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Moving Towards a Circular Economy: Rethinking Waste Management Practices

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Abstract. Nowadays waste has become a vital part of our economy, as a by-product of economic activity. It originates from businesses, the government and households and following appropriate management techniques, it can be used as an input to economic activity for instance through material or energy recovery. Waste is produced by all activities and although it is a locally arising problem it has both local and global effects. Societies need to dispose their waste products thus creating a source of environmental pollution. Sustainable waste management requires the combination of skills and knowledge of physical sciences and engineering together with economics, ecology, human behaviour, entrepreneurship and good governance. This paper discusses extensively the policy framework and the legislative background around waste and its management in the EU and worldwide. In this way, it focuses on the treatment options for waste under the Circular Economy approach having in mind the idea of closing the loop and hence achieving a more efficient use of resources.

Keywords. Municipal solid waste, Waste management, Resources, Circular economy, Waste infrastructure.
JEL. O13, O52, Q50, Q53, Q56, R11.

1. Introduction

Nowadays waste has become a vital part of our economy, being a by-product of economic activity and originating from businesses, the government and households; at the same time it can be used as an input to economic activity for instance through material or energy recovery (Defra, 2011a). Waste arisings have been increasing over the past few years, hence their management has proved to be a rather challenging issue in the 21st century and a lot of research is being conducted in this field. First of all, it is important to define waste in order to be able to manage it successfully.

According to the European Union's (EU) Waste Framework Directive 2008/98/EC, 'any substance or object which the holder discards or intends or is required to discard is defined as waste'. In addition municipal waste consists of waste collected by or on behalf of municipal authorities and disposed of via established waste management systems. The waste sector has conventionally referred to municipal solid waste (hereafter MSW) excluding "wastewater", which is considered under the water or industry sectors (UNEP, 2011). Therefore it is important to note that MSW excludes the following waste streams: waste from

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sewage treatment, construction and demolition activities. MSW consists primarily of waste generated by households, although it also includes waste from sources (and of similar composition) such as commercial and industrial waste (Eurostat, 2014a).

Every country produces different amounts of MSW and with diverse composition. This is because waste generated is influenced by the degree of urbanisation, patterns of consumption, household revenue and lifestyles in each country (Eurostat, 2014a). For instance there is a strong link between affluence and waste generation, despite of improvements in efficiency nowadays (World Bank, 1999). Market failures exist in the economic markets all around us and these prevent economic agents from making optimal choices, ultimately leading to an over-production of waste; environmental externalities are one of the primary market failures – whereas economic decisions do not account for the environmental impacts of waste generated (Defra, 2011a). The treatment options of MSW can be classified in broad terms as: landfill, incineration, recycling and composting. Sustainable Waste Management is one of the most challenging issues faced by both developed and developing countries which are now trying to meet pressure from national and international communities to reduce their environmental impacts overall. Developed countries are examining how to avoid waste going to landfill, and increase the recycling and recovery of materials. An important driver to this notion is the Waste Hierarchy (Figure 1). This gives top priority in preventing waste in the first place. Even when waste is finally created, priority is given in preparing it for re-use, then recycling, then recovery and as last resort disposal (i.e. landfill) (Defra, 2011b).

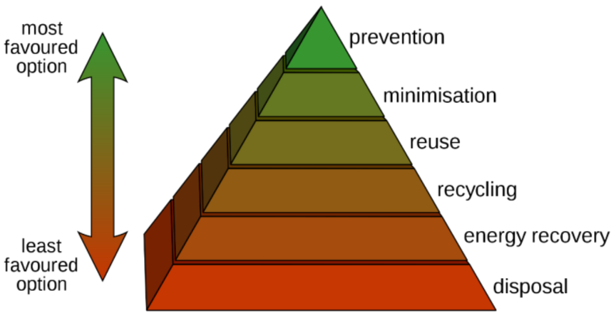

Figure 1. *Waste hierarchy (Defra, 2011b)*

Member States of the EU are bound by a number of Directives to not only reduce the amount of waste going to landfill but also to increase the recoverability of this waste through recycling. Namely the EC Landfill Directive (99/31/EC) states that Member States need to reduce the amount of biodegradable municipal waste (BMW) sent to landfill to 35% of 1995 levels, whereas the revised Waste Framework Directive (2008/98/EC) requires a 50% recycling rate for household waste and waste of similar nature to household by 2020.

Moreover in 2011, the European Commission launched an important initiative entitled ‘A resource-efficient Europe’ which supports the shift towards a resource-efficient, low-carbon economy with the ultimate goal to achieve sustainable growth (Eurostat, 2014a). Whether it is re-used, recycled, incinerated or sent to landfills, the management of household and industrial waste brings in financial and environmental costs (European Commission, 2010a). The main issue around waste is that one cannot manage it, unless one measures it appropriately. Therefore this sector provides a great pool of research and is already creating a new business area worth investigating and developing further.

2.Background

This section provides an overview of the waste sector both in terms of its composition and infrastructure. At the same time and to start with the policy framework and legislation background are outlined.

2.1. Policy framework and legislative background

From its founding in 1957 until today, the European Community had managed to develop the most integrated environmental policy framework in the world through the six Environmental Action Programmes (EAP), under which several strategies and policies have been deployed (ISWM-Tinos, 2012). The most recent 6th EAP and the thematic strategies on waste prevention and recycling and on natural resources particularly, evolves around the notion of *'to become a recycling society that seeks to avoid waste and uses waste as a resource'* (ISWM-Tinos, 2012).

