown in **Figure 23**). The production of bulk chemicals from biomass waste can be 3.5 times more profitable than the production of energy (Tuck et. al., 2012).

R&D in the area of bio-refining of waste materials previously focused on the production of energy and fuel; but now both the production of bulk and fine chemicals from waste lignocellulosics are being targeted. Lignocellulose is the biopolymer matrix of biomass present in bio-waste. Bio-waste lignocellulosic feedstocks include agricultural residues, short rotation crops, the segregated bio-waste fraction of municipal solid waste, manufacturing waste, and co-product streams.

Agricultural residues and food manufacturing wastes are preferred as they provide waste streams of homogeneous composition, with large volumes, security of supply and simpler logistics in comparison to post-consumer bio-waste.

Biotechnology is seen as key to harnessing the market for fine chemicals, since their value can justify the higher capital investment requirements, especially as they are less prone to the volatility of oil prices. Bio-refining R&D aims to produce bulk chemicals for energy applications alongside the extraction and/or synthesis of fine chemicals. Several pilot plants following this concept are being set-up. For example, the GFBiochemicals plant is producing levulinic acid in Caserta, Italy. It began operating in the summer of 2015, aiming to produce 10 000 tonnes of levulinic acid per year by 2017 through a process based on thermochemical conversion of biomass from wheat straw, corn stover, wood, cellulose and grass (Biomass Magazine, 2015). Further examples are provided in Annex 8.

4.4. Critical raw materials

Valuable CRMs enjoy some of the highest recycling rates, with mature recycling infrastructure and optimised processes. The UNEP estimates that 50-60 per cent of all Platinum Group Metals (PGM)[12] used in catalytic converters are recycled (UNEP, 2011). Whilst the recovery of PGM's from WEEE and other more complex waste streams is not yet as high, perhaps only 5-10 per cent (Hagelüken, 2012), they do receive more attention from researchers than the lower value elements such as indium, gallium and germanium that are economically less viable to recover. Undoubtedly waste prevention for CRMs deserves attention with 'thrifting' or substituting for CRM's in the design of new products. There is also further scope to improve collection and recovery from CRM intensive waste streams, as well as steps to increase remanufacturing and re-use.

[12] The Platinum Group Metals are ruthenium, rhodium, palladium, osmium, iridium and platinum

4.4.1. WEEE recovery technologies

WEEE recovery technologies in summary:

WEEE (waste electric and electronic equipment) recovery processes include decontamination, sorting and separation processes, granulation, shredding and grinding process followed by various separation techniques for the different elements.

Likely role in achieving circular economy objectives: The drivers for recovery of CRM's are derived as much from the sustainability agenda as it is from economic requirements to ensure a consistent and secure flow of materials. The value of many CRMs and the existence of secondary markets clearly indicates potential for increased recovery and recycling rates where economically viable.

Material recycling rates of 77 per cent in Sweden demonstrate that WEEE recovery technologies are well developed in certain applications. However, for WEEE such as printed circuit boards, which are considered the most complex, hazardous and valuable of all WEEE, the recovery rates are still very low (D'Adamo, 2016). The technologies enabling economic recovery of such products has been the focus of much activity for a number of years. The typical treatment process is (D'Adamo, 2016):

- Disassembly: hazardous components are removed from the main board and sent to specialised treatment plants.
- Treatment: the printed circuit boards (PCBs) are crushed in micro pieces using shredders and grinders to make a uniform powder. The powders are then sorted into metal and non-metal streams.
- Refining: the powders are refined using technologies such as pyrometallurgy, hydrometallurgy or a mix. Hydrometallurgy is used when high purity products are sought.

Table 19 provides examples of four pyrometallurgical plants in operation in Europe and the metals that are being recovered.

The European Commission report on the **Best Environmental Management Practice for the Electrical and Electronic Equipment Manufacturing Sector** states that non-destructive extraction methods for PCBs is preferred to destructive methods since the yield rates for gold, silver and palladium are higher. The manual dismantling into main components can yield 80 per cent of the gold, 50 per cent of the silver and 66 per cent of the palladium (European Commission, 2015c).

Table 19: Some integrated pyrometallurgical processes for WEEE recycling

Industrial processes	Metals recovered	Main process features
Umicore's process: in Hoboken, Belgium	AU, Ag, Pd, Pt, Se, Ir, Ru, Rh, Cu, Ni, Pb, In, Bi, Sn, As, Sb	Isasmelt smelting, copper leaching and electrowinning and PMs refinery, lead smelting and refining
Boliden Rönnskär smelters in Sweden	Cu, Ag, Au, Pd, Ni, Se, Zn, Pb, Te	Smelting in Kaldo reactor, upgrading in copper and followed by refining, high PMs recovery
Outotec process	Zu, Cu, Au, Ag, In, Pb, Cd, Ge	Ausmelt TSL furnace, smelting of WEEE in copper/lead/zinc processes
Aurubis: in Germany	Au, Ag, Cu, Pb, Zn, Sn and PGMs	Cu concentrate and WEEE in TSL reactor, black copper processing and electrorefining

Source: Zhang et al., 2015. TSL = Top submerged lanced PGMs: Platinum Group Metals.

The European Commission have financed several projects to develop technologies for recovering WEEE. These include the innovative hydrometallurgical processes to recover metals from WEEE including lamps and batteries (HydroWEEE) and the critical raw material closed loop recovery project (CRM Recovery) (D'Adamo, 2016).

4.4.2. Batteries

Battery recycling technology in summary:

There are well-established methods for the recycling of most batteries containing lead, nickel-cadmium, and mercury. For some, such as newer nickel-hydride and lithium batteries, recycling is still in the early stages.

Likely role in achieving circular economy objectives: Battery re-use is, with or without refurbishment, possible in certain applications. Automotive batteries, including lithium-ion ones, can be used for energy storage applications even if they are at or below 80 per cent of original capacity (ELIBAMA, 2014). With appropriate testing, some of the portable batteries disposed of along with WEEE are also reusable. Further research into developing re-use and remanufacturing options for lithium-ion batteries is necessary, given the difficulties associated with their recycling. The processing of materials recovered from lithium-ion batteries back into the high-purity forms required for their manufacture can also be cost prohibitive.

Batteries can contain heavy metals such as nickel, cadmium and mercury. There are three types of batteries – disposable dry cell batteries (including zinc-carbon and zinc chloride batteries and silver oxide button cells), rechargeable dry-cell batteries (such as nickel cadmium batteries) and wet cell batteries (such as lead-acid batteries).

Table 20 provides a summary of the treatment technologies for waste batteries and the secondary markets. The type of battery is also a key determining factor in its recyclability: established battery technologies, such as lead-acid and nickel metal hydride have better developed recycling infrastructure than newer, often more complex, batteries including lithium-ion.

Currently, lead-acid batteries are used in all petrol and diesel vehicles because they are the only ones that will reliably start in temperatures down to -30 °C. These have the highest levels of recyclability of all batteries, and the recycling rate is approximately 90 per cent. However, the development in lithium-ion batteries able to substitute for lead-acid in this very important automotive starter battery market is widely thought to be imminent. Some lithium-ion batteries can contain up to 35 per cent cobalt (by weight of the metallic portion), as well as graphite anodes and lithium, but are less recyclable than lead-acid because of the variability in their cathode chemistry and complexity of the geometries employed (Gaines, 2014; Nitta, 2015).

Some WEEE and battery projects related to building the knowledge base on CRMs and improving CRM recovery from WEEE and end of life batteries are listed in Annex 6.

Table 20: The treatment technologies and secondary markets for waste batteries

Battery type	Treatment technologies	Secondary materials
Zinc-carbon and alkaline manganese	Hydrometallurgical and pyrometallurgical processes	Zinc, steel and ferromanganese
Button cell	Vacuum thermal treatment	Mercury, zinc, steel and silver
Nickel cadmium	Pyrometallurgical process	99.9 per cent pure cadmium can be re-used in batteries, iron-nickel used in steel production

Nickel-metal hydride	Mechanical separation of plastic, hydrogen and nickel in a vacuum chamber	Nickel for use in stainless steel and other metals such as iron.
Lithium-ion	Pyrolysis	Cobalt and other metals such as iron and copper. The remaining products are used in smelting works, cement factories and as road building materials
Lead-acid batteries	Lead, plastics and acid are separated prior to processing or the batteries are processed whole through heat treatment in a furnace	Lead recovered for re-use in new batteries

Source: European Recycling Platform, 2012

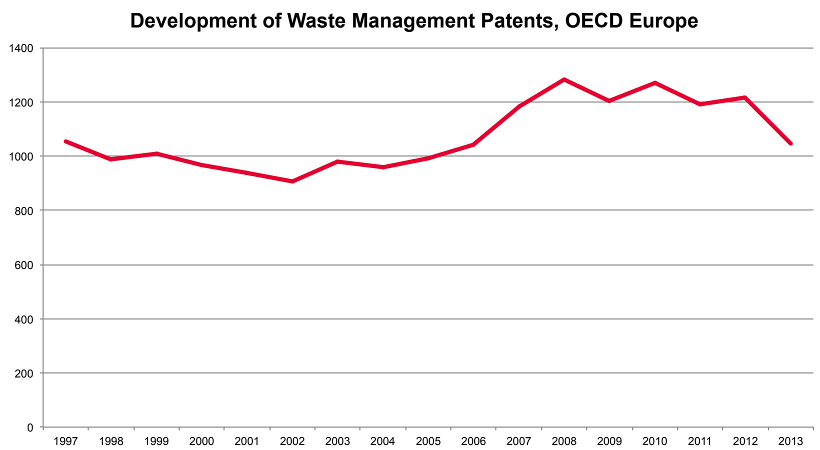
4.5. Key challenges

The analysis of selected waste management technologies highlights that from a purely technological point of view already today almost every waste could be treated as a potential resource and that every material could potentially be recovered. Nevertheless the actual recovery rates for many raw materials are disappointingly low (see Graedel et al., 2011) and underline the need for integrated approaches that embed these technologies into systems of separation at source, and separate collection and production of high-quality secondary raw materials that can replace virgin materials in production processes.

Inter alia, UNEP International until recently highlighted that recycling so far concentrated on specific materials, including metals, as most products were relatively simple; this form of recycling follows a so-called material-centric approach. However, products have become increasingly complex, mixing almost any imaginable metal or other material, and recycling these products consequently became increasingly difficult as trying to recover one material would often destroy or scatter another. It became clear that a product-centric approach would be needed: 'Here, recycling targets the specific components of a product, devising ways to separate and recover them' (Reuter et al., 2013).

Despite these new challenges, an assessment of technological innovations in the waste management sector highlights a stagnation of technological innovations in the waste management sector. As illustrated in the following figure the number of patents filed actually decreased from 1997 to 2013; in clear contrast to e.g. the issue of climate protection where the number of patents more than doubled (Hasic and Migotto, 2015).

Figure 25: Development of waste management patents in Europe, 1997-2013



Source: OECD 2015

The analysis shows that new framework conditions or new financial investments might be needed to attract additional investments into new technologies. Clear and credible targets might be another way to increase the overall level of innovation.

Box 11: Key findings and messages from Chapter 4

- This chapter focuses primarily on technologies to separate and segregate waste streams from mixed or commingled streams to enable the further use of the resulting secondary materials.
- Mechanical biological treatment can contribute to ensuring the achievement of the targets in the Landfill Directive, but cannot secure sufficient recycling to achieve recycling targets. It is thus characterised as a disposal option, instead of as one to gain high-value inputs for the circular economy.
- The waste hierarchy clearly states that recycling should be preferred over waste incineration and deviations from the waste hierarchy must be justified on a case-by-case basis by a 'life-cycle analysis'.
- A greater variety of technologies are needed to recycle plastic than any other waste types, making it an area subject to high levels of innovation. However, the move towards more complex multi-layer and multi-material products in the food packaging sector – which extend product shelf life – have the negative impact of being a barrier to recycling.
- Currently, the EU recycles only 5 per cent of its bio-waste. It is estimated that if more were recycled it could replace up to 30 per cent of the non-organic fertiliser used. Bio-waste valorisation (e.g. conversion to chemicals and materials) is considered to extract more value from waste streams than anaerobic digestion and composting, which are high-volume but low-value.
- Valuable critical raw materials enjoy some of the highest recycling rates, but there is considerable scope to improve collection and recovery from CRM intensive waste streams, as well as steps to increase remanufacturing and re-use.
- Recycling has so far concentrated on specific materials, including metals, in a so-called material-centric approach. As products have become increasingly complex, future efforts may use a product-centric approach focused on the specific components of a product and ways to separate and recover them.

5. Employment and industry considerations

The European Commission (2010) 2020 strategy for smart, sustainable and inclusive growth sets a target of 75 per cent of 20 to 64 year olds to be in employment by 2020. To achieve this target 17.6 million additional jobs are needed. Three main areas that were identified as offering important job creation potential were (European Commission 2012a):

- The green economy;
- Health and social care; and;
- ICT professionals.

Additionally, Draghi (2014) reports that another important factor is the apparent lack of redeployment opportunities for displaced low-skilled workers since recent job losses across Europe have been greatly concentrated among low-skilled workers.

In terms of the green economy, the transition from the 'collect and dispose' method of waste management to one of maximising the retention (value and volume) of resources within the economy will inevitably impact both the numbers of and skillsets of those employed in the sector.

The All-Party Parliamentary Sustainable Resource Group (APSRG, 2015) in the UK states that:

'every tonne of waste diverted from landfill into activities involving re-use, recycling or energy recovery has the capacity to generate new jobs, since these activities are generally more resource-intensive than operating landfill'.

5.1. Current employment estimates

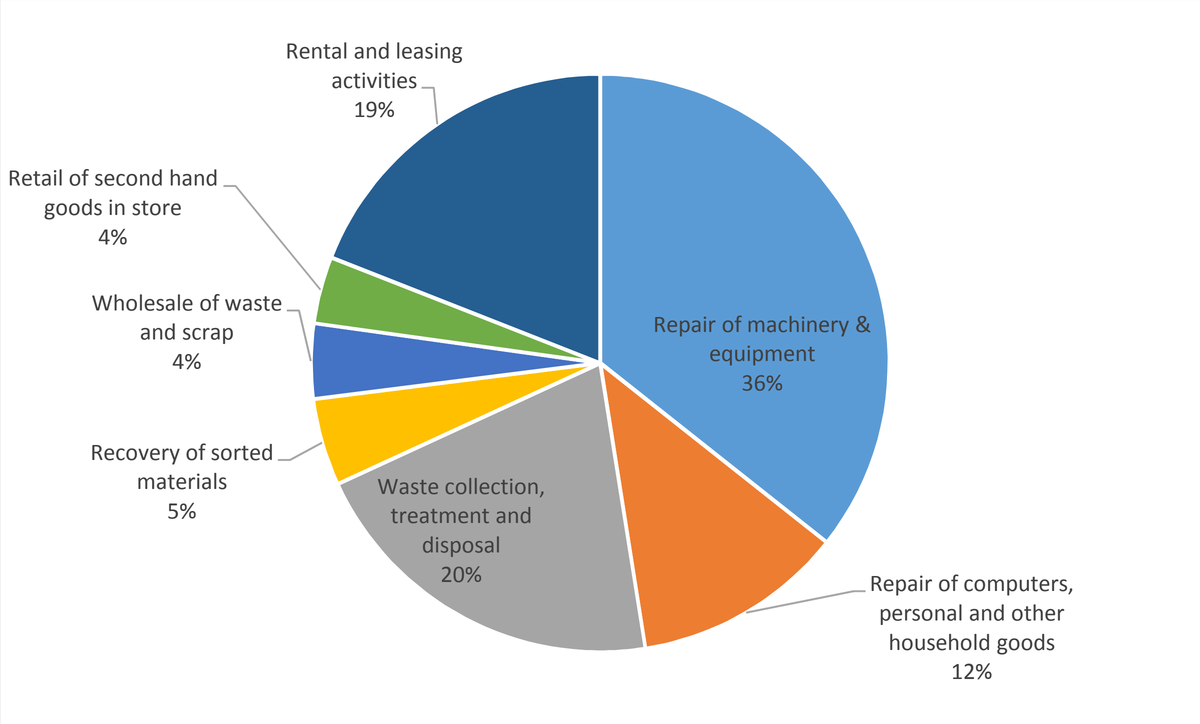
The transition towards a circular economy is seen as important opportunity to create new jobs in Europe. Social innovations associated with waste avoidance, re-use, recycling, eco-design, a sharing economy and other developments offer opportunities to establish more sustainable patterns of consumer behaviour and thus to contribute to human health and consumer safety. In particular, the circular economy can generate new employment opportunities in Europe. It is nevertheless worth noting that the European Commission´s CE Action Plan refers to the growth and jobs potential of the circular economy, while staying shy of major conclusions and figures, except for some figures for the waste sector.