Apart from the Waste Hierarchy already mentioned, the main elements forming the waste legislative background in the EU include the following (European Commission, 2015b):

- Waste Framework Directive (WFD), or Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste. It provides the general context of the waste management requirements and establishes the basic definitions around waste management for the EU. Within the WFD there are specific provisions for each waste stream and how it should be managed.
- European Union legislation on waste management operations, which includes Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste and Directive 2000/59/EC of the European Parliament and of the Council of 27 November 2000 on port reception facilities for ship-generated waste and cargo residues.
- Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste. This one specifies the details regarding the shipment of waste between countries.
- Decision 2000/532/EC which sets a list of wastes. This Decision establishes the classification system for waste, including but not limited to a distinction between hazardous and non-hazardous wastes.

Directive 2006/12/EC on waste has been revised in order to be more up-to-date and restructure its provisions, therefore in the revised Directive 2008/98/EC (Waste Framework Directive) the basic concepts and definitions related to waste management are established and new waste management principles such as the "polluter pays principle" or the "waste hierarchy" are outlined as well (European Commission, 2015a). The main legislation in the EU environmental policy is the WFD which provides the legal framework on how to treat waste within the Community with the aim to protect the environment and human health through the prevention of the harmful effects of waste generation and waste management (European Commission, 2008). All relevant EU regulations in relation to the waste management sector are presented schematically in Figure 2.

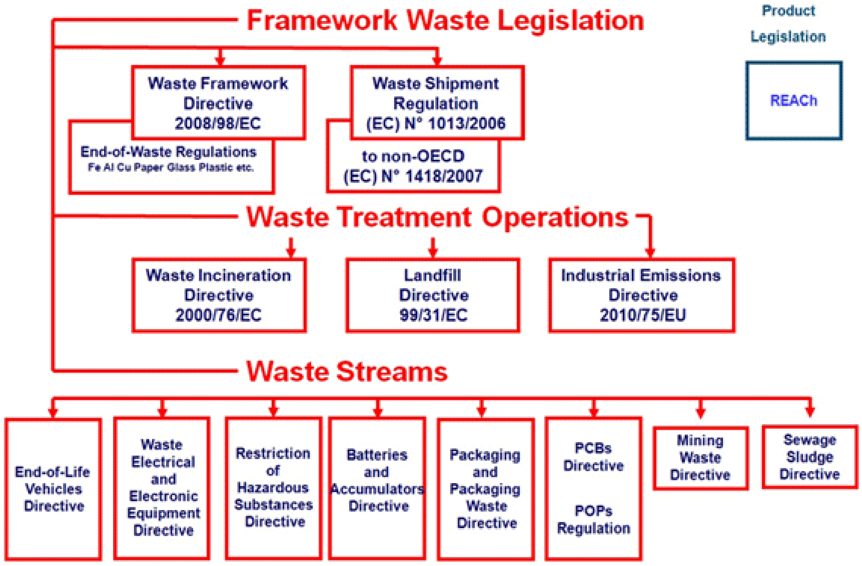

Figure 2. *Waste laws (Eurometrec, 2015)*

Not all Member States have to date implemented waste prevention as part of their environmental policies and hence implemented the regulations set out by WFD. Countries in Central and Northern Europe perform above average but have problems in decoupling waste production from growing consumption; average performing countries are mainly located in Southern and Central to Eastern Europe, whereas these have deficits in collection coverage and in the planning of future treatment capacity (FhG-IBP, 2014). The largest implementation gaps can be found in Member States in Southern and Eastern Europe in all key elements for good waste management systems (FhG-IBP, 2014). These performances can be seen also in Figure 3.

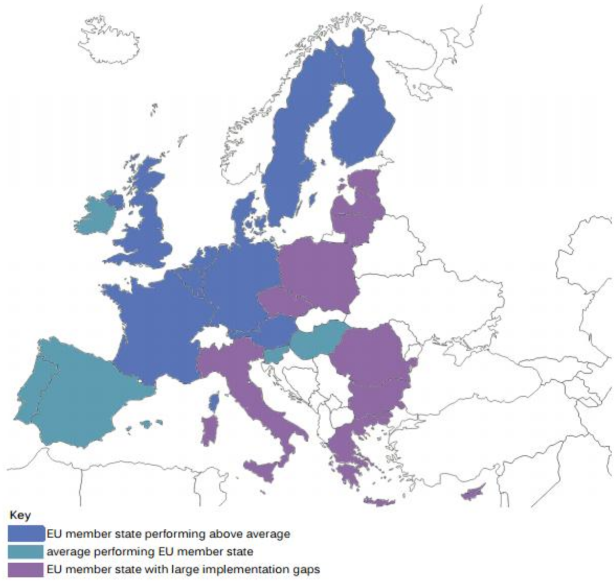

Figure 3. *Waste management performance across Europe (FhG-IBP, 2014)*

Over the last couple of years (2014 onwards) the EU has proposed some measures to enhance Europe's transition to a more circular economy, thus creating a new policy background (European Commission, 2016a). By providing greater resource efficiency and ultimately turning waste into a resource, this approach entails benefits for competitiveness, growth and employment, as well as the environment in whole (European Commission, 2016a). Moreover and based on these regulations, waste prevention programmes are running in European countries to tackle the issue of effective waste management. As expected the status of implementation differs widely among European countries of the North and South.