A Club of Rome (2015) report stresses that 'an economy favouring re-use and recycling of materials as well as product life extension is, by definition, more labour-intensive than one based on a disposal philosophy. The main reason, of course, is that caring for what has already been produced – through repair, maintenance, upgrading and remanufacturing – is more labour intensive than both mining and manufacturing (often in highly automated and robotised facilities)'.

A study by the Public Services International Research Unit (PSIRU, 2012) states that Eurostat data shows that over 900 000 people are employed in the waste sector, including material recovery, across the EU. Due to caveats regarding the quality of the Eurostat data, it is concluded that data may underestimate the number of jobs in the sector. Other studies estimate that the sector employs between 1.2 and 1.5 million people. Underestimates might result from Member States using different sector definitions and the method of classifying public sector (municipal) jobs on Eurostat (for example some roles might not be classified as waste management, such as street cleaners, or some roles might not be included as only a proportion of the role is related to waste management.

Going beyond waste management towards a circular economy, WRAP (2015) reports that 3.38 million people were employed in circular economy activities in the EU-28 in 2012. Figure 26 shows that the main activity, accounting for over one-third of employment, is the 'repair of machinery & equipment' and, when combined with the 'repair of computers, personal and other household goods', employment associated with 'repair' activities accounts for nearly half of all people employed in circular economy activities. France Stratégie (2014) reports that in France in 2014 over 214 000 were employed in the repair sector, 100 000 in waste management and 36 000 in recycling which appears in line with these overall EU-28 estimates. RREUSE (2015) reports that thousands of social enterprises across Europe have been active in the repair sector for many years, providing job and training opportunities for disadvantaged workers and giving them a fresh start on the labour market. The core waste management activities of 'waste collection, treatment and disposal' can be seen to account for a rather modest 20 per cent of employment. This highlights the relatively high labour intensity associated with repair activities and the more mechanised nature of waste management.

Figure 26: Distribution of employment by circular economy activity across EU-28 Member States in 2012



Source: WRAP, 2015

Unfortunately, the Re-use and Recycling EU Social Enterprises network[13] (RREUSE, 2015) reports that EU waste policies have led to a priority for recycling, at the expense of re-use, which is much more energy and resource efficient as well as being labour intensive. RREUSE states that jobs in the repair sector are in decline because of increasing obstacles and costs to re-use and repair. For example: in the Netherlands, the number of repair specialist firms for consumer electronics dropped from 4,500 to 2,500 between 1990 and 1997; in Germany 13 per cent of radio and television repair shops closed in 1996 and in Poland, between 2008 and 2010, the number of repair enterprises of personal and household goods decreased by 16 per cent to 14 070 enterprises and the number of people employed dropped by 25 per cent (20,905 employees). France Stratégie (2014) shows that between 2008 and 2014 employment in the repair sector in France dropped from 267 000 to 214 000. Barriers to the repair of modern electronic equipment include (RREUSE, 2015):

[13] RREUSE is a European umbrella organisation for national and regional networks of social enterprises with re-use, repair and recycling activities. Approximately 130 000 workers, trainees and volunteers work across 16 European countries and the USA.

- Lack of access to and high cost of spare parts: costs of repair are higher than purchasing a new appliance;
- Lack of appropriate repair information: no free access to service manuals, software and hardware of product and components, for independent repair operators; and;
- Product design and components without re-use potential: new designs make it increasingly difficult to repair a product or components without breaking them forcefully.

RREUSE (2015b) reports that 'EU waste policy must be more flexible and help facilitate and encourage the possibility of re-use of goods once they have become waste. This is currently a major legal obstacle in some Member States where once products become waste, it is legally impossible to re-use them'. RREUSE reports that exceptions to this downward trend include:

- the automotive sector where repair friendly policies are in place (Regulation EC 595/2009 on type approval of motor vehicles and engines);
- the Austrian Durability Mark for Electrical and Electronic appliances designed for easy repair (ONR 192102);
- Flanders (Belgium) set an employment target of 3 000 FTE[14] jobs alongside a specific re-use target of 5 kg re-used material per capita by 2015 (RREUSE, 2015b);
- Spain has introduced a legally binding preparation for re-use target, separate to recycling, for waste electronics, i.e. the Royal Decree (20 February 2015);
    - From 1 January 2017 to 14 August 2018 for large appliances (2 per cent) and IT equipment (3 per cent);
    - From 15 August 2018 for large appliances (3 per cent) and IT equipment (4 per cent).
- France has a target to increase the amount of used furniture put back on the market by social enterprises by 50 per cent over a 4-year period in comparison to a baseline situation, within the requirements of the French Extended Producer Responsibility Scheme for furniture (RREUSE, 2015b); and;
- Social enterprise re-use networks are currently making available on the market 0.2 kg per capita of re-used textiles, furniture and WEEE in Spain, 1.7 kg per capita in France and 2.3 kg per capita in Belgium (RREUSE, 2015b).

The European Commission funded the European Remanufacturing Network (ERN) through Horizon 2020 and Table 21 provides a summary of the results of a market study undertaken in November 2015 showing activity in remanufacturing in the EU-28 MS (European Commission 2015e). This shows an overall total of 192 000 jobs in the remanufacturing industry, with aerospace and automotive being the prominent sectors accounting for nearly 60 per cent.

[14] FTE = full-time equivalent

Table 21: Summary of employment in remanufacturing activities in EU-28 in 2014

Sectors	Employment (000)
Aerospace	71
Automotive	43
Heavy duty and off road (HDOR)	31
EEE	28
Medical equipment	7
Machinery	6
Furniture	4
Rail	3
Marine	1
Total	**192**

The European Commission report (2015e) shows that the barriers to the further uptake of remanufacturing are very similar to the barriers for repair highlighted above, including:

- Lack of technical information on third party products. Product information is not readily available to non-Original Equipment Manufacturers (OEMs);
- Legal ambiguity. Lack of clarity over what remanufacturing entails;
- Definition of waste. Whether the activities undertaken during remanufacturing are considered 'waste processing';
- Poor design for remanufacture. Particularly where remanufacturing is not embedded within the OEM culture;
- A lack of remediation techniques. In some sectors, technological advances in remediation are needed to ensure that remanufactured products match the performance of new products.

From a recycling perspective, Fischer et al (2011) reports that employment in the European recycling sector increased from 177 000 to 301 000 jobs between 2000 and 2007 with many of the jobs created being for people with relatively low skills.

5.2. Future employment projections

The European Commission (2014k) reported that the implementation of existing legislation on waste prevention and management could create more than 400 000 new jobs and that a review of legislation could lead to a further 180 000 jobs. Again this is a rather conservative estimation that focuses on the waste management sector alone and does not take into account a broader transition towards a circular economy.

Table 22 shows the results of scenario tests undertaken as part of the UK's WRAP study (WRAP, 2015). This shows that current circular economy activities are estimated to result in over 1 million new jobs across the EU-28 by 2030 and further 'transformation' circular economy activities would result in nearly 3 million new jobs.

Table 22: Annual increase in jobs (gross) from expanding circular economy activity to 2030 across EU-28

Scenario	Increase in jobs (gross)
No new initiatives	251 000
Current development	1 191 000
Transformation	2 941 000

Source: WRAP, 2015

The WRAP (2015) report compares the estimates with those summarised from additional literature reported by the Ellen MacArthur Foundation (2015) and concludes that they compare well. For example, the estimates for Sweden ranged from 30 000 to 70 000 for an expansion of the circular economy, in the Netherlands 36 000 to 74 000 and 1.2 million to 3 million across the EU-28.

The analysis by WRAP also highlights the huge differences between gross and net job gains. Table 23 compares all three scenarios of the circular economy and shows all will create new jobs but simultaneously will make jobs in the 'linear sectors' obsolete. A limited net-job profit is expected but will still be significant. An important factor for the interpretation of these figures is the development in other regions of the world: Without a transition towards a circular economy in Europe, jobs might be lost to circular frontrunners somewhere else around the globe without creation of new jobs. To avert skill bottlenecks that may delay the development of new value chains or the deployment of new technologies it is essential to strengthen the education and training that focus on short and long run strategies. This study initiated by DG Environment highlights that 'regarding skill requirements, it can be assumed that skill levels are being raised as a consequence of technical change and (eco-)innovation. This tendency can be explained by the fact that technical change is associated with the need for higher-level skills, which also holds true for green technical change' (SERI 2015).

Table 23: Potential labour market impacts from expanding circular economy activity to 2030 across Europe

	Scenario 1	Scenario 2	Scenario 3
	No new initiatives	**Current development**	**Transformation**
Gross jobs growth*	250 000	1 200 000	3 000 000
Net job creation*	64 000	250 000	520 000
Fall in unemployment rate (% points)	0.02	0.09	0.31

*Figures are rounded to the nearest thousand

A comprehensive literature overview by Horbach et al. (2015) shows the overall potential employment effects of a circular economy as well as the key uncertainties, differentiating between gross and net employment. All in all, the analysis of the economic and especially the employment effects of a circular economy remains an open research field as the available studies only cover parts of this broad concept. The effects of energy savings, the introduction of more renewables or the savings of (raw) material are comprehensively analysed, whereas for instance the employment effects of increased recycling, refurbishment activities, the sharing economy or the digitisation of the economy need to be examined further. Nevertheless, in most cases, the already existing studies point to the positive employment effects occurring in the case that a circular economy is implemented.

5.3. Employment by activity

As already outlined above, the transition towards a circular economy will have very different – positive as well as negative – employment effects for specific activities and sectors. RE-USE (2015c) provides an estimate of the potential for re-use using current practice in Flanders. Assuming 1 per cent of the 243 million tonnes of MSW generated in Europe can be re-used, and taking 80 jobs per 1 000 tonnes of material re-used, 200 000 new jobs would be created. For WEEE re-use an estimate of 93 500 to 170 000 new jobs is made and for textiles 120 000 new jobs. It must be noted that these are very conservative estimates and do not align with the transformation scenario shown in Table 22.

The European Commission (2015e) market study included a scenario test to estimate the future potential in remanufacturing in 2030 (Table 24). This shows that in the transformational case that remanufacturing has the potential to account for nearly 600 000 jobs in 2030 with sectors such as EEE being a major growth area. The possible results of investment in the bio-economy through projects like those funded by the BBI, are that it will create 700 000 jobs, replace 30 per cent of oil-derived chemicals, diversify farmer revenue and reduce greenhouse gas (GHG) emissions. BBI funding should create opportunities for the production of chemicals from biomass, including biodegradable waste through processes developed with the partnership of industry in Europe. In addition, the approach to encouraging security of supply for CRMs will go some way to support the resilience of a number of sectors in the EU. Sectors depending on access to raw materials, such construction, chemicals, automotive, aerospace, machinery, equipment, renewable energy devices, have a combined added value in excess of EUR 1 000 billion and provide employment for some 30 million people (European Commission, 2008a).

Table 24: summary of the future potential employment in remanufacturing activities in EU-28 in 2030

Sectors	Employment (000)		
	Base case	Stretch	Transformation
Aerospace	110	155	198
Automotive	68	95	122
EEE	57	103	145
Furniture	7	13	19
Heavy duty and off road (HDOR)	33	40	47
Machinery	6	8	9
Marine	1	2	2
Medical equipment	15	26	37
Rail	4	6	8
Total	**302**	**449**	**587**

RREUSE (2015c) highlights the significance of re-use from a job creation perspective with estimations showing that for 10 000 tonnes of waste products and materials; 1 job can be created if incinerated, 6 jobs if landfilled, 36 if recycled, up to 296 if refurbished (computers 296, textiles 85, wooden pallets 28) and re-used, and 800 if re-used.

Table 25 provides a summary of the employment requirements in a number of different waste segments. This highlights the low employment intensity of landfill. Interestingly, it also shows that separate household waste collection is less labour intensive than the collection of mixed household waste. This could be due to the crew sizes being smaller for separate collection rounds. A study by the European Compost Network (2016) reports that the number of jobs in the composting sector is dependent on the collection area with 0.72 FTE jobs per 1 000 tonnes required in a rural area but only

0.22 in urban areas. This would be a major contributor to the cost difference between urban and rural collections.

Table 25: Employment in different waste segments in France in 2009

Activity		FTE jobs per 1 000 tonnes
Collection	Mixed household waste collection	1.4
	Separate household waste collection	1.3
	Sorting centres for household waste	0.7
	Transfer stations	0.2
	Civic amenity sites	1.0
	Mixed small business waste collection	0.7
	Separate small business waste collection	0.4
	Sorting centres for small business waste	0.7
Treatment	Incineration	0.3
	Landfill	0.1
	Biological treatment (composting)	0.4

Source: PSIRU, 2012

Table 26 clearly shows the job intensity associated with the recycling of plastics and WEEE. The job intensity of plastic recycling is due to the lightweight nature of plastic, whilst with WEEE it is the complexity of the product. In both, high job intensity translates into high collection and sorting costs, which can be a major barrier to increasing recycling rates.

Table 26: Job gains from specific material recycling activities in the UK

Materials	Collection /sorting	Re-processing (if in London)	Jobs gain per 1 000 tonnes
Plastics	15.6	0	15.6
Paper	2.6	1.9	3.5
Glass (mixed)	0.33	0.42	0.75
Glass (separated)	0.6	0.42	0.75
Green waste	0.5	0.8	1.3
WEEE	40	0	40
Aluminium	11	0	11
Steel	5.4	0	5.4

Source: Friends of the Earth, 2010

5.4. Potential skill requirements

The All-Party Parliamentary Sustainable Resource Group (APSRG, 2015) in the UK describes how the traditional skills of the sector focused primarily on the needs of waste collection and landfill, with civil engineers and mechanical engineers being the most common professionally qualified staff employed as landfill designers and site managers. Chemists and environmental scientists complete the required skillsets, undertaking such support functions as site monitoring.

The introduction of processing technologies results in the need for operational staff with a technical, process-related background and the move to a commodity-market driven model means greater demand for staff with a background in procurement, sales and commodity trading.

Table 27 provides a breakdown of the required potential skillsets by circular economy activity in the United Kingdom. The Green Alliance (2015) study concludes that it seems likely that low and intermediate skilled labour would continue to be a significant proportion for re-use and recycling (closed and open loop, area of collection, handling and processing materials.). Remanufacturing, closed loop recycling and bio-refining would continue to require more mid-level skilled employment. In general, these pay rates are in the mid-wage range and, therefore, it is quite likely that growth in the circular economy has the potential to create employment in mid-range posts.

Bio-refining and, to a lesser extent, servitisation were also thought to need some higher end professional and technical skills. However, jobs in the biorefinery sector especially offer a very broad mix of professions with high to low skill level need, 'ranging from plant and crop development, cultivation and harvesting, transport, distribution and storage of feedstock, plant design, deployment, maintenance and repair through to higher skilled work in development, testing and marketing' (Green Alliance 2015).

Summarised regarding the occupations involved in the circular economy, the available data suggests that waste and recycling tends to require a comparatively high proportion of lower paid occupations.

Table 27: Potential skill needs by circular economy activity

Activity	Potential skill needs			Areas of concentration
	Low skilled	Skilled	Professional	
Closed loop recycling	✓✓✓✓	✓✓✓✓	✓	Near manufacturing sites, logistics and supply chains
Open loop recycling	✓✓✓✓	✓✓	✓	Near feedstock and markets, close to major ports
Servitisation	✓✓✓	✓✓✓	✓✓✓	Head office jobs may be in the South East and London; back office and servicing jobs may go abroad
Remanufacturing	✓✓	✓✓✓✓✓	✓✓	Near manufacturing sites, transport hubs and population centres, with some overseas plants
Re-use	✓✓✓✓	✓✓	✓	Dispersed throughout the country
Bio-refining	✓	✓✓✓✓	✓✓✓✓	Near major ports, consuming industries, manufacturing sites, population centres and sources of domestic feedstock

Source: Green Alliance, 2015

5.5. Small and Medium-Sized Enterprises (SMEs)

The European Commission (2014k) stressed that 42 per cent of SMEs were estimated to have at least one full or part-time 'green' employee, representing a 5 per cent increase since 2012 and amounting to 20 million jobs across the EU. Inevitably there will be opportunities for SMEs operating in the waste management, materials recycling and remanufacturing sectors to benefit from the transition to a circular economy. As always with SMEs, barriers such as access to finance, administrative burdens, lack of technical skills and greater vulnerability to the supply and demand of products and services tend to be more acute than for larger companies (Rizos et al., 2015).

The Commission has supported SMEs in their transition to the circular economy through the continued implementation of the Green Action Plan for SMEs. EU funds have also supported thousands of SMEs in the past decades, boosting resource efficiency, energy efficiency, and innovation in manufacturing and production. This support to SMEs continues from the cohesion policy funds in the 2014-2020 period.

The Executive Agency for Small and Medium-sized Enterprises in particular manages programmes on behalf of the European Commission and turns EU policies into action. It manages significant parts of large-scale projects, such as COSME, LIFE, Horizon 2020 and EMFF. Therefore, they help to create a more competitive and resource-efficient European economy based on knowledge and innovation. Within the Horizon 2020 SME Instrument, projects like 'Boosting the potential of small businesses in the areas of climate action, environment, resource efficiency and raw materials' recognise SMEs as being able to become the engine of the green economy and facilitate the transition to a resource efficient, climate-smart circular economy.

All across the EU Member States, SMEs often lack the time and resources to actually look into untapped economic opportunities from more circular business models and even limited consultancy support can help to 'pick low-hanging fruit' in terms of economically viable investments with short amortisation periods.

The European Commission (2014j) produced a list of EU actions supporting SMEs in a green economy. The list included:

- The European Resource Efficiency Excellence Centre (set up in 2015) to provide information, advice and support on:
    - Actual SME resource efficiency performance, benchmarked by sector;
    - Technological options to increase this resource efficiency in their sector; and
    - Cost effectiveness of those options, with a view to financing them.
- The SME Instrument of Horizon 2020 providing funding for innovative projects, please see Table 28 for example projects;
- The Enterprise Europe Network aimed at raising awareness of the positive benefits and opportunities of resource efficiency for SMEs and the transfer of good practice;
- The LIFE programme funding projects implementing new business models for resource and energy efficiency focusing on the durability, re-use, repair and recycling of SME products and processes.

Table 28: example projects funded under the H2020 SME Instrument programme

Project	**Description**	**Company (EU contribution)**
Whey2Value: valorising waste whey into high-value products	The development of an innovative and disruptive high-value technology to address a major economic and environmental challenge of the world's dairy industry: waste whey.	ACIES BIO (€1 781 938)
A demonstration plant of enhanced biogas production with add-on technology	A technology that enables the broader utilisation of high-nitrogen organic waste such as chicken manure in biogas production, enabling millions of tonnes of used organic waste in Europe being processed, cleanly, economically and efficiently. This would displace the use of maize silage.	Ductor Oy (€1 414 754)
Swap.com on-line department store for massive amount of pre-owned items	Swap.com provides an on-line consignment store for pre-owned items in a cost efficient and easy to use way. Unwanted items are sent to Swap.com's fulfilment centre where they are sorted, photographed, packed and stored.	Netcycler Oy (€1 293 590)
Robotic recycling revolution	The ZenRobotics Recycler (ZRR) is said to have the potential to revolutionise commercial and industrial waste sorting, replacing low performing hazardous manual handling with highly efficient and fast autonomous robotic pickers	Zenrobotics OY (€1 416 625)
Novel devulcanization machine for industrial and tyre rubber recycling	DEVULC is a novel rubber recycling technology which uses supercritical CO_2 instead of chemical solvents banned by the REACH Directive	PHENIX (€1 697 736)
Quality determination of solid biofuels in real time	A novel biomass scanner for the measurement of inhomogeneous biomass to determine the key parameters of moisture content, calorific value, ash content and unwanted items.	Mantex (€1 634 885)
PAPTIC-the good conscience alternative	Developing the world's first economically sound and environmentally-friendly alternative to plastic bags	PAPTIC OY (€2 195 812)
LAMPACK	A new method for separation and full recovery of multilayer packaging waste to create high value materials	MATRIX recycling systems (€50 000)
PROMETHEUS	The substitution of Platinum Group Materials (PGMs) used in autocatalysts with copper nanoparticles via a disruptive innovation	Monolithos recycling technologies EPE (€50 000)

Source: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/sme-instrument

The European Commission (2016e) provides the results of a survey of SMEs across the EU-28. Table 29 shows the results of a question on circular economy activities undertaken in the last 3 years – this included the minimisation of waste by recycling or reusing waste or selling it to another company and the redesign of products and services to minimise the use of materials or use of recycled materials. This shows the high level of variability across the EU with 95 per cent of SME respondents in Malta reporting activity but only 44 per cent in Estonia and Bulgaria.

Table 29: SME circular economy activities in the last three years

Percentage undertaking some circular economy related activity	Member States
90-100	Malta (95)
80-89.99	Ireland (89), Luxemburg (85), Estonia (85), UK (84), Austria (84), Belgium (84), Portugal (82)
70-70.99	Finland (79), Germany (78), Croatia (78), France (74), Greece (73), Netherlands (73), Sweden (71) Slovakia (70), Czech Rep (70)
60-69.99	Cyprus (67), Italy (67), Denmark (63), Romania (62), Slovakia (62), Poland (62)
50-59.99	Hungary (57), Latvia (54)
40-49.99	Lithuania (47), Estonia (44), Bulgaria (44)

Box 12: Key findings and messages from Chapter 5

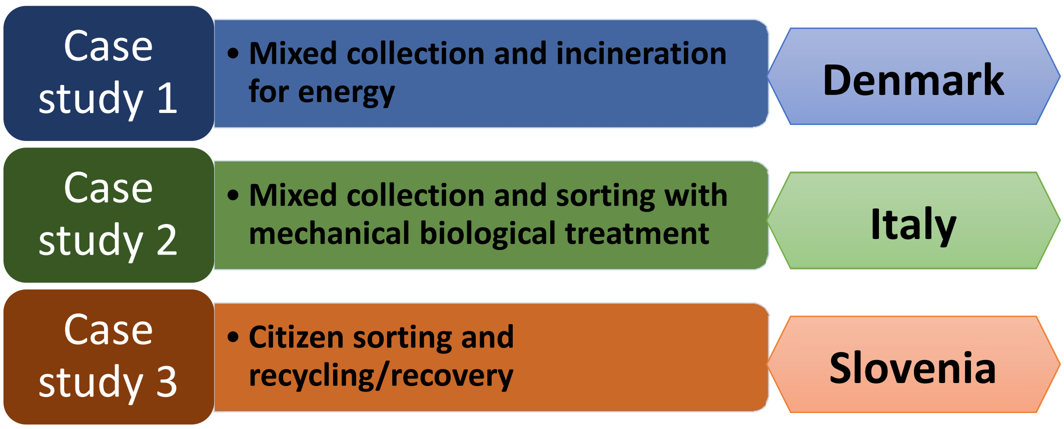
- The transition from the ‘collect and dispose’ method of waste management to one of maximising the retention (value and volume) of resources within the economy will inevitably impact both the numbers of and skillsets of those employed in the sector.
- An economy that prioritises repair, re-use, remanufacturing and recycling of materials is more labour intensive than one based on a disposal philosophy, leading to increased job opportunities.
- ‘Repair’ activities account for nearly half of all people employed in circular economy activities, and may generate considerable co-benefits by providing job and training opportunities for disadvantaged workers and giving them a fresh start on the labour market.
- Jobs in the repair sector are in decline because of increasing obstacles and costs to re-use and repair. To this end, a more flexible EU waste policy regarding the possibility of re-use (e.g. in cases where legal obstacles hinder the re-use of ‘waste’) would help facilitate and encourage greater uptake of such activities.
- It was estimated that there were 192 000 jobs in the remanufacturing industry in 2014 in the EU, with aerospace and automotive being the prominent sectors accounting for nearly 60 per cent, and with considerable potential for growth.
- Existing studies point to the positive employment effects of a wider circular economy implementation. For example, a WRAP study shows that current circular economy activities are estimated to result in over 1 million new jobs across the EU by 2030 and further ‘transformational’ circular economy activities would result in nearly 3 million new jobs.
- Low and intermediate skilled labour will likely continue to make up a significant proportion of future re-use and recycling processes while remanufacturing, closed loop recycling and bio-refining would continue to require more mid-level skilled employment.
- There is a high level of variability across the EU as regards SME engagement with circular economy related activities: 95 per cent of SME respondents to a 2016 survey in Malta reported activity, but only 44 per cent in Estonia and Bulgaria.

6. Case studies of waste management in action

Three case studies reveal the wide range of municipal waste management collection and treatment options practiced across the EU. Each case study focuses on a specific aspect of the waste management collection and treatment chain using a 'base country' as an example. In that sense, the case studies are not intended to be a completely comprehensive picture of waste management in each of the Member States depicted, but rather to show some of the differing conditions, practices and circular economy challenges in the different cities, regions and Member States of the EU.

Figure 1 provides an overview of the case studies. The first case study focuses on mixed collection of municipal waste with direct incineration for energy recovery. This is the most common treatment in Denmark, and Denmark is used as a base country for this case study. The second case study looks also at mixed collection, but focuses on the option of sorting with mechanical biological treatment to reduce the amount of waste landfilled and to sort municipal waste for recycling and composting as far as possible. Italy is used here as a base country, due to the relatively long history of this type of mechanised municipal waste sorting in Italy. Finally, sorted collection is considered in Slovenia. This means that citizens sort their municipal waste themselves for separate collection. Slovenia was chosen as it has significantly increased recycling rates over the last 5 years, in particular enabled by citizen sorting into high quality waste streams.

Figure 27: Case study overview



Finally, this chapter concludes with a list of indicators that could be further developed into a STEEPED (social, technological, economic, environmental, political, ethical, demographic) analysis for expanding the case studies, for example to assess the wide reaching positive and negative impacts of a circular economy transition in different economies and societies of the EU.

6.1. Denmark – mixed collection and incineration for energy

Denmark has the highest level of per capita municipal waste generation in the EU. Around 789 kg/capita were generated in 2015 and the trend between 2005 and 2015 shows growing per capita municipal waste generation.

Denmark also has the highest share of municipal waste incineration in the EU, with around 55 per cent incinerated for energy recovery. Waste is mainly collected mixed and is not sorted after collection – at least for the fraction that is incinerated for energy recovery. Each tonne of waste produces approximately 2 MWh of heat and 0.67 MWh of electricity in the incineration facilities (Rambøll, 2006). As such, it is used for district heating and electricity generation. It is estimated that the city of

Copenhagen has one of the most efficient district heating networks,[15] producing around one-third of district heating and 22 per cent of electricity from waste incineration in 2013 (Hofor, 2014).

The total cost for incineration of waste is €270 million per year (made up of transport €31 million, administration €2 million, incineration €236 million) (Danish EPA, 2010). This is estimated to be half the price of landfilling.[16] Note that the fee for landfilling (€63/tonne) waste is higher than for incineration (€44/tonne). There is no fee on waste being recycled.

There are 27 dedicated waste-to-energy facilities distributed across the country. The capacity of the facilities ranges from 10 000 to 600 000 tonnes, with most having a capacity between 150 000 and 300 000 tonnes. Transport distances are estimated as commonly less than 20 km in densely populated areas (DTU/COWI, 2014). These facilities are subject to a 'cost cover' principle, i.e. they must balance their budgets. Income streams come from selling electricity (13 per cent), providing district heating (50 per cent) and gate fees for the waste (37 per cent); equalling €169 million per year (Dansk Affaldsforening, 2013). It should be noted that incineration plants are not allowed to profit from their activities, so that consumers will benefit directly from cheaper energy prices. The value of using imported waste depends on the variable cost per tonne of waste. The cost for incineration is €17 per tonne. The potential value added when utilising the full capacity of the facilities is €12-37 million per year based on an import of 400 000-500 000 tonnes (EA Energianalyse, 2014).

In total 31 000 people in Denmark are employed in the waste sector (14 000 directly and 17 000 indirectly). There are 54 people employed in R&D in non-commercial institutions who are doing research within the field of waste (Danish EPA, 2013) and a total of 318 companies deal with waste handling.[17] Among these are 45 inter-municipal companies engaged with waste management from recycling to incineration and landfilling (DTU/COWI, 2014).

As regards direct environmental impacts, emissions to air are a key impact of waste incineration. It has been estimated that emissions of 23.9 g/GJ SO_2 and 124 g/GJ NOx per tonne of waste treated are emitted (Rambøll, 2003). Moreover, high levels of waste generation per capita indicate high levels of environmental pressures associated with resource use. In the future, recycling and a greater roll out of circular economy processes could be hindered by vested interests in maintaining waste incineration facilities at high capacity, thereby competing for waste.[18]

6.2. Italy – mixed collection and sorting with mechanical biological treatment

The mechanical-biological treatment (MBT)[19] of municipal waste has a relatively long history in Italy. It began around two decades ago, to currently reach more than 120 MBT plants across the country,

[15] Copenhagen aims to be the first city in the world to go zero-carbon by 2025 and along with these efforts has recently started construction of a waste to energy power plant (running with waste wood). The power plant will also offer recreational activities (e.g. a ski slope) in efforts to integrate it into the social and physical infrastructure of Copenhagen. Source: online article; https://www.theguardian.com/cities/2016/oct/26/incinerator-copenhagen-waste-plant-bjarke-ingels-ski-slope; accessed 13 June 2017.

[16] https://www.affald.dk/da/7-10/deponi/artikler/322-deponi-sadan-er-det-lavet-7-10.html.

[17] NACE_R2, Waste collection, treatment and disposal activities; materials recovery and remediation activities and other waste management services.

[18] The competition between waste for incineration to produce energy (with positive effects for reducing GHG emissions compared to using fossil fuels) and waste for recycling, as well as potential trade-offs with waste reductions, over the long term should be explored further.

[19] MBT comprises mechanical sorting of recyclable materials and homogenisation of waste, followed by biological treatment that reduces and stabilises biodegradable matter using aerobic or anaerobic processes.. The primary objective of MBT is to reduce the volume of waste that is landfilled. Over time technologies for sorting recyclable materials have advanced, and MBT contributes

which treat around 22.4 per cent of municipal solid waste (MSW). In total around 8 million tonnes of mixed MSW was mechanically-biologically treated in 2010 in Italy.[20] Of this, around 34 per cent was recovered for recycling, 23 per cent was stabilised as 'grey' compost and around 10 per cent was recovered for energy. Around a quarter (24 per cent) was sent to landfill (Newman, 2010).