To that end and to enhance these approaches, the EC has adopted an ambitious Circular Economy Package, with aims to accelerate Europe's transition towards a circular economy by certain legislative proposals (European Commission, 2016b). To make sure this plan is implemented effectively, along with the waste reduction targets there are concrete measures to overcome obstacles on the ground and smoothen the different situations across EU Member States (European Commission, 2016b).

As mentioned the new proposals come along a review of the EU's current waste targets and stress that waste policy has been and should continue to be a powerful driver for recycling and re-use, but there is more work to be done before being able to close the loop, as presented in Figure 4 (European Commission, 2016a). The measures provide a holistic framework, including all the steps from raw materials, design, production, distribution, consumption, collection and recycling – back to the reuse of materials.

Figure 4. *EU Circular Economy – Closing the loop (European Commission, 2016a)*

All these measures mentioned above, could bring net savings to EU businesses of up to €600 billion, while also reducing greenhouse gas emissions. These along with further measures to increase resource productivity by 30% by 2030, could enhance GDP by nearly 1% and create 2 million additional jobs (European Commission, 2016a). In addition to this, a report by the Imperial College London (ICL, 2015) stresses the business case for adopting a circular economy and it is shown that using resources in a closed loop system has the potential to contribute £29 billion (1.8%) of GDP and create 175,000 new jobs in the UK alone. The numbers are quite astonishing and therefore the circular economy demands further research all over Europe.

In these lines it is essential to establish an EU indicator to account for resource productivity which will help Member States enhance their policies and at the same time promote synergies across EU policy areas such as employment, enterprise and research; for instance resource productivity could be measured against a target which would combine raw material consumption and GDP, suggesting an improvement of 30% in this measure by 2030 (European Commission, 2016a). Overall it is very clear that coordinated action among Member States is needed to achieve the Circular Economy in the EU and the associated targets.

2.2. Waste arisings and composition

Finding data on waste management and waste treatment has shown to be a challenge in the past years, as the available data is diverse and sometimes (most often) outdated. In order to be able to plan and assess waste and its management it is important to have accurate and reliable data on waste (Edjabou et al., 2015). So far there are no international standards for solid waste characterisation, which has led to various sampling and sorting approaches that in turn make comparisons of results from different studies challenging (Dahlén & Lagerkvist, 2008). One way to overcome this obstacle and manage to ensure uniform coverage of the geographical area under study, is stratification sampling, which involves dividing the study area into non-overlapping sub-areas with similar characteristics (Dahlén & Lagerkvist, 2008; Sharma & McBean, 2007; European Commission, 2004). Thus far the inconsistencies in the definitions provided, may cause confusion and limit comparability of waste composition data between studies (Dahlén & Lagerkvist, 2008).

Based on the information presented above, it comes to reason that waste composition differs not only across countries, but also by region according to but not limited to the following factors (Eunomia, 2015): socioeconomic status, consumption habits, season, whether or not households have gardens and presence (or not) of tourists. There is also a connection between buying capacity of the population in urban centres and amount of MSW generated (Ojeda-Benitez et al., 2003). From a recent study conducted in Denmark it was found that the waste composition from single-family and multi-family houses were different showing that differences in housing types cannot be ignored either (Edjabou et al., 2015). Moreover the statistics depend on the methodology that is employed and should account for other factors related to waste as well for instance the physical characteristics of waste such as moisture (Eunomia, 2015).

The Waste Atlas Partnership has evaluated the world's 50 biggest active dumpsites (Figure 5) most of which are located in Africa, Asia and Latin America/Caribbean and two in Europe (UNEP, 2015). These differ in size, in the waste they handle and accommodate different numbers of people either working at the dumps or living in the surroundings; however these 50 sites all have in common that they are dangerous to human health and the environment (UNEP, 2015). A close interrelationship between waste quantity/quality and socio-economic status of households in developing countries have not been proven by many researchers thus far (Qu et al., 2009; Sujauddin et al., 2008; Thanh et al., 2010).

Figure 5. *World's 50 biggest dumpsites (UNEP, 2015)*

In all parts of the world, an increase in income can affect the consumption patterns of households and therefore the composition and quantity of MSW (Ogwueleka, 2013). At the same time and as shown in Figure 6 there is also a proven strong relationship between waste per capita and income levels per capita; namely there is a strong positive correlation, with the average generation in high-income countries being about six-fold greater than in low income countries (UNEP, 2015). In urban cities of developing countries, management of MSW is highly neglected (Zhen-shan et al., 2009; Batool & Ch, 2009; Chung & Carlos Lo, 2008; Imam et al., 2008; Berkun et al., 2005; Metin et al., 2003; Ahmeda & Alib, 2004) and there is limited space for further development because government budgets are limited and more than often collection is disregarded (McBean et al., 2005). The main issue is not the absence of environmental legislation, but rather the lack of enforcement and/ or the availability of viable alternatives in place (Fourie, 2006). At the same time, there is also considerable variation within countries themselves.