Costs to collect MSW vary among regions and municipalities in Italy. For instance, the average cost to collect MSW in the Verona province is around €140 per tonne (Guerrini et al, 2015). The costs of collection are assumed to be the same for mixed MSW that will be processed to MBT or MSW sent directly to the landfill, whereas collection costs of source-separated MSW are considerably higher than of the mixed MSW. The costs of the MBT treatment vary depending on technology application, plant capacity and degree of mechanisation applied. The average operation costs vary between €24 and €81 per tonne, whereas the investment costs vary from €203 to €560 per tonne per year.[21] The gate fee for MBT varies between €40 and €90 per tonne,[21] whereas the landfill charge in Italy including gate fee and tax is around €88-104 per tonne, but that also depends on the region (CEWEP, 2012).

The quality of recycled materials recovered from mixed collected waste through MBT processes is usually lower than the quality of materials recovered from the source-separated waste. This means that MBT-treated waste has lower potential for high value markets. MBT allows the recovery of metals but not all households collect these materials. In Italy only 69 per cent of households occasionally sort hazardous waste e.g. batteries (Eurobarometer, 2014). Recycling of glass from MSW, which is processed through MBT, requires special glass automated segregation, or manual segregation which hikes up labour costs. The value of the paper for recycling from MBT is also low when compared with source-separated collected paper. Therefore, it is often used to produce refuse-derived fuel (RDF) and solid recovered fuel (SRF). These fuels are used for energy recovery purposes and can substitute virgin resources. In 2010, 1.07 million tonnes of SRF was produced in Italy, and 16 per cent was used for energy recovery as an alternative fuel in cement kilns. The price of RDF in Italy is €17.1 per tonne,[22] compared to the rest of the EU where it can range from €99 to €117 per tonne.[23]

The compost-like outputs of MBT are typically used for soil restoration, remediation or for landfill cap restoration. They may contain elevated levels of heavy metals, plastics, metals and other unwanted materials. The Italian Composting Association indicates average sale prices for compost in Italy at between €3 and €10 per tonne (EC, 2014a). The value of compost produced from mixed MSW is between €0 and €2 per tonne.[24]

Employment in an MBT plant with a capacity of 50 000 tonnes per annum is between two and eight workers. Additional employment is sought if manual sorting processes are carried out. In general, MBT facilities offer employment opportunities, both for low skilled workers (e.g. engaged in the sorting process) and for specially trained and highly qualified personnel in complex facility management.[25]

to waste valorisation and minimisation of landfilled waste (Pellegrini et al, 2013). According to Montejo et al (2013), MBT enables more than an 80 per cent recovery rate for organic matter and up to 95 per cent for metals. The new technologies are evolving, allowing MBT plants to treat separately collected organic kitchen and garden waste.

[20] www.ieabioenergytask36.org/vbulletin/attachment.php?attachmentid=302&d.

[21] http://www.epem.gr/waste-c-control/database/html/costdata-00.htm.

[22] http://eimpack.ist.utl.pt/docs/0.5%20Massarutto.pdf.

[23] UK market price: http://www.letsrecycle.com/prices/efw-landfill-rdf-2/.

[24] Derived from French market price; Source: EC, 2014a.

[25]http://www.ecoinnovation.eu/index.php?option=com_content&view=article&id=422:mechanical-biological-waste-treatment-mbt&catid=59:germany.

Around 75 per cent of all crimes related to waste occur in Southern Italy, and are associated with the high share of landfills located in that region (Newman, 2010). The MBT of waste can potentially reduce the negative impact associated with the landfills and improve political stability within the country.

As regards the environment, MBT allows a reduction of 40-60 per cent of original organic carbon and theoretically can reduce CH_4 emissions by 90 per cent when compared with landfilling (Bogner et al., 2007). Despite the fact that Italians aim to improve the efficient use of resources,[26] MBT alone has little or no impact on social values as the mixed collection of waste does not provide incentives to separate and reduce waste. MBT may also be viewed as more of a disposal option as the quality of waste streams for re-use is of a lower quality. The transition to a more circular economy may require separate collection and citizen engagement to ensure both higher efficiency and prevention as well as higher quality.

6.3. Slovenia – sorted collection with significant recycling success

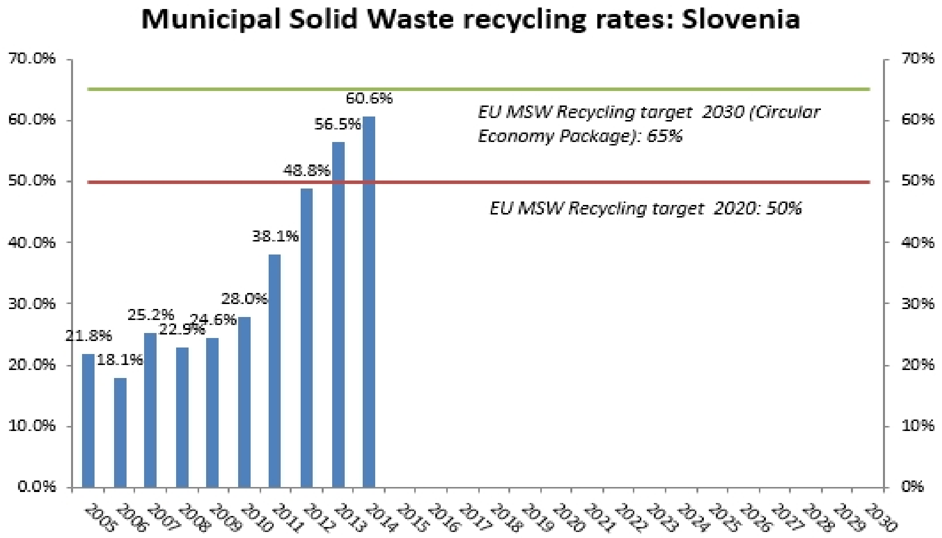
Since Slovenia's entry into the EU in 2004, it has advanced from a situation where the nation largely landfilled their waste to the present where some of the targets set out by the EU for 2030 in the Circular Economy Package have almost been met (e.g. for MSW recycling and packaging recycling; see Figure 28).

When joining the EU, the national municipal waste management plan included separate collection, regional biological treatment (MBT) plants and two large-scale incineration plants. The last two were never built, because to some extent separate collection and increasing recovery rates made them redundant. There is a MBT heating plant at Celje that diverts municipal waste from around 250 000 inhabitants. Recently (in 2015) a regional waste management centre was built near Ljubljana that includes 37 municipalities serving approximately one third of the Slovenian population. Therefore, energy from waste facilities remain low in the country. It is also worth noting that backfilling is an important treatment option for waste in Slovenia when compared to the rest of the EU. Although this alternative is considered as waste recovery, it is not considered as a recycling activity (DG ENV, 2011).

The success of recycling rates in Slovenia, at least for municipal waste, is based on separate collection. It is implemented primarily via door-to-door collection for paper, glass, and bio-waste, commingled door-to-door collection for plastic and metal, and other secondary systems such as bring points, civic amenities, or producer/retail take back systems (e.g. for glass) (DG ENV, 2015). The targets for separate collection are set in the Slovenian Waste Management Plan (2012). The country is one of seven in the EU-28 where at least 70 per cent of the respondents sort eight types of waste (including paper, plastic, glass, household hazardous waste, metal, electrical and electronic, kitchen waste, and garden waste).

[26] According to the Eurobarometer survey (2014), 93 per cent of Italians make efforts to reduce the amount of waste that they generate. Additionally, 45 per cent of Italians undertake home composting, a rate that is low when compared to other countries (e.g. Slovenia 56 per cent, Austria 66 per cent).

Figure 28: Municipal solid waste recycling rates



Source: Eurostat (accessed 2016)

Ljubljana is a particularly successful case. Waste management is handled by the public company Snaga. In addition to the separate collection system, a pay as you throw (PAYT) charge has been introduced from 2000 for mixed municipal waste and from 2013 for the door-to-door collection systems. Furthermore, the frequency of collection for residual waste (the part that is not separated) has increasingly declined. At the end of 2013, the first re-use centre in Ljubljana opened its doors.

Part of the success is due to awareness campaigns to engage citizens and encourage them to separate at source. Some of the measures (e.g. frequency of collection) met with strong opposition by the public and were counteracted by strengthening communication campaigns. The campaigns not only addressed separate collection but also the reduction of waste quantities with a specific focus on food waste. Ljubljana was declared the European Green Capital for 2016 and is the first European capital to move towards zero waste (ZeroWaste Europe, 2015). Between 2004 and 2014, the waste kg/person/year in Ljubljana dropped by 15 per cent to 283 kg (compared to 474 kg/person/year in the EU), while the reduction in residual waste fell by 59 per cent. Ljubljana separately collected 61 per cent of total municipal waste generated in 2014.

Ljubljana has a fairly efficient system for managing MSW since the average yearly costs are €100/household while for the rest of the country the costs are €150/household. Moreover, the cost of MSW management has decreased in recent years and annual running costs equal €8.86 million. In general, among the possible collection systems (mixed or with drop-off points), door-to-door separate collection is the most expensive system in terms of running costs (but has lower start-up costs).[27]

Construction of the regional waste management centre was calculated at a set-up cost of €144 million to serve the needs of 30 per cent of the population in Slovenia for at least 30 years. There is no data available for running costs. Landfilling fees (such as gate fees plus landfill taxes) are quite high in Slovenia at around €120 per tonne (e.g. double that of Denmark).

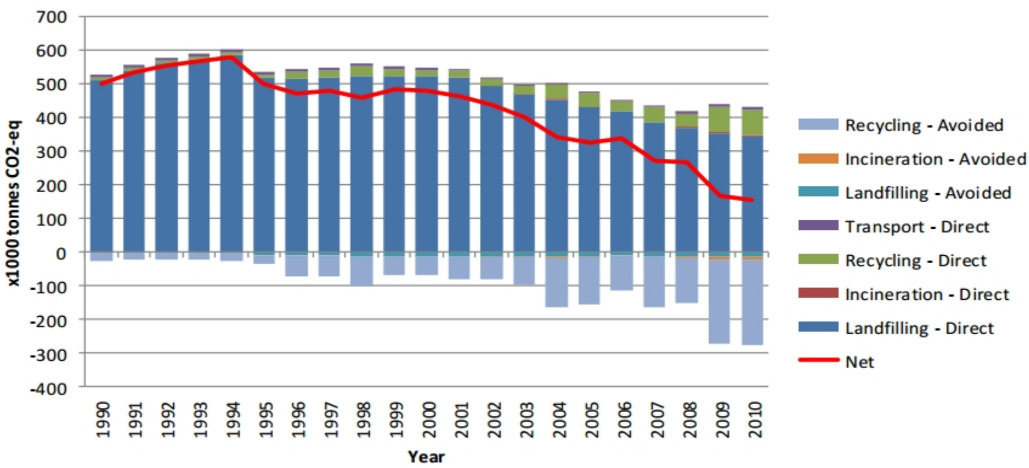
According to the 2015 Labour Force Survey, 7 000 employees worked directly in 'waste collection, treatment and disposal activities; materials recovery' (NACE rev.2 code 38). The sector has experienced a large increase since 2008. In absolute terms these jobs represented 0.4 per cent in 2008 and doubled to 0.8 per cent in 2015. Furthermore, the sector displayed a strong resilience to the economic crisis.

[27] DG Env, 2015 and ZeroWaste Europe, 2015, 'Case study 5: The story of Ljubljana'.

A similar pattern is observed for the number of firms operating in the sector; noting a steady increase in Slovenia between 2008 and 2013, from 231 to 290. In 2013 the sector attributed 0.23 per cent to the total number of Slovenian enterprises. Close to 35 per cent of the 290 firms are dedicated to the recovery of materials.

As regards the environmental impacts, greater recycling is associated with many benefits. While the recovery process might have direct emissions, emissions are saved from producing a product with virgin materials. In particular, processing recycled materials uses less energy than processing virgin materials.[28] The emissions saved are generally much higher than the direct emissions, so the net balance is a reduction of GHG emissions from increased recycling activity. This is depicted in Figure 29.

Figure 29: GHG emissions from MSW in Slovenia



Source: EEA, 2013c

Altogether, the trends in Slovenia indicate progress away from wasteful and environmentally harmful landfilling and toward more circular economy activities, with benefits for job creation. Citizens, through their sorting of waste, have played a key role in the success Slovenia has experienced so far.

6.4. Towards a STEEPED analysis

Further evaluation should be underpinned by indicators addressing the wide range of potential impacts across the economy, environment and society. To this end a STEEPED analysis could play a role, as it provides a socio-economic framework within which possible impacts of various future municipal waste management and circular economy scenarios can be identified. Table 30 depicts a preliminary overview of potential indicators that could become part of such an analysis. Depending on the options evaluated, the indicators could be adapted, expanded or deepened as needed. Data for the indicators presented in Table 30 is in general judged to be available in some form (e.g. in annual statistics such as Eurostat, one-off surveys such as Eurobarometer, or through dedicated studies or reports). Nevertheless, it presents a first suggestion that can be built on in future research, and shows the wide range of variables that must be taken into account when considering a circular economy transition.

[28] The energy savings depends on the recycled material and ranges from 95 per cent in aluminium to 33 per cent in glass.

Table 30: Potential STEEPED analysis indicators

	Key areas	Potential indicators
Social	Social and cultural values	Awareness and willingness to change behaviours
	Lifestyles	Time spent by households sorting/composting
	Advertising/information	Public campaigns; examples, frequency
Technological	Knowledge	Use of best available technology
	R&D funding	R&D funds allocated (private and public)
	Innovation	Stages of technology
	Energy	Energy production, consumption
	Transport	Distance
	Patent regulations	Number of patents
Economic	Direct costs	Costs of collection, sorting and treatment
	Direct income	Value of recycled products
	International trade	Value of traded waste
	Taxes	Taxes on management options
	Employment	Share of employment
	Entrepreneurship	Number of new companies
	New business activities	Engagement in circular economy actions like remanufacturing
Environmental	Air quality	Air pollution
	Climate change	GHG emissions
	Water quality	Water pollution
	Land use	Area of land appropriation and use
	Waste prevention	Change in per capita waste generation
	Resource use and efficiency	Change in material footprints and resource productivity
Political	Environmental Policy	Compliance with EU targets and directives
	Political stability	Energy and resources supply security
	Regulation of monopolies	Energy and resources supply security
Ethical	Progress toward SDGs	Contribution toward sustainable development
	Hazardous waste	Share of hazardous waste production
	Impacts abroad	Share of exported waste
Demographic	Profession	Employment of educated, highly-skilled employees
	Social job creation	Jobs created for low-skilled workforce

Box 13: Key findings and messages from Chapter 6

- Widely different options for sorting, treating and managing municipal waste are in practice across and within the Member States of the EU.
- Denmark produces the highest level of municipal waste in per capita terms and also incinerates the greatest share of municipal waste for energy generation. While this option provides greater environmental benefits than landfilling, it may also lower incentives to reduce waste generation and hinder greater recovery, re-use and recycling for non-energetic purposes.
- Mechanical biological treatment (MBT) of mixed municipal waste enables recovery of certain metals and other resources. It diverts waste to recycling (e.g. 34 per cent of MBT in Italy is recovered for recycling), to composting (e.g. 23 per cent in Italy), and energy (e.g. 10 per cent in Italy). Nevertheless around 24 per cent of MBT treated municipal waste lands in landfills in Italy. Waste streams are also of lower quality and citizens may lack incentives to prevent and sort waste. MBT thus seems to be more of a disposal mechanism than a circular economy enabler.
- Ljubljana, Slovenia was declared the European Green Capital for 2016 and the first European capital to move towards zero waste. This reflects the trend in Slovenia toward greater shares of recycling, in particular made possible by separate collection of municipal waste. Despite some original citizen opposition – countered by strong awareness campaigns – Slovenia is a country where at least 70 per cent of the respondents sort eight types of waste. This enables higher levels of recovery and is the first step toward a circular economy.
- A wide array of indicators must be used to evaluate and assess future options. To this end a STEEPED analysis may be useful to put expected changes into the context of a socio-economic and ecological circular economy transition.

7. Policy options

There are many waste management challenges in moving to a more circular economy – not only to achieve the targets currently proposed in the EU circular economy package, but eventually to take them further towards a 'vision' of prevalent, widespread and sustainable circular production and consumption models. Three general challenges identified in this study are:

- Prevent waste generation;
- Align the objectives of waste management and the circular economy;
- Improve monitoring for evidence-based policy making.

The first two relate to central challenges identified in Chapter 1 and confirmed in the analysis of subsequent chapters. Namely, there is a need to decouple environmental impacts from waste generation, in particular by reducing the amount of municipal waste generation, especially in high-income countries. To develop a circular economy, industries engaged in promoting circular supply chains will have to become critical partners of the waste management sector, in order to gain access to high-quality secondary raw materials that may be recovered for further re-use and production. The third key challenge – the need for improved monitoring – has emerged throughout this report as a key obstacle to developing a reliable evidence base for depicting both knowledge on the current state of practices as well as future options.

The policy options presented in this report stem from key opportunities to meet these challenges. They arise from the discussions and conclusions of the analysis provided by previous chapters, and also from suggestions presented in literature to best address the challenges identified. However, they do not represent a comprehensive depiction of all relevant areas and options for policy action in the circular economy transition. In order to provide a concise list of policy options it was decided to focus on municipal waste and food waste streams due to their high visibility in the population and high potential for inducing changed practices. However, waste streams such as critical raw materials and biowaste, including residues, are also key areas for greater policy support. In particular, these areas are in need of strengthened research to identify key challenges and opportunities in a more detailed way. Waste streams beyond municipal waste, in particular construction minerals, should also be noted as a key area for policy action, in particular due to their large volume, but are beyond the scope of this report. Moreover, the policy options present some key areas of action that are judged as feasible in the short and medium-term with a focus on waste management (for more suggestions related to circular economy development more specifically, e.g. on the need to consider synergies and trade-offs between recovery and re-use options, see EEA, 2017). Each policy option is presented in a short text box describing the issue and suggestion. As such, the options presented should be considered as a brief overview that may contribute to broad policy-making discussions, but which require additional, detailed analysis.

Table 31 provides an overview of the policy options identified in this report related to each of the three challenges.

Table 31: Overview of key policy options addressing three key challenges presented in this report

Promote waste prevention	Mandate the inclusion of food waste prevention as part of national waste prevention programmes
	Take actions to directly engage and encourage key players able to influence food waste reduction
	Implement a new 'household or similar' waste target to encourage reductions in residual levels of mixed waste
Align waste management objectives with those of the circular economy, and vice versa	Provide clarity around incineration and achieving options higher up the waste hierarchy
	Develop an integrated EU-wide infrastructure for waste management toward recovery
	Support business infrastructure for business models that consider end-of-life recovery options in the design phase
	Implement individual re-use, remanufacturing or repair targets for WEEE
	Consider the wider role of economic instruments in promoting circular economy objectives
	Consider specific targets to promote recovery of critical valuable materials (in addition to volume based targets)
	Promote a coherent policy approach from the EU to the municipal levels, in particular by sharing best practices at the municipal and inter-municipal level
	Provide training and promote different kinds of employment, including financial support for high-level skills training and social jobs
Promote reliable, harmonised and consistent reporting and monitoring of waste statistics as well as research toward a circular economy	Provide clarity on the calculation protocol for household waste fractions within municipal waste
	Harmonise the calculation of municipal waste recycling rates
	Include 'edible food waste' as a category into Member State waste data reporting requirements
	Promote transparency around the volume and end destination of residues from waste pre-treatment, treatment and recycling processes
	Promote transparency around the environmental outcomes arising from recycling options
	Develop a monitoring system tracking and evaluating progress toward a circular economy, including a dashboard of economic, environmental and social indicators
	Improve the effectiveness of European Union funding for waste management projects
	Perform a more detailed STEEPED analysis as a key next step

7.1. Promote waste prevention

In the context of this study on waste management, and with specific reference to MSW, a fundamental question is: What waste prevention measures can be implemented to both drive down the levels of waste generated in the high-GDP Member States and to avoid the low GDP Member States from progressively generating more waste as they develop?

As described in section 2.3 of this report, there is a general lack of adequate focus on food waste prevention measures across the EU. There is growth in awareness campaigns and activities in Member States which show a positive trend toward reduction and may be replicated and mainstreamed across the EU. As food waste is the waste stream representing the most significant waste prevention opportunity, two policy options are discussed below as a starting point, as well as a target for mixed collection, which could help to incentivise prevention. Nevertheless, this is an area in need of strengthened and dedicated policy review and action.

Mandate the inclusion of food waste prevention as part of national waste prevention programmes	
The policy issue	51 million tonnes of edible food are wasted each year in the EU-28 (FUSIONS, 2016). The current wording in the draft proposal from the European Parliament amending the Waste Framework Directive (European Parliament, 2015a) recommends, but does not mandate the inclusion of food waste prevention measures in national waste prevention programmes. Further detail for this issue is covered in section 3.1.4 of this report.
Suggested policy option	Revise the Waste Framework Directive to make it compulsory for food waste to be included within national waste prevention programmes, including clear responsibilities and milestones in the context of an action plan. In addition, suitable and measureable targets should be considered and recommended to Member States which should include the setting of quantitative targets once agreement is reached on the issues of food waste measurement. This policy option was discussed in the STOA (2013) study.

Take actions to directly engage and encourage key players able to influence food waste reduction	
The policy issue	A great deal of food waste is produced by countries with high GDP. Much of the waste is produced within the household. Solutions to food waste reduction in particular requires technological, but very significantly behavioural change. Changing the behaviour of consumers regarding food purchasing will require action by a range of stakeholders including manufactures, retailers and consumers. This is made more complex as some stakeholders have commercial interests in selling more product. Further detail for this issue is covered in section 3.1.4 of this report.
Suggested policy option	Consider and facilitate ways in which stakeholders (in particular the key retailers) could support behaviour change. This could include: • Improving awareness and communication of best practices in edible food waste prevention across the EU-28; • Providing good practice and guidance to retailers on assisting households to reduce waste; • Considering ways to encourage transparent communication by corporates along the food value chain regarding the actions they are taking to tackle food waste.

Implement a new 'household or similar' waste target to encourage reductions in residual levels of mixed waste	
The policy issue	The generation of mixed waste is still a significant problem and is a legacy from the traditional 'collect and dispose' waste management approach. The collection of mixed waste limits any ability to promote waste management higher up the hierarchy. Further detail for this issue is covered in section 3.1.1.1 of this report.
Suggested policy option	An alternative or additional new target for 'household or similar' waste classification used in Eurostat should be included within the review of the Waste Framework Directive. In conjunction with recovery and recycling targets this would encourage reductions in residual levels of mixed waste. This could be undertaken in a similar way to that of biodegradable municipal waste with the total quantity arising in the baseline year being set and then reduction targets being set over an extended time period.

7.2. Align waste management objectives with those of the circular economy, and vice versa

A general conclusion cited in research is that much of the EU policy on waste centres on the diversion of waste from landfill to incineration or recycling. As such it is very much an end-of-life disposal perspective (waste as a problem). The goal of a circular economy is to create value-added from waste (waste as a resource). As such it aims to separate waste into high quality waste streams for re-use, recovery and recycling. This transition will require active co-operation of waste industries with businesses active in the circular economy. It will also mean that more attention to end-of-life recovery options are needed already in the design phase. For example in concrete terms, recycling may be supported by the avoidance of glue or welding of parts (to make disassembly easer) or an index of the materials used in a product. The research in this study highlights the significant benefits of focusing higher up the waste hierarchy. It is also associated with considerable co-benefits. Repair is a case in point with high employment opportunities especially in the social enterprise sector.

Provide clarity around incineration and achieving options higher up the waste hierarchy	
The policy issue	In countries with high GDP and high volumes of waste, incineration including with energy production has been advanced as a favoured option. This sets up a requirement in contractual and energy security terms to feed the incinerators with waste. There is overcapacity in some incinerators and waste is transported internationally as a feedstock. The consequences of this in relation to the waste hierarchy are likely to be a lack of pressure to reduce overall volumes of waste or promote re-use, remanufacturing or repair. In other words, it may lead to systemic lock-in due to infrastructure investments and costs. See also the EC Communication on waste-to-energy (European Commission, 2017). Further detail for this issue is covered in section 3.1.1.3 of this report as well as in the Denmark case study (section 6.1).
Suggested policy option	Undertake a review and consider options to provide clarity regarding where incineration fits within the context of the circular economy. The objectives of such a review would include: • Highlight the issues and scale of the problem in relation to achieving a circular economy; • Provide direction for infrastructure investment decision making before EfW becomes an optimal solution;

	• Offer realistic options for and targets needed for waste prevention, re-use, remanufacturing and repair to reduce reliance on incineration.

Develop an integrated EU-wide infrastructure for waste management toward recovery	
The policy issue	The absence of an integrated European waste management and recycling infrastructure blocks coordinated efforts of Member States toward the circular economy in the EU. This links back to the idea that waste is an environmental burden that should be dealt with locally. However, recycling often needs large amounts of a specific type of waste to be economically viable, making trade a necessary recycling prerequisite for especially critical raw materials. Data reveal an increase in trade of waste, in particular to meet capacities in incineration (see e.g. Wilts and Gries, 2014), which could be further developed into a European network for recycling Further detail for this issue is covered in section 3.1.1.3 of this report and is exemplified by Denmark (which imports significant levels of waste from the UK and Ireland).
Suggested policy option	Develop an infrastructure that encourages networks of recovery and recycling – which have co-developed smart logistics for waste collection, separation and transport together with municipalities, citizens and industry – to secure waste streams at economies of scale which lower investment risks (see also EIO, 2014).

Support business infrastructure for business models that consider end-of life recovery options in the design phase	
The policy issue	Most activities toward the circular economy are characterised as market niches on the level of single products and companies. Further mainstreaming best practice examples of success will require changes across the entire business environment. For example, modular design for remanufacturing not only requires production of a high-quality product, but also innovation in the way post-sales services, notably maintenance and repair, and end-of-life collection are delivered and organised. This will require new business skills, citizen engagement and possibly municipal infrastructures. Further detail for this issue is covered in section 3.2.2 of this report.
Suggested policy option	Support business innovation and green skills training as well as information campaigns. In particular, promote individual producer responsibility to strengthen the link between producers and end-of-life management options as well as eco-design requirements to make re-use and repair activities economically viable (Wilts et al., 2014). Ultimately, embrace the idea of system innovation (see EIO, 2014) and specifically support development of networks of actors.

Implement individual re-use, remanufacturing or repair targets for WEEE	
The policy issue	WEEE is reportedly one of the fastest growing wastes in the EU-28 and since it contains high levels of CRMs represents a priority waste stream. Currently European policy such as the WEEE Directive contains a combined re-use and recycling target which does not encourage Member States to select the most environmentally beneficial treatment route. Further detail for this issue is covered in section 4.4.1 of this report.
Suggested policy option	Undertake a review and consider options to provide individual targets for the re-use, remanufacturing or repair of WEEE. The objectives of such a review would include: • To quantify the added value in promoting these waste management solutions; • Identify and mitigate against the market barriers; • Offer realistic options for and targets needed for re-use, remanufacturing and repair.

Consider the wider role of economic instruments in promoting circular economy objectives	
The policy issue	Landfill taxes and gate fees show correlation with greater recycling shares. Further economic instruments, such as a tax reduction on repair activities in Sweden, have also started to emerge. Both incentives and penalties may be used, and more research is needed into potential rebounds by making one option cheaper than another (e.g. waste avoidance should remain the ultimate goal). That said there seems to be potential to widen the use of economic instruments toward a circular economy. Further detail for this issue is covered in sections 2.2 and 2.4 of this report.
Suggested policy option	Undertake exploratory studies considering how economic instruments might be used to support key players in the waste management and prevention sectors in achieving circular economy objectives. This would include understanding what conditions (such as good data quality) might be required to realise the potential of economic instruments, and whether such approaches could drive more rapid improvements. Options might include: • Developing a trading scheme allowing countries with high GDP to meet their targets (in part) through supporting countries with lower GDP to improve waste separation and recycling where it is economically and environmentally favourable to do so; • Promoting the development of the criteria required to raise capital through 'green bonds' to finance projects aimed at moving waste management practices up the waste hierarchy; • Consideration of including the provision of PAYT for residual waste in all national waste plans; • Implement and/or gradually raise taxes on waste – e.g. for landfill, incineration, plastic bags, etc.

Consider specific targets to promote recovery of critical valuable materials (in addition to volume based targets)	
The policy issue	The circular economy aims to increase value – both environmental and financial. Current waste targets are primarily volume based. Whilst this does, in part, promote waste management up the waste hierarchy, it does not necessarily promote the recovery of the most valuable or resource intensive materials (like critical raw materials). Further detail for this issue is covered in section 3.1.5 of this report.
Suggested policy option	Explore specific targets to promote the recovery of critical, valuable materials from end-of-life products. These could complement the existing volume-based targets. Along these lines, develop indicators that would demonstrate both in terms of volume and value the circularity of materials within the EU-28.

Promote a coherent policy approach from the EU to the municipal levels, in particular by sharing best practices at the municipal and inter-municipal level	
The policy issue	A key challenge is different levels of policy making and regional inconsistency in waste performance, linked to municipal regulations and practices. Further detail for this issue is covered in section 2.10 and also reflected in some of the data of the case studies (e.g. for Slovenia).
Suggested policy option	Harmonisation and coherence across policy levels must be supported and promoted. The EEA (2013) call for a cascading of European legislation and best practices down to the municipal and inter-municipal level.

Provide training and promote different kinds of employment, including financial support for high-level skills training and social jobs	
The policy issue	On the one hand, new business models toward circularity will require a highly-skilled labour force engaged in new types of activities (like reverse logistics). On the other hand, social enterprise activities particularly associated with re-use may provide job opportunities for disadvantaged workers. However, these types of jobs are in decline in many repair markets across the EU. Further detail for this issue is covered in chapter 5 of this report.
Suggested policy option	Provide support for jobs training as well as support to social enterprises to boost the repair sector. In particular, aim to help remove socio-economic barriers to repair activities, such as competition with recycling and energy recovery.

7.3. Promote reliable, harmonised and consistent reporting and monitoring of waste statistics as well as research toward a circular economy

Data gaps and inconsistencies relate to a lack of harmonised definitions and measurement methodologies. This has large consequences on both the availability and quality of waste statistics and hinders a comprehensive assessment of waste management performance in the EU. Reporting on progress toward a circular economy is also largely absent and suffers from similar challenges concerning reporting and monitoring. This also lowers the reliability of future modelling of potential options and could limit progress in moving towards a more circular economy. While steps are underway to improve the quality and consistency of waste data, it should also be noted that the nature of the scale, collection processes and multiple routes for treatment and disposal, present considerable challenges to the development of good quality data. The policy options presented here focus on strengthening monitoring capacities as well as research in general toward the circular economy.

Provide clarity on the calculation protocol for household waste fractions within municipal waste	
The policy issue	Household waste is frequently collected in the same vehicles as commercial waste, so disaggregation of volumes from the two waste streams is impossible. As household waste is a good indicator of waste management performance, and is required by Eurostat, it is worth disaggregating these sources within municipal waste data. No guidance is provided for Member States on how to calculate household waste where this issue exists. Further detail for this issue is covered in sections 3.3.1 and 3.3.2 of this report.
Suggested policy option	Develop the Guidance Report (European Commission, 2012) to include a standard protocol for disaggregating the household and non-household fractions of municipal waste.