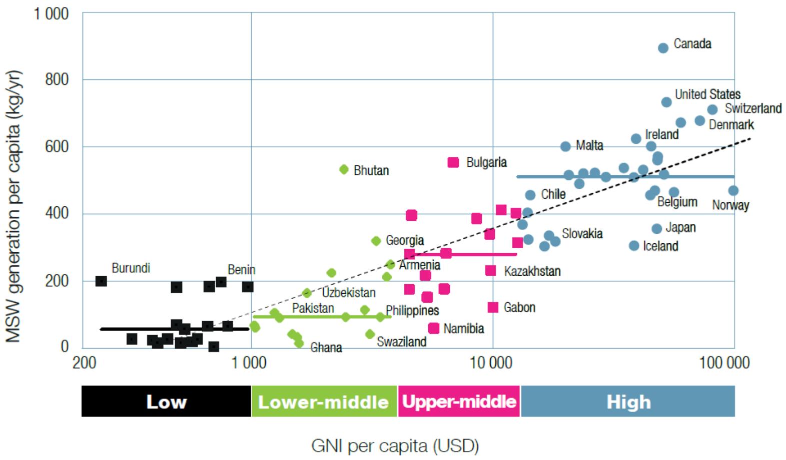

Figure 6. *Waste generation versus income level by country for 82 countries (UNEP, 2015)*

The definition of municipal waste varies across countries; however, for most countries MSW includes waste collected by local authorities in the form of household waste as well as commercial waste and also waste originating from maintenance of public areas (Eunomia, 2015). Apart from MSW there are also some other concepts around waste which need to be further defined. For instance biodegradable waste includes waste capable of being decomposed by the action of biological processes. This category is often neglected and includes garden, kitchen and food waste accounting for about 1/3 of the waste that is thrown away at home – translating to around 88 million tonnes across Europe each year (European Commission, 2010a). The amount of MSW should be rather well known today as Member States in the EU are required to provide this information under the Waste Framework Directive (Eunomia, 2015). Figure 7 presents the MSW generated per Member State in 2003 and 2014 sorted by 2013 waste per capita. Generation of municipal waste per capita has declined slightly from 2004 to 2012 with better management techniques in place as well, whereas the number of countries recycling and composting increased from 11 to 17 out of 35, and those landfilling more than 75% of their municipal waste declined from 11 to 8 (European Environmental Agency, 2015a).

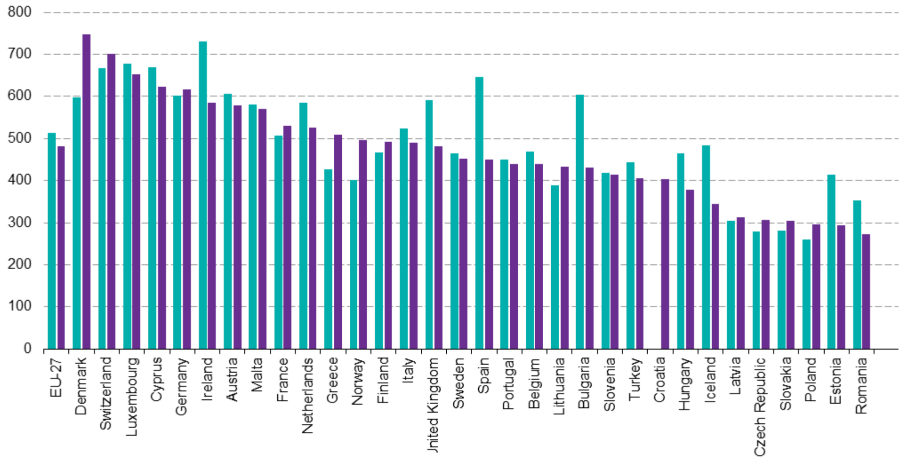

Figure 7. *Municipal waste generated by country in 2003 and 2013, sorted by 2013 level (kg per capita) (Eurostat data) (blue: 2003 and purple: 2013)*

Apart from generating the exact amount of waste produced in a country, understanding the composition of waste is also important which in most cases is not straightforward, because waste composition is very different across the world (Eunomia, 2015). In Figure 8 the aggregated data on the amount of waste fractions [t/a] for EU Member States and associated countries are shown, presenting the varying composition of waste among EU countries.

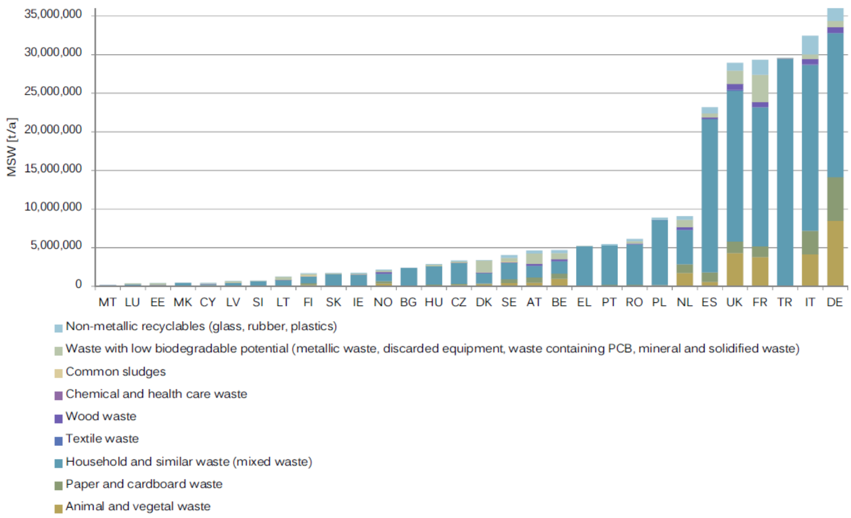

Figure 8. *Aggregated data on amount of MSW (t/a) in EU Member States (2010 Data) (FhG-IBP, 2014)*

In relation to Figure 6, Figure 9 presents the variation of MSW composition grouped by country income levels from data on 97 countries. Organic material takes most space in all income levels, but obvious differences can be noticed among different income levels which are associated with the living conditions and lifestyle of the people there.