Harmonise the calculation of municipal waste recycling rates	
The policy issue	Member States can select one of four methods for calculating compliance with the Waste Framework Directive municipal waste recycling targets. Each of the different methods have significantly different outcomes in terms of the actual percentage of municipal waste that is recycled. Further detail for this issue is covered in Section 3.3.1 of this report.
Suggested policy option	Review the impact of retracting the Commission decision to determine the effect this will have on those Member States that have committed to infrastructure builds on the basis of the decision.

Include 'edible food waste' as a category into Member State waste data reporting requirements	
The policy issue	A significant volume of food waste is generated within the EU, although a lack of data means that the scale of the problem is difficult to assess. In addition, lack of clarity around definitions makes the setting and delivery of food waste prevention targets difficult. Further detail for this issue is covered in sections 2.6 and 3.1.4 of this report.
Suggested policy option	The suggested policy options follow those outlined in the STOA (2013) study on food waste, namely, to develop a definition for edible food waste that can be used by Member States to measure the quantities of edible food waste being generated by householders and relevant business sectors. Integrate 'edible food waste' as a dataset on Eurostat and standardise the methods used by Member States for the collection and calculation of data on food waste generation, e.g. based on the 'food waste quantification manual to monitor food waste amounts and progression' provided by the FP7 project FUSIONS (Tostivint et al., 2016). The European Commission is currently investigating ways in which food waste more generally can be included as a waste stream on Eurostat.

Promote transparency around the volume and end destination of residues from waste pre-treatment, treatment and recycling processes	
The policy issue	Residues arising from primary treatment or pre-treatment processes (including incineration, MBT and materials recycling) are considered as 'leakage' unless processed into secondary materials. This residue might be incinerated without energy recovery and, following incineration, disposed of to landfill. These landfilled volumes are not included in the Eurostat data for municipal waste disposed of to landfill. As such, the complete picture of volumes of municipal waste landfilled in particular, is not clear. Further detail for this issue is covered in section 3.3.3 of this report.
Suggested policy option	Eurostat (European Commission) or the European Environment Agency (EEA) to review the reporting protocols used by EU-28 Member States in the latest dataset and the European Commission to amend the 2012 Guidance Document accordingly. This is a recommendation made by the packaging trade associations.

Promote transparency around the environmental outcomes arising from recycling options	
The policy issue	Having volume based waste management targets has driven considerable change and improvement away from landfilling. There is, however a danger in some cases that volume based targets compromise the value that might be derived from waste streams. The term 'recycling' is used to cover a number of options and approaches for any particular product. Whilst all may be considered valid options in terms of achieving EU waste management targets, each will have different environmental outcomes and be considered more or less favourable in terms of reaching a circular economy 'vision'. Further detail for this issue is covered in chapter 4 of this report.
Suggested policy option	Clarity on the environmental impacts of various technological options for different waste streams could be strengthened, considering also the wider impacts and implications within systems of innovation.

Develop a monitoring system tracking and evaluating progress toward a circular economy, including a dashboard of economic, environmental and social indicators	
The policy issue	Data on the level of circular economy activities is lacking across the EU. This not only hinders monitoring, but also blocks evaluation of policy effectiveness and could hinder a sharing of best practices across the EU. Consistent and reliable statistics of business activity, citizen engagement and environmental performance could also help to raise visibility and awareness of circular economy principles and practices. Further detail for this issue is covered in section 3.2 of this report.
Suggested policy option	Strengthen data and indicators toward monitoring and evaluating a circular economy transition. For example, secondary material consumption as a percentage of overall material consumption is a key component. A dashboard could be a viable option to depict multiple facets of the circular economy transition.

Improve the effectiveness of European Union funding for waste management projects	
The policy issue	The financial support provided under such initiatives as the Cohesion Fund should have a critical role to play in changing waste management patterns. The findings of the European Court of Auditors (2012) report suggest that improvements can be made in the way funded infrastructure build projects are procured and monitored. Two of the fundamental criticisms in the 2012 report were the lack of development of supplementary support policies and poor data analysis regarding the performance to plan of the facility. Further detail for this issue is covered in section 2.11 of this report.
Suggested policy option	An update of the 2012 report by the European Court of Auditors is recommended to determine the current state of play in terms of the success rates of the projects funded under the Cohesion Fund post 2012. A critical part of the review would be an assessment of the Cohesion Fund evaluation criteria.

Perform a more detailed STEEPED analysis as a key next step	
The policy issue	Preliminary indicators for a potential STEEPED analysis were suggested in this report and should be expanded on to evaluate the full scope and wide range of impacts regarding different scenarios associated with different types of a circular economy transition. Further detail for this issue is covered in chapter 6 of this report.
Suggested policy option	To set options in a wider socio-economic framework and explore future scenarios, a STEEPED analysis of circular economy transition scenarios may be elaborated on.

Box 14: Key findings and messages from Chapter 7

- There are a broad spectrum of potential measures to overcome the challenges associated with managing waste that meets environmental and health criteria and makes progress toward a circular economy transition. This report highlights some of these options related in particular to municipal waste.
- To maintain the overarching goal of waste prevention, a holistic, systemic and integrated policy approach is needed which considers synergies and trade-offs between recovery, incineration and prevention measures. Preventing edible food waste is a key area of action for policy, in particular mandating prevention and improving both data quality (for monitoring) and information campaigns (for promoting behaviour change).
- To manage waste as a resource, instead of as a problem, the waste industry will have to become a key partner of businesses operating in the circular economy. This will require political support across all levels, including actions directed at the ground level, e.g. training, business infrastructure development, sharing municipal best practices – and overarching framework conditions, e.g. developing an EU-wide infrastructure for waste management toward recovery and recycling of waste streams at necessary economies of scale.
- Reliable, consistent and harmonised data is needed to better monitor and compare the state of waste management and progress toward a circular economy across and within EU Member States. Policy-makers may provide stronger clarity on definitions as well as support further research toward development of a monitoring system including future modelling assessments taking wider social, environmental and economic indicators into account.

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Annex 1: List of interviewees

Organisation	Country	Contact person
AB Agri Ltd	UK	Christine Parry
BBRI (Belgian Building Research Institute)	BE	Johan Van Dessel
CEWEP (Confederation of European Waste-to-Energy Plants)	EU	Ella Strengler
Consorzio Italiano Compostatori (Italian Composting Association)	IT	Massimo Centemero
Technical University of Denmark (DTU)	DK	Marie Münster
Euromines	EU	Johannes Drielsma
European Biogass Association	EU	Nicolas de la Vega
European Cement Association	EU	Karl Downey
FAO (UN Food & Agriculture Organisation)	Intl	Camelia Bucatariu
International Solid Waste Association (ISWA)	Intl	David Newman
Metabolic	NL	Eva Gladek & Anna Krotova
Municipal Waste Europe	EU	Vanya Veras
UK Organics Recycling Group	UK	Jeremy Jacobs
Plastics Europe	EU	Adrian Whyle
UK Renewable Energy Association	UK	Jeremy Jacobs
TNO (Netherlands Organisation for Applied Scientific Research)	NL	Ton Bastein
University degli studi di Milano	IT	Monica Delsignore
Zero Waste Europe	EU	Joan Marc Simon

Annex 2: Challenges and gaps related to definitions

Defining food waste

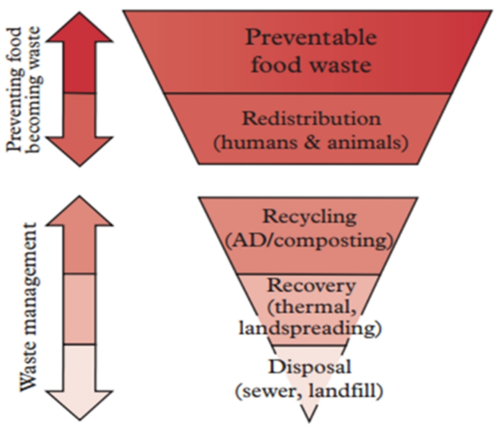
The two main definitional issues regarding food waste are firstly whether or not to include inedible food waste, and secondly at what point waste disposal becomes waste prevention.

There is some disagreement about whether the food waste definition should include both edible and inedible waste. Inedible waste includes bones, organs that cannot be eaten, inedible skins and peels, etc. This is significant in terms of achieving the target of a 50 per cent reduction in food waste. Of total food waste including inedible waste over 40 per cent is estimated to be inedible. The target to halve food waste (see section 2.6) therefore becomes almost impossible if at the outset 40 per cent of the waste stream is unavoidable. It amounts to, in reality, a target of nearly 100 per cent of edible food waste avoided. This challenge is reflected in the EU's proposed circular economy action plan measure: To develop a common EU methodology to measure food waste and define relevant indicators

The Horizon 2020 funded FUSIONS project (2014) states its definition of food waste as 'food and inedible parts of food removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)'. This differs from other definitions, for example unconsumed food suitable for human consumption, therefore excluding inedible food components, used by the Food and Agricultural Organization (FAO). Further confusion can be generated by the use of a variety of terms such as inedible or avoidable, and whether the definition should include or exclude food fit for animal consumption, but not human (for example potato skins)

Further clarity is needed as to whether food (edible and inedible) diverted to bio-based products or animal feed should be defined as 'waste' or 'waste prevention'. shows a food use hierarchy, adapted from the waste hierarchy, that demonstrates the various options for food waste, including where there might be a divide between 'waste' and 'waste prevention'. Does waste valorisation fit within recycling or waste prevention? The Horizon 2020 funded FUSIONS project (2014) suggests:

Figure 30: Food use hierarchy



Source: House of Lords, 2014

'Any food, or inedible parts of food, sent to animal feed, bio-material processing or other industrial uses (B1-B2) are termed "valorisation and conversion" and are distinct from "food waste."'

STOA (2013) provides the definition of food loss as 'the amount of food, which is produced for human consumption, but gets out of the supply chain for different reasons' and food waste as 'a subset of food loss and represents the amount of food, still suitable for consumption, which is discarded as a result of human action or inaction'.

The STOA (2013) study confirms the critical judgement made in earlier studies that discrepancies on food waste generated per Member State are likely to be the result of a lack of standardisation in definitions and data processing rather than actual exceptional differences. It is considered a high priority to have a definition of food waste. However, food waste streams, in some respects more so than other waste streams, are complex to separate and fully understand, and so it is important to take into consideration the observation made by the European Commission (EC2014e) that 'calculation methods are too complex and not sufficiently harmonised to allow proper comparison of Member State performance'.

Defining repair, refurbishment and remanufacturing

The Centre for Remanufacturing & Re-use (2008) stressed that literature grapples with the distinction between remanufacturing, repair, refurbishment, rebuilding and reconditioning. These end-of-life treatments share similar objectives, i.e. the maintenance and restoration of the original product to as near as possible original condition, albeit with different warranties. Significantly, however, they are all distinguishable from recycling, which concerns the destruction of products into their constituent parts. Examples of this 'grappling' process is still evident. For example, the European Commission (2014l) provided definitions for product refurbishment and component manufacturing:

'Product refurbishment: a process of returning a product to good working condition by replacing or repairing major components that are faulty of close to failure, and making "cosmetic" changes to update the appearance of a product, such as cleaning, changing fabric, painting or refinishing. Any subsequent warranty is often less than issued for a new or remanufactured product, but the warranty is likely to cover the whole product (unlike repair);

Component remanufacturing: A process of disassembly and recovery at the subassembly or component level. Functioning, reusable parts are taken out of a used product and rebuilt into a new product. In other words, remanufacturing means restoring used, discarded or traded in product to like new condition'. The key term in this definition is like new. From the viewpoint of the producers this represents the manufacturers' intent, their claim for the product and their ability to live up to that claim. The remanufacturing process includes quality assurance and potential enhancements or changes to the components.

The H2020 European Remanufacturing Network (ERN) uses the definitions supplied in British Standards that do not align with the definitions above, namely:

'According to BS:8887 Design for manufacture, assembly, disassembly and end-of-life processing (MADE) Part 2: Terms and definitions:

- remanufacture: return a used product to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product.
- recondition: return a used product to a satisfactory working condition by rebuilding or repairing major components that are close to failure, even where there are no reported or apparent faults in those components.'

Annex 3: A summary of the inputs, recycling rates and landfilling of priority materials (2012)

Material	Inputs				Functional recycling in the EU		Landfill and tailings in the EU	
	Import into the EU		Domestic (EU)					
	Tonnes	%	Tonnes	%	Tonnes	% of input	Tonnes	% of input
Aggregates	21 500 000	0.87	2 440 000 000	99.13	235 000 000	8.72	360 000 000	13.35
Antimony	37 862	100	-	-	9 710	20.41	5 480	11.52
Beryllium	175.3	100	-	-	-	-	45	25.67
Borates	87 476	93.62	5 960	6.38	465	0.50	31 600	33.65
Chromium	1 371 000	78.43	377 000	21.57	517 000	22.83	265 000	11.70
Cobalt	22 176	93.55	1 530	6.45	6 320	21.05	9 290	30.94
Coking coal	32 020 000	63.26	18 600 000	36.74	-	-	453 000	0.89
Fluorspar	384 350	70.54	160 500	29.46	4 860	0.88	210 000	38.20
Gallium	863.5	90.16	94.2	9.84	26.8	2.72	836	84.92
Gallium (ind)	162.5	93.39	11.5	6.61	26.8	13.35	51.5	25.65
Germanium	79.1	100	-	-	15.8	16.65	30.9	32.57
Indium	171.1	60.23	113	39.77	3.7	1.28	66.7	23.18
Lithium	29 810	93.13	2 200	6.87	16	0.05	12 500	39.03
Magnesite	948 048	35.94	1 690 000	64.06	34 300	1.28	720 000	26.94
Magnesium	168 150	94.84	9 140	5.16	21 600	10.86	114 000	57.32
Graphite	102 766	99.68	334	0.32	2 520	2.39	42 100	39.86
Niobium	16 404	100	-	-	1 870	10.23	217	1.19
Palladium	128.3	99.39	0.8	0.61	10.9	7.79	9.3	6.63
Platinum	115.1	99.26	0.9	0.74	13.6	10.50	4.4	3.39
Rhodium	16.9	99.64	0.1	0.36	1.7	9.03	0.7	3.87
Phosphate rock	1 817 135	95.06	94 440	4.94	180 000	8.61	108 000	5.16
Dysprosium	266.7	100	-	-	-	-	18.4	6.90
Erbium	40.1	100	-	-	-	-	3.2	7.92
Europium	89.5	77.55	25.9	22.45	33.5	22.50	-	-
Neodymium	1 421	100	-	-	14	0.98	187	13.03
Terbium	110.9	100	-	-	21.7	16.37	45.5	34.32
Yttrium	1 253	82.43	267	17.57	362	19.23	781	41.50
Silicon	596 100	65.71	311 000	34.29	113 200	11.09	222 000	21.76
Total	59 106 169.9	2.35	2 461 252 617.3	97.65	235 892 391.5	8.56	362 195 266.6	13.14

Source: Own compilation based on BIO by Deloitte (2015)

Annex 4: Eurostat waste category analysis

The structure of Eurostat has been investigated to understand how data could be gathered and presented to avoid double counting and wrong assumptions on what is included in scope. Table 32 summarises all European Waste Catalogue (EWC) categories.

Table 32: How Eurostat defines different wastes (EWC-Stat). Used by the Member States to standardise how waste data is collected.

Code	Main waste stream	Code	Sub-category
01	Chemical compound wastes	01.1	Spent Solvents
		01.2	Acid, alkaline or saline wastes
		01.3	Used oils
		01.4	Spent chemical catalysts
02	Chemical preparation wastes	02.1	Off-specification chemical wastes
		02.2	Unused explosives
		02.3	Mixed chemical wastes
03	Other chemical wastes	03.1	Chemical deposits and residues
		03.2	Industrial effluent sludges
		03.3	Sludges and liquid wastes from waste treatment
05	Health care and biological wastes	05.1	Infectious health are wastes
		05.2	Non-infectious health care waste
06	Metallic wastes	06.1	Metal waste, ferrous
		06.2	Metal waste, non-ferrous
		06.3	Metal wastes, mixed ferrous and non-ferrous
07	Non-metallic wastes	07.1	Glass wastes
		07.2	Paper and cardboard wastes
		07.3	Rubber wastes
		07.4	Plastic wastes
		07.5	Wood wastes
		07.6	Textile wastes
		07.7	Waste containing PCB
08	Discarded equipment	08.2	Discarded electrical and electronic equipment
		08.4	Discarded machines and equipment components
08.1	Discarded vehicles		(not part of 08)
08.41	Batteries and accumulators wastes		(not part of 08)
09	Animal and vegetal wastes	09.1	Animal and mixed food waste
		09.2	Vegetal wastes
		09.3	Slurry and manure
10	Mixed wastes	10.1	Household wastes (incl. mixed municipal waste)
		10.2	Mixed and undifferentiated materials
		10.3	Sorting residues
11	Common sludges	11.1	Waste water treatment sludges
		11.2	Sludges from purification of drinking and process water
		11.4	Cesspit contents
12	Mineral wastes	12.1	Construction and demolition wastes
	'Other mineral wastes' (12.1+12.3+12.5)	12.2	Asbestos wastes
		12.3	Waste of naturally occurring minerals
		12.5	Various mineral wastes
		12.6	Soils
		12.7	Dredging soils
		12.8	Waste from waste treatment
12.4	Combustion wastes		(not part of 12)
13	Solidified, stabilised or vitrified waste	13.1	Solidified or stabilised waste
		13.2	Vitrified wastes

Source: Eurostat, 2010

Eurostat also contains more specific information for a few key categories of waste as a result of there being specific waste related indicators and/or reporting obligations (such as those for producer responsibility monitoring) associated with them. The waste related Sustainable Development Indicators (SDIs) and Europe 2020 Indicators maintained by Eurostat include: municipal waste generation and treatment, generation of hazardous waste (by economic activity) and waste generation excluding mineral waste. The producer responsibility measures related to waste, introduced as a result of EU directives are summarised in Table 33. The 'worst' waste treatment option, from a waste hierarchy perspective (in env_waspac), for packaging waste (there is no landfill or disposal) is incineration for energy recovery. Env_waspac data are reported according the Directive on Packaging and Packaging Waste 2004/12/EC.[29]

Table 33: Additional selected Eurostat categories

Detailed waste stream		Code	Sub-categories	Code	Sub-sub-categories	Due to
W0841	Batteries	W08410	Non hazardous batteries	W160604	Alkaline batteries (except 16 06 03)	Directive 2006/66/EC
				W160605	Other batteries and accumulators	
				W200134	Batteries and accumulators other than those mentioned in 20 01 33	
		W08411	Hazardous batteries	W160601	Lead batteries	
				W160602	Ni-Cd batteries	
				W160603	Hg - containing batteries	
				W200133	Unsorted batteries and accumulators containing hazardous batteries	
EE	WEEE	EE_LHA	Large household appliances			Directive 2002/96/EC
		EE_SHA	Small household appliances			
		EE_ITT	IT and telecommunications equipment			
		EE_CON	Consumer equipment			
		EE_LIT	Lighting equipment	EE_GDL	Gas discharge lamps	
		EE_EET	Electrical and electronic tools			
		EE_TLS	Toys, leisure and sports equipment			
		EE_MED	Medical devices			
		EE_MON	Monitoring and control instruments			
		EE_ATD	Automatic dispensers			
W081	ELVs	W160103	End of life tyres			**Directive 2000/53/EC**
		W160107	End of life oil filters			

[29] Eurostat Helpdesk, e-mail response, 07 March 2016.

		W1601A	End-of-life vehicles: Other materials arising from depollution (excluding fuel)			
		W1601B	End-of-life vehicles: metal components			
		W160119	End-of-life vehicles: large plastic parts			
		W160120	End-of-life vehicles: glass			
		W1601C	End-of-life vehicles: Other arising from dismantling			
		W1608	Catalysts			
		W1910	Total shredding	W191001	Ferrous scrap (steel) from shredding	
				W191002	Non-ferrous materials from shredding	
				W1910A	Shredder Light Fraction (SLF)	
				W1910B	Other materials arising from shredding	
W1501	Packaging waste	W150101	Paper and cardboard packaging			Directive 94/62/EC
		W150102	Plastic packaging			
		W150103	Wooden packaging			
		W150104	Metallic packaging	W15010401	Aluminium packaging	
				W15010401	Steel packaging	
		W150107	Glass packaging			
		W150199	Other packaging			
W1011	Household wastes	W200301	Mixed municipal waste			

Source: Eurostat, 2010 based on env_waspac and env_wasmun.

Table 34 shows which main waste stream categories are available, and what sub-categories are available under each main stream. This is not an exhaustive list of all EWC-Stat categories, but the ones used in the available Eurostat dataset. In two cases there is a possibility for double counting, these are indicated in white. Env_wasgen data are reported according to the Waste Statics Regulation: 2150/2002/EC.[30]

[30] Eurostat Helpdesk, e-mail response, 07/03/2016.

Table 34: Eurostat dataset on general waste types for generation and treatment of waste (env_wasgen)

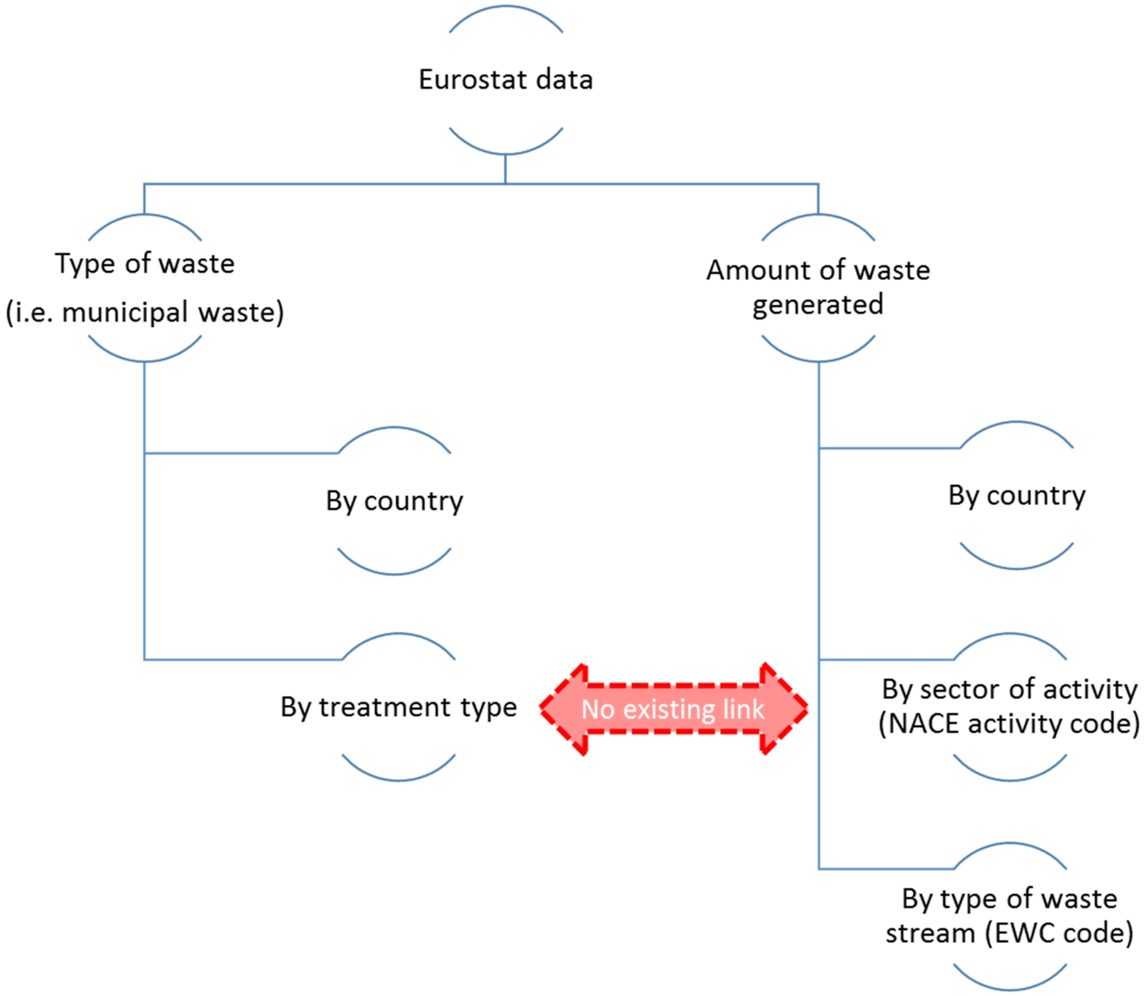
Code	Label	code	Available sub-categories
TOTAL	**Total Waste**		
W01-05	Chemical and medical waste (subtotal)	W01.1	Spent solvents
		W01.2	Acid, alkaline or saline wastes
		W01.3	Used soils
		W02A	Chemical wastes
		W03.2	Industrial effluents
		W03.3	Sludges and liquid wastes from waste treatment
		W05	Health care and biological wastes
W06-07A	Recyclable wastes (subtotal) W06 (metallic wastes) + W07 (non-metallic wastes, except W077 - waste containing PCB)	W06.1	Metal wastes, ferrous
		W06.2	Metal wastes, non-ferrous
		W06.3	Metal wastes, mixed ferrous and non-ferrous
		W07.1	Glass wastes
		W07.2	Paper and cardboard wastes
		W07.3	Rubber wastes
		W07.4	Plastic wastes
		W07.5	Wood wastes
		W07.6	Textile wastes
W06	Metallic wastes (W061+W062+W063)		(part of W06-07A – i.e. avoid double counting)
W077_08	Equipment (subtotal)	W07.7	Waste containing PCB
		W08A	Discarded equipment (W08 except W081, W0841)
		W08.1	Discarded vehicles
		W08.41	Batteries and accumulators wastes
W09	Animal and vegetal wastes (subtotal)	W09.1	Animal and mixed food waste
		W09.2	Vegetal wastes
		W09.3	Animal faeces, urine and manure
W091_092	Animal and mixed food waste; vegetal waste (W091+W092)		(part of W09 – i.e. avoid double counting)
W10	Mixed ordinary wastes (subtotal)	W10.1	Household wastes
		W10.2	Mixed and undifferentiated materials
		W10.3	Sorting residues
W11	Common sludges		
W12_13	Mineral and solidified waste (subtotal)	W12.1	Construction and demolition wastes
		W12B	Other mineral wastes (12.1+12.3+12.5)
		W12.4	Combustion wastes
		W12.6	Soils
		W12.7	Dredging soils
		W12.8_13	Mineral wastes from waste treatment and stabilised wastes

Source: Eurostat (2010) based on env_wasgen and env_wastrt.

*Note: **A** – means a sub-category is left out from the label. **B** – means sub-categories within a label are merged. The symbol: **_** means something has been altered in the label compared to the EWC structure (e.g. included a sub-category from another label.*

There is a limit to how specific Eurostat data is. Figure 31 illustrated the structure of the dataset. There are two streams of data where one shows how different types of waste streams are treated (e.g. municipal waste) and the other shows where the waste are derived from (e.g. manufacture of food products). It is not possible to find how waste from manufacturing are treated. Another barrier with Eurostat data is that the Member States are not all measuring the waste streams in enough detail, or are defining waste streams differently. Hence the results of the Eurostat analysis should be treated with care and cross-checked when necessary, such as for data regarding food waste.

Figure 31: This structure of Eurostat's database illustrates that there is a lack of data for certain areas



Another barrier with Eurostat data is that waste levels pre- and post-EU entry will be difficult to gain on a detailed level as such data is only available for 2010 and 2012 on Eurostat for most waste categories. However, total waste levels are available.

Table 35 and Table 36 show how waste treatment options have been defined and presented in Eurostat (env_wastrt). The white lines in Table 36 indicates available categories that can mean double counting if included. Further, Table 36 shows what the waste treatment options are called in this report.

Table 35: The codes associated with each treatment category

Incineration	
R1	Use principally as a fuel or other means to generate energy
D10	Incineration on land
Recovery operations (excluding energy recovery)	
R2	Solvent reclamation/regeneration
R3	Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes)
R4	Recycling/reclamation of metals and metal compounds
R5	Recycling/reclamation of other inorganic materials
R6	Regeneration of acids or bases
R7	Recovery of components used for pollution abatement
R8	Recovery of components from catalysts
R9	Oil refining or other re-uses of oil
R10	Land treatment resulting in benefit to agriculture or ecological improvement
R11	Use of wastes obtained from any of the operations numbered R1 to R10
-	Backfilling*
Disposal operations	
D1	Deposit into or onto land (e.g. landfill etc.)
D5	Special engineered landfill (e.g. placement into lined discrete cells which are capped and isolated from one another and the environment etc.
D12	Permanent storage (e.g. emplacement of containers in a mine etc.)
D2	Land treatment (e.g. biodegradation of liquid or sludgy discards in soils etc.)
D3	Deep injection (e.g. injection of pumpable discards into wells, salt domes or naturally occurring repositories etc.)
D4	Surface impoundment (e.g. placement of liquid or sludge discards into pits, pounds or lagoons etc.)
D6	Release into a water body except seas/oceans
D7	Release into seas/oceans including sea-bed insertion

Source: OJEU, 2010. *Backfilling is part of recovery and includes recovered materials that do not fall under the categories R2-R11 (Eurostat, 2016c).

Table 36: A summary of Eurostat's structure of waste treatment and how it has been used in this report

Cat.	Label	Code	Available sub-categories	Incl.	Called in this report
TRT	Total waste treatment	DSP_L	Deposit onto or into land	D1, D5, D12	Landfill
		DSP_O	Land treatment and release into water bodies	D2, D3, D4, D6, D7	Land treatment and release into water bodies
		INC	Incineration / disposal (D10)	D10	Incineration / disposal
		RCV_E	Incineration / recovery (R1)	R1	Incineration/ recovery
		RCV_B	Recovery other than energy recovery - Backfilling		Backfilling
		RCV_O	Recovery other than energy recovery – Except backfilling	R2 - R11	Recovery other than energy recovery – Except backfilling
	Avoid double counting	DSP_L	Landfill / disposal (D1-D7, D12)	D1-D7, D12	Landfill / disposal (D1-D7, D12)
	Avoid double counting	RCV_NE	Recovery other than energy recovery (RCV_B + RCV_O)		

Source: Eurostat (env_wastrt) and Eurostat Metadata, 2014

Packaging waste and municipal waste have an additional dataset (not to be compared with env_wastrt). The waste treatment operation categories available for these two waste streams are available in Table 37 and Table 38.

Table 37: Waste treatment categories available for Eurostat packaging waste

Code	Treatment	Code	Sub-categories of recovery	Code	Sub-categories of recycling
RCV	Recovery	RCV_E	Incineration / Energy recovery (R1)		
		RCV_NE	Recovery other than energy recovery		
		RCV_I	Incineration with energy recovery at waste incinerators		
		RCY	Recycling	RCY_M	Material recycling
				RCY_O	Other form of recycling (including composting)

Source: Eurostat (env_waspac) and Eurostat Helpdesk, e-mail response, 16/03/2016.