As previously mentioned, there are waste prevention programmes already in practice all over Europe. Of course at the same time it is important to have a clear picture of the waste prevention programmes by sector and not just by country. It is important to note that waste prevention does not only take place during collection but it starts even from production and under a life-cycle thinking approach includes preventative steps during production (including production and transport), consumption and collection. These in summary can be seen schematically in Figure 10.

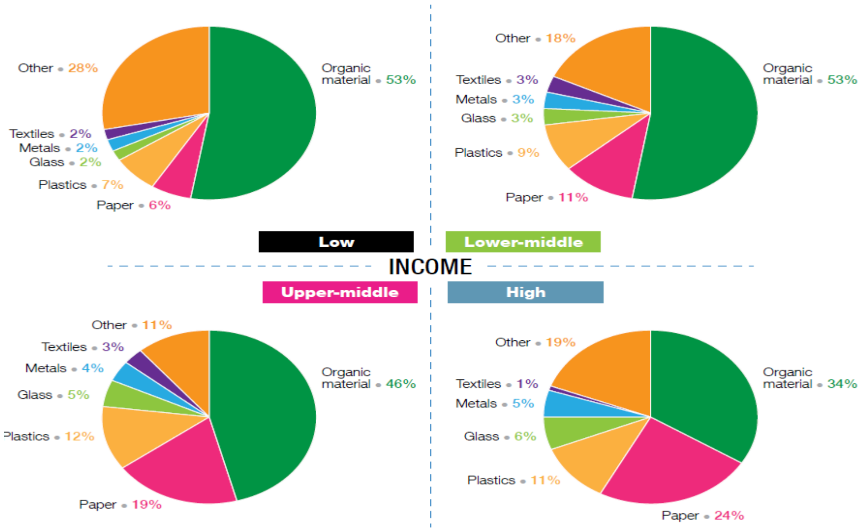

Figure 9. *Variation in MSW composition grouped by country income levels (UNEP, 2015)*

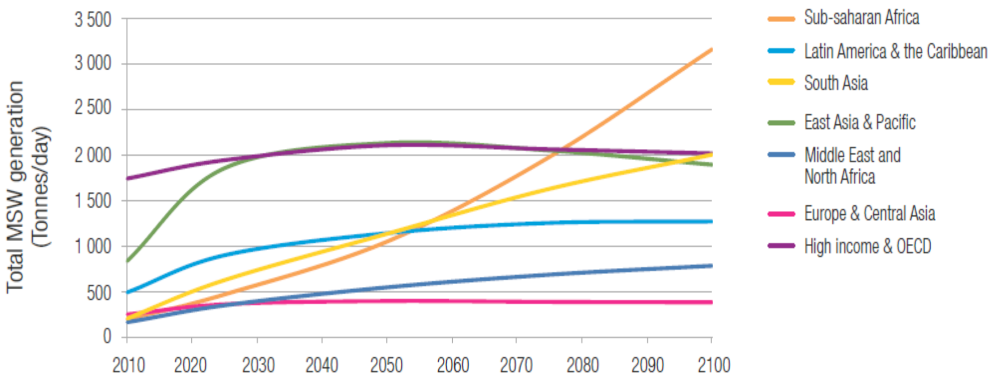

Figure 10. *Waste prevention at different stages in product life-cycle (UNEP, 2015)*

Sustainable consumption and production (SCO) thinking has gained a lot of attention recently and one important pillar of this, is waste prevention as at the same time awareness is increasing that our society is reaching the limits of a finite planet in terms of resources and resource use (UNEP, 2015). These waste prevention programmes need to be more stringent and put in place as waste arisings are projected to further increase by 2100.

2.3. Waste infrastructure and treatment options

Sustainable growth is an important part of the Europe 2020 growth strategy to become a 'smart, sustainable and inclusive economy', with the aim to lower greenhouse gas emissions by 20% (or even 30% if the conditions are right) compared to levels of 1990, to generate 20% of its energy from renewable sources and to increase energy efficiency by 20% (European Commission, 2010b). Despite these regulations, the countries within the EU employ different treatment options in their areas with some already moving towards materials recovery systems while for others this is still a virgin territory (Eunomia, 2015). A well-planned waste management system includes all activities that aim to minimize the health, environmental and aesthetic impacts of MSW (Suthar & Singh, 2015); as the uncontrolled waste disposal can pose serious threats to urban surface water resources and significant environmental health risks to those living in the vicinity (Bhuiyan, 2010).

The flow chart in Figure 11 presents the most common municipal waste treatment operations which are broken down into these categories (European Commission, 2012): incineration, landfilling, recycling and composting. All these treatment options are used to a different extent in every country. Furthermore the following sub-sections present the main points around the most used waste management treatment options used worldwide and in the EU.

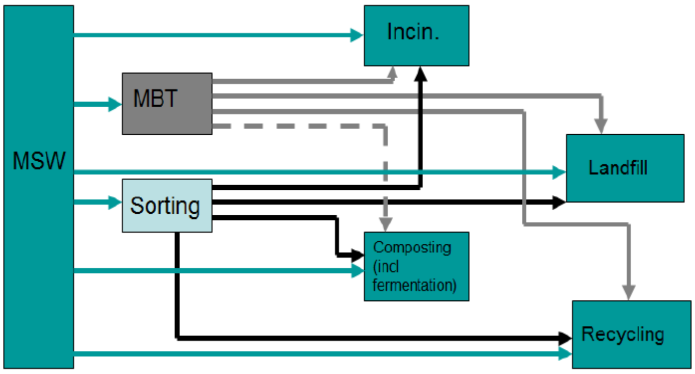

Figure 11. *Municipal waste treatment options (European Commission, 2012)*

2.3.1. Landfill

Landfilling is being considered in the last few years as inappropriate because it poses great risks to human and environmental health. Still there are uncertainties as to how landfills affect human health; for instance research in the UK points out the possibility of landfills being responsible for birth defects in the vicinity (Elliott et al., 2000). A modern engineered landfill includes a waste containment liner system to separate waste from the subsurface environment, systems for the collection and management of leachate and gas, and placement of a final cover after waste deposition is complete (Laner et al., 2012).

Containment has been put forward, and involves operating the landfill in a condition that accelerates the decomposition processes, so that the production of leachate and landfill gas occur at the beginning and when the collection and treatment systems are in working order (Bramryd et al., 1999). One of the main outputs of landfill is methane, which is produced through the decomposition of organic wastes under anaerobic conditions. Landfill gas which originates from the landfill operation, can be used either in a gas engine to generate electricity and/or heat, or it may be used into a natural gas grid or for direct utilisation as a transport fuel (UNEP, 2015).

Moreover a common technique to pre-treat waste before it can be disposed in landfill is mechanical biological treatment as this option can lead to the material to be landfilled being relatively harmless and not so potent to generate methane and leachate (Eunomia, 2015). A schematic representation of the process is shown in Figure 12.

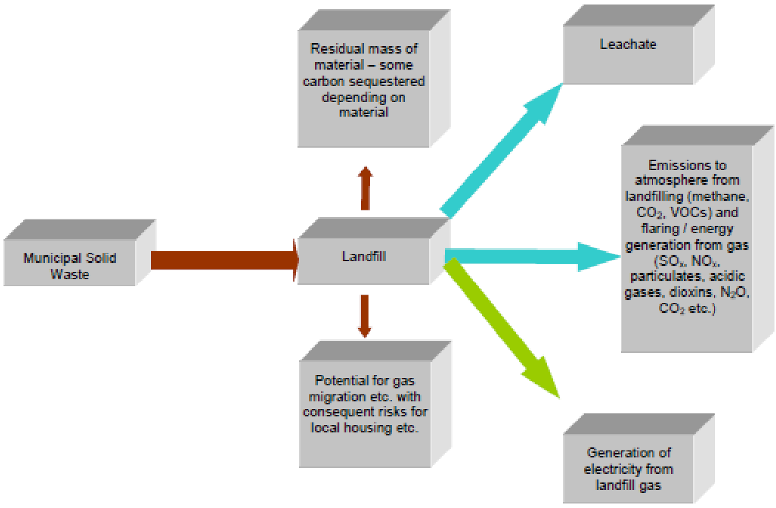

Figure 12. *Landfill option (Eunomia, 2015)*
Note: red arrows represent residual materials, blue arrows represent negative outputs (environmental costs) and green arrows are positive outputs (environmental benefits).

An important point in relation to landfill is aftercare management which typically includes monitoring of emissions (e.g. leachate and gas) and receiving systems (e.g. groundwater, surface water, soil, and air) and maintenance of the cover and leachate and gas collection systems (Laner et al., 2012). Regulations specify a minimum period of aftercare for which funding must be accrued; for example, the European Landfill Directive (European Commission, 1999) specifies a period of at least 30 years of aftercare as a basis.

2.3.2 Mechanical Biological Treatment

Mechanical biological treatment (MBT) is a process designed to optimise the use of resources by recovering materials for one or more purposes and stabilising the organic fraction of residual waste (Eunomia, 2015). MBT is a residual waste treatment process that involves both mechanical and biological treatment (Defra, 2013a).

Some of the benefits of MBT include the fact that materials and energy can be recovered, space requirements are reduced and gas and leachate emissions from landfill are reduced at the same time (Eunomia, 2015). MBT systems basically comprise two simple ideas: either to separate the waste and then treat or to treat the waste and then separate (Defra, 2013a). Aerobic biological unit processes are used to ‘stabilise’ the organic fraction, to reduce its biodegradability and therefore its ability to generate methane, whereas anaerobic biological unit processes can help produce biogas from the organic portion of MSW (UNEP, 2015). Figure 13 presents a schematic representation of the MBT inputs and outputs.