Table 38: Waste treatment categories available for Eurostat municipal waste

Code	Sub-categories of treatment options
DSP_L	Landfill / disposal (D1 – D7, D12)
RCV_E	Incineration / Energy recovery (R1)
RCV_NE	Recovery other than energy recovery
RDV_I	Incineration with energy recovery at waste incinerators
RCY_M	Material recycling
RCY_OC	Composting and digestion
INC_RCV	Total incineration (including energy recovery)

Source: Eurostat (env_wasmun)

Table 39 shows the NACE codes used in Eurostat and its letter code.

Table 39: NACE codes in combination with Eurostat's definition of the main waste streams

Code	Statistical Classification of Economic Activities in the European Community
Agriculture, forestry and fishing	
A	Agriculture, forestry and fishing
Mining and quarrying	
B	Mining and quarrying
Manufacturing	
C	Manufacturing
Energy, water and waste	
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation activities
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
Construction	
F	Construction
Services	
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H	Transportation and storage
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence; compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other service activities
Households	
T	Activities of households as employees; undifferentiated goods- and services-producing activities of households for own use
Other	
U	Activities of extraterritorial organisation and bodies

Source: Eurostat, 2016d and 2016e

Annex 5: Performance of EU-28 Member States in 2012 against the proposed EU Circular Economy Package 2030 targets

Member State	Municipal solid waste		Packaging materials					
	<10% Landfill	>65% Recycle	Glass >85%	Metallic >85%	Paper & cardboard >85%	Wood >75%	Plastic >55%	Total >75%
Austria	**4.2%**	*59.7%*	*82.9%*	61.4%	*84.9%*	21.5%	34.7%	*65.9%*
Belgium	**1.0%**	*56.2%*	**100.0%**	**97.3%**	**89.8%**	*66.1%*	*41.5%*	**80.3%**
Bulgaria	69.1%	26.6%	60.5%	*75.6%*	**94.2%**	53.1%	*40.7%*	*66.5%*
Croatia	82.6%	15.1%	62.8%	12.5%	**96.1%**	0.4%	*45.4%*	*59.7%*
Cyprus	79.4%	22.1%	32.4%	**98.7%**	**88.9%**	6.2%	*44.8%*	*55.3%*
Czech Republic	56.5%	23.2%	*81.1%*	*69.2%*	**85.9%**	25.7%	**58.2%**	*69.9%*
Denmark	***2.1%***	41.0%	*80.6%*	51.8%	*76.5%*	40.4%	29.4%	*60.1%*
Estonia	34.8%	28.7%	*70.7%*	*65.3%*	*77.2%*	*59.7%*	29.8%	*61.3%*
Finland	32.9%	33.3%	*77.6%*	**85.3%**	**99.2%**	16.9%	25.4%	*59.3%*
France	*26.7%*	37.8%	*73.5%*	*73.9%*	**91.8%**	28.6%	25.1%	*64.9%*
Germany	***0.2%***	**65.2%**	*84.7%*	**92.3%**	**87.6%**	30.3%	*49.5%*	*71.3%*
Greece	80.7%	19.3%	54.7%	38.2%	*83.6%*	41.8%	32.2%	*58.6%*
Hungary	65.4%	25.5%	34.2%	*80.8%*	*73.0%*	18.1%	27.8%	48.5%
Ireland	38.2%	40.4%	**85.5%**	*75.8%*	*83.0%*	**82.3%**	*40.4%*	*74.0%*
Italy	39.1%	40.0%	*70.9%*	*73.6%*	*84.5%*	54.2%	*37.5%*	*66.6%*
Latvia	84.2%	15.8%	55.1%	57.8%	*75.3%*	36.7%	24.0%	51.1%
Lithuania	73.0%	24.3%	*72.2%*	*67.2%*	*82.4%*	48.8%	*38.9%*	*62.2%*
Luxembourg	*17.6%*	*47.4%*	**94.6%**	*82.4%*	*76.7%*	23.4%	*36.7%*	*62.5%*
Malta	82.2%	12.8%	21.3%	41.5%	*77.2%*	0.8%	32.8%	46.6%
Netherlands	**1.5%**	*49.4%*	*71.3%*	**90.7%**	**88.9%**	29.3%	*47.7%*	*69.3%*
Poland	59.2%	24.8%	51.2%	46.9%	53.1%	28.5%	22.2%	41.4%
Portugal	54.4%	26.1%	59.6%	*72.3%*	*66.1%*	*69.7%*	30.4%	*56.9%*
Romania	67.9%	17.5%	*66.3%*	55.5%	*69.8%*	41.1%	*51.3%*	*56.8%*
Slovakia	73.1%	13.8%	*69.4%*	*67.8%*	*84.7%*	36.7%	**57.0%**	*68.1%*
Slovenia	42.5%	*48.8%*	**87.3%**	41.6%	*78.7%*	33.1%	**64.8%**	*66.9%*
Spain	60.6%	29.8%	64.2%	*78.0%*	*77.8%*	*57.9%*	*35.1%*	*65.5%*
Sweden	**0.6%**	*47.2%*	**88.2%**	*74.4%*	*76.8%*	17.2%	34.9%	*56.9%*
UK	*37.1%*	*43.3%*	*67.8%*	52.1%	**86.5%**	51.3%	25.2%	*61.4%*
EU-28	*31.7%*	*42.6%*	*72.2%*	*72.3%*	*83.9%*	37.9%	*35.5%*	*64.5%*

Annex 6: Examples of funded CRM and battery projects

- The **MINEA COST Action** (2016-2020) aims to harmonise secondary material resource and reserve reporting with that of primary deposits. Secondary material resources and reserves can include in-use stocks, historic tailings and landfills as well as the WEEE and batteries collected for recycling. It will bring together a network of stakeholders from across the EU with a common interest in improving the quantification and valuation of wastes containing CRMs.
- **ProSUM** (2015-2017) is an example of a Horizon2020 project which, similarly to the MINEA COST Action, is focused on expanding the knowledge base on opportunities for secondary raw material recovery in urban mines and mining wastes. The inventory of secondary raw materials is tasked with producing is to have a particular focus on critical raw materials arising in WEEE, ELVs, waste batteries and mining wastes.
- **ReCreew COST Action** (2015-2019) is a network for innovative recovery strategies of rare earth and other critical metals from electrical and electronic waste. They aim to consider all aspects of WEEE management including collection, pre-treatment, advanced treatment and standardisation.
- **HydroWEEE**, funded under FP7 (2009-2012) and followed by **HydroWEEE Demo** (2012-2016), focused on developing and demonstrating a mobile plant for extracting metals, including CRMs, from WEEE using a hydrometallurgical process. The plant was designed such that it could be shared between multiple SME recyclers and improve their competitiveness as well as their recovery of CRMs.
- **CloseWEEE** (2014-2018) is a Horizon 2020 funded project carrying out research into improving the resource efficient recycling of the polymeric materials and CRMs from WEEE. One of the three research themes in this project is centred on improving lithium ion battery recycling and the recovery rates of the CRMs cobalt, graphite and antimony from these batteries in particular.
- **Critical Raw Material Recovery** (2015-2018) is a project that received contributions from the LIFE financial instrument of the EC for the partners across three EU countries and Turkey to trial collection and recovery strategies for increasing precious metal recovery from WEEE with the aim of achieving 5 per cent recovery by 2020 (20 per cent by 2030).

Annex 7: Waste treatment technologies – environmental impacts

Table 40: Main environment impacts arising from landfill

Environmental aspects	Main environmental impacts
Infrastructure construction and maintenance	-Abiotic resource depletion -Fossil resource depletion -Land occupation -Landscape appearance and loss of amenity value -Biodiversity displacement
Machinery operation	-Fossil resource depletion -Global warming -Acidification -Photochemical ozone formation
Sequestered resources	-Abiotic resource depletion
Landfill gas leakage	-Global warming (CH_4) -Acidification and eutrophication (NH_3 and NO_X) -Photochemical ozone formation (VOC and NO_X) -Odour nuisance
Landfill gas capture and energy recovery	-Avoided fossil fuel combustion burdens -Acidification -Photochemical ozone formation
Leachate generation	-Eutrophication -Eco-toxicity -Waste water treatment plant burdens

Source: European Commission (2016i)

Table 41: Main environmental impacts arising from incineration (with energy recovery) of mixed waste

Environmental aspects	Main environmental impacts
Infrastructure construction and maintenance	-Abiotic resource depletion -Fossil resource depletion -Land occupation
Machinery operation	-Fossil resource depletion -Global warming -Acidification -Photochemical ozone formation
Incinerated resources	-Abiotic resource depletion
Combustion	-Global warming (CH_4) -Acidification (NO_X and SO_X) -Photochemical ozone formation (VOC and NO_X) -Human toxicity (particulate matter, dioxins, furans, PCBs)

Energy recovery	-Avoided fossil fuel combustion burdens -Destruction of pathogens (avoided health burden)
Ash/slag production	-Abiotic resource depletion -Eco-toxicity -Landfill burdens

Source: European Commission (2016i)

Table 42: Main environmental impacts arising from organic waste recycling

Environmental aspects	**Main environmental impacts**
Separated organic waste collection	-Fossil resource depletion -Traffic congestion and noise -Odour nuisance -Pest nuisance
Infrastructure construction and maintenance	-Abiotic resource depletion -Fossil resource depletion -Land occupation
Machinery operation	-Fossil resource depletion -Global warming -Acidification -Photochemical ozone formation
Incinerated resources	-Abiotic resource depletion
Biogas leakage (composting and anaerobic digestion)	-Global warming (CH_4) -Acidification and eutrophication (NH_3 and SO_X)
Digestate and compost storage and application	-Acidification and eutrophication (NH_3, NO_3, PO_4) -Fossil resource depletion -Global warming potential (diesel CO_2 plus soil N_2O) -Avoided fertiliser manufacture and application burdens Avoided global warming potential (soil carbon sequestration)
Energy recovery (biogas or biomass combustion)	-Acidification (NO_X and SO_X) -Photochemical ozone formation (volatile organic compounds and NOx) -Human toxicity (particulates and polycyclic aromatic hydrocarbons) -Avoided fossil fuel combustion burdens
Extracted non-organic materials and combustion ash	-Landfill burdens

Source: European Commission (2016i)

Table 43: Main environmental impacts arising from material recycling

Environmental aspects	Main environmental impacts
Waste collection / separation	-Waste sorting and disassembly impacts
Infrastructure construction and maintenance	-Abiotic resource depletion -Fossil resource depletion -Land occupation
Machinery operation	-Fossil resource depletion -Global warming -Acidification -Photochemical ozone formation
Material cleaning	-Water stress (consumption) -Abiotic resource depletion (chemicals) -Fossil resource depletion -Global warming -Acidification -Photochemical ozone formation -Eco-toxicity (discharges to water)
Material recovery	-Avoided resource depletion (credit) -Avoided raw material processing (credit)
Rejected materials	-Waste disposal impacts

Source: European Commission (2016i)

Table 44: Main environmental impacts arising from product re-use

Environmental aspects	Main environmental impacts
Collection and transport	-Fossil resource depletion -Traffic congestion and noise
Product cleaning (energy and cleaning products)	-Fossil resource depletion -Global warming -Acidification -Photochemical ozone formation -Eco-toxicity (discharges to water)
Avoided production	-Avoided resource depletion (credit) -Avoided raw material processing (credit) -Avoided manufacturing and transport burdens (credit)

Source: European Commission (2016i)

Annex 8: Examples of valorisation of bio-wastes

PULP2VALUE	
Raw material used	Sugar beet pulp, a co-product of the sugar beet industry
Products produced	Functional additives for the agro-food industry
Description	Approximately 13 million tonnes of sugar beet pulp is available in the EU. Here, microcellulose fibres (detergents, oil & gas, paints & coatings, composites), arabinose (food additive) and galacturonic acid (thickener) are targeted alongside the production of biogas, feed and biomaterials in parallel to sugar production. The project was funded by the BBI initiative (€11.5 million, €6.6 million BBI funding for four years). The process is based on a cascading biorefining with the aim of extracting between 20 and 50 times more value from beet. The Bio Base Europe Pilot Plant will be looking at the optimisation at pilot scale of the biomass hydrolysis together with the extraction, filtration, ion exchange, evaporation, membrane filtration, fermentation, crystallisation and drying technologies, showing how downstream processing is crucial. The project is expected to end in June 2019 with the full set-up of a cascading biorefinery. The PULP2VALUE will target the creation of nine new value chains resulting in a market potential of approx. 350.000 tonnes and a potential revenue of € 200 million. The project is expected to 'spur rural development in sugar beet growing districts by connecting them in new cross-sectoral value chains with the chemical and food industry'. (EC CORDIS website, project reference 669105)

FIRST2RUN	
Raw material used	Oil crops
Products produced	Azelaic acid, pelargonic acid, esters and glycerol
Description	This project led by Novamont focuses on the creation of a value chain valorising underutilized oil crops (cardoon, 3.5 kha) for the production of azelaic acid, pelargonic acid, esters and glycerol using catalytic and biocatalytic processes. The project is expected to yield an azelaic and pelargonic acid manufacturing plant with a production capacity of up to 10 000 tonnes per year for each acid. The targeted applications fields are biolubricants, cosmetics, bioplastics. The batch production of biodegradable esters of up to 20 000 tonnes per year is expected to be demonstrated. A 35 per cent reduction in greenhouse gas emissions will be achieved as well as a consumption of thermal and electric energy for chemical processes is reduced by up to 50 and 20 per cent respectively. Other expected impacts include the use of currently unexploited 3,500 ha of marginal lands, the installation of 16.2 MWh of thermal power from the energy generation plant using the lignocellulosic fraction (co-generation), the creation of an estimated 60 new skilled jobs for every kilo tonne of produced bioplastics, taking into account the whole value chain (i.e. municipalities, composting plants) and the rehabilitation of the Porto Torres oil refinery into a biorefinery. The project

	was funded by the BBI initiative (€52 million, €17 million BBI funding for four years until June 2019).

ABOWE	
Raw material used	Cellulosic, food industry, agricultural and sorted municipal bio-wastes.
Products produced	2,3-butanediol
Description	This mobile pilot plant looked at the production of 2.3-butanediol through bacterial fermentation technology alongside the production of bio-ethanol and hydrogen. The process has been proved to operate on cellulosic, food industry and agricultural, as well as sorted municipal bio-wastes. The application targeted are: synthetic rubber, plastic monomers, anti-icing chemicals, textiles and cosmetics. This EU Baltic Sea Region project, funded between 2009 and 2012 by €1.6 million European Regional Development Fund funding for a total budget of €2 million. The aim was to scale-up the process developed in a previous project (REMOWE), trial the pre-treatment and hydrolysis protocol on various industrial (potato residues, slaughterhouse waste, carton board waste, dried wastewater sludge) and municipal types of waste, optimise the bacterial fermentation and make preliminary plans for simultaneous product collection. The mobile pilot plant was tested in three different countries (Finland, Sweden and Poland)

Life GIS Waste	
Description	This Basque regional project focused on the development of an IT tool designed to provide the best treatment option for a given source of vegetable, meat, and dairy by-products from the agrifood sector. The software takes into account treatment option available, the distance to the recovery plants and the existence of similar sources of waste within a delimited radius to report the best suited recovery method available for a given type of agrifood by-product. The project has been funded by the European Union's Life project and is led by the consortium coordinated by the AZTI-Tecnalia centre over a period of four years, finishing in June 2017 (€1.4 million) (Life GIS Waste, 2016).

This STOA study explores waste management in the EU. Around one third of EU municipal waste was sent to landfill in 2012. To turn waste into a resource, waste management objectives must be aligned with the goals of a circular economy transition. This report highlights progress and challenges across Member States and in municipalities for (1) reducing waste, and (2) generating high-quality waste streams for re-use and recovery. It focuses on the current policy landscape, trends, and technologies for the five waste streams identified in the European Commission´s Circular Economy Action Plan. Employment opportunities for the different steps of the waste hierarchy as well as future policy options are identified and discussed.

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