The main outlets for outputs from MBT systems for MSW include (Defra, 2013a):

- Materials recycling: recyclables from the various MBT processes are typically of a lower quality and therefore have a lower potential for high value markets, but generally contribute to enhancing the overall recycling levels.
- Use of Compost-like output (CLO): the processing of mechanically separated organics can produce CLO or digestate material.
- Production of biogas: an MBT plant with Anaerobic Digestion (AD) as its biological process will be able to produce biogas.

- Materials recovered for Energy: where the MSW is sorted to produce a high calorific value waste stream for instance including mixed paper, plastics and card, this stream may be known as Refuse Derived Fuel (RDF).

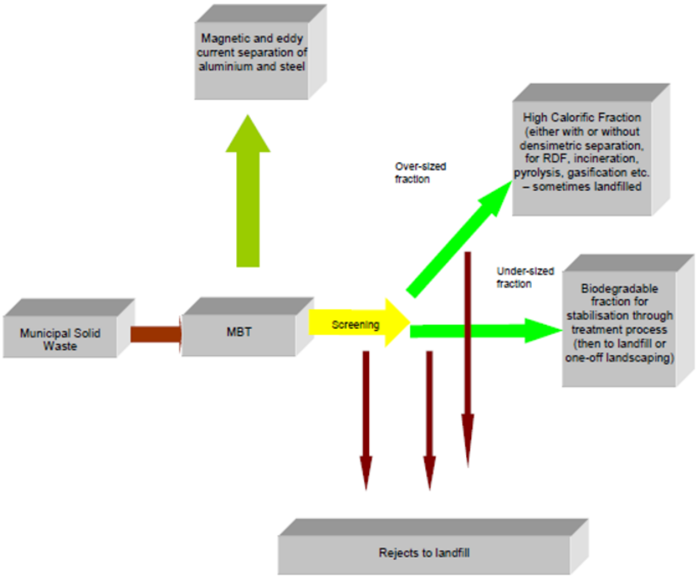

Figure 13. *Schematic representation of MBT inputs and outputs (Eunomia, 2015)*

2.3.3. Incineration

The combustion of waste for recovering energy, is called incineration, where under conditions of high temperature these waste treatments are recognised as thermal treatments (WMR, 2009). Incineration reduces the form of the waste from 95 to 96% and this reduction depends on the recovery degree and composition of materials; this means that incineration does not replace the need for landfilling but reduces the amount to be disposed that way (WMR, 2009). Figure 14 presents the main outputs and inputs from oncineration and Table 1 summarises the key outputs from this process.

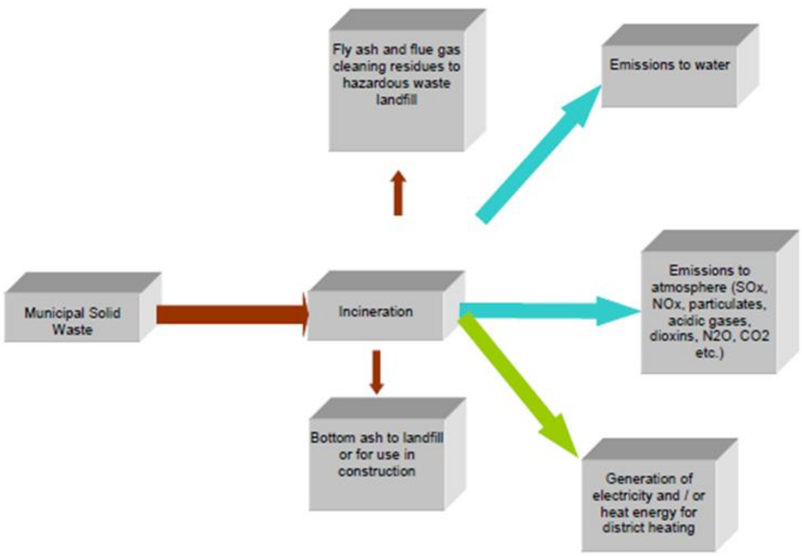

Figure 14. *Schematic Representation of Incineration Inputs and Outputs (Eunomia, 2015)*

Table 1. Main output of incineration (Adapted from Defra, 2013b)

Outputs	State	Quantity by weight of original waste	Comment
Incinerator Bottom Ash (IBA)	Solid residue	20-30%	Potential use as aggregate replacement or non-biodegradable, non-hazardous waste for disposal
Metals (ferrous and non-ferrous)	Requires separation from MSW or IBA	2-5%	Sold for re-smelting
APC residues (including fly ash, reagents and waste water)	Solid residue / liquid	2-6%	Hazardous waste for disposal
Emissions to atmosphere	Gaseous	Represents 70-75%	Cleaned combustion products

In 2009 there were 449 Incineration plants operating across 20 Western and Central European countries with a total throughput of around 69.4 million tonnes of waste for 2009 (Defra, 2013b). Incineration is a quite controversial technology and opinions are separated as to where and if it should be used. WMR (2009) provides a summary of the main points against and in favour of incineration. Specifically, some of the arguments supporting incineration are*:*

- Despite concerns on the health effects of incineration processes, emission can be controlled by developing modern plants and more stringent regulations.
- Incineration plants can produce energy and thus substitute other power generation plants.
- The bottom ash is considered non-injurious and still capable of being landfilled and recycled.
- Fine particles are removable through filters and scrubbers.
- Finally treating and processing of medical and sewage waste produces non-injurious ash as end product.

Similarly some of the arguments against incineration are*:*

- Many consider the products of incinerations as extremely injurious matter which require adequate disposing of, meaning additional miles and special locations for landfilling this.
- There are still many concerns about the emission of furans and dioxins.
- Incinerating plants are producers of heavy metals, which are injurious even in minute quantities.
- Initial investment costs are only recovered under long-term contracts.
- Local communities always have and probably will be opposed to the presence of incinerating plant in their vicinity.
- The supported view is to recycle, reuse and reduce waste instead of using incineration.

At the same time likewise relatively new technologies include pyrolysis and gasification but these still remain fairly unproven in European usage (Eunomia, 2015). During pyrolysis (Figure 15) organic waste is heated in the absence of air to produce a mixture of gaseous and/or liquid fuels and a solid, inert residue (mainly carbon) (Defra, 2013b). The scale of the pyrolysis is usually much smaller and it is said that if incinerators had the same scale then their costs would be the same or even higher.

Gasification is considered as a process between pyrolysis and combustion because it entails the partial oxidation of a substance (Defra, 2013b). Gasification (Figure 16) is the process in which carbon based wastes are heated in aerobic conditions to produce a solid, low in carbon and a gas from coal (Defra, 2013b). It constitutes therefore a thermochemical process including many steps.

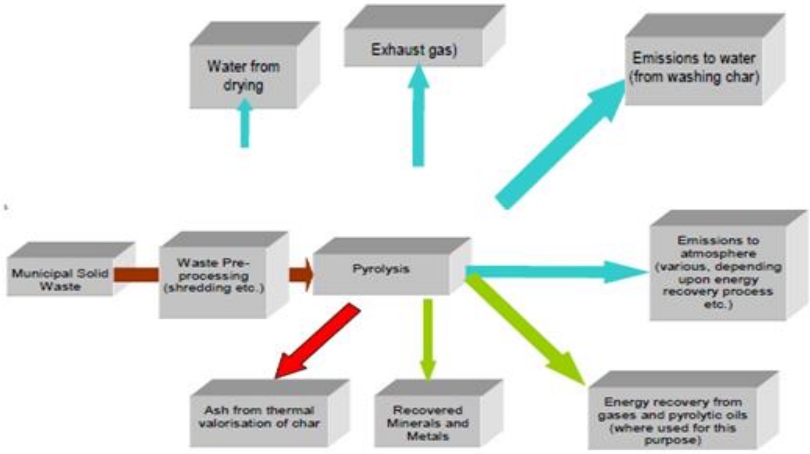

Figure 15. *Schematic representation of single pyrolysis process inputs and outputs (Eunomia, 2015)*

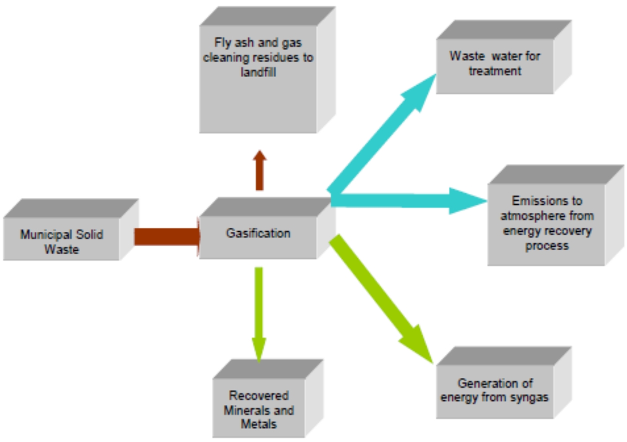

Figure 16. *Schematic representation of gasification inputs and outputs*

Incineration, pyrolysis and gasification are all considered thermal treatment but differ in the levels of air used in those as shown in Figure 17.

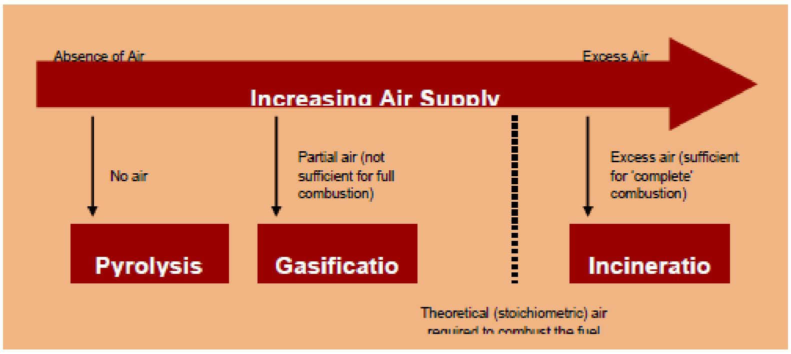

Figure 17. *Levels of air (oxygen) present during pyrolysis, gasification and incineration for MSW (Defra, 2013b)*

2.3.4. Composting

Composting is a term used to describe the biodegredation of organic matter through an aerobic process which converts organic matter into a stable humic substance (Eunomia, 2015). In most developing countries an astonishing 50 to 70% of the MSW is organic materials which are therefore suitable for composting, so the process can usually be furthered through separation at source (UNEP, 2015). More specifically for this process, the microorganisms employed are part of three main categories; bacteria, fungi and actinomycetes.

The key factors that need to be accounted for to achieve effective composting rates include: temperature, air supply, moisture content, the porosity of the material and its carbon to nitrogen ratio (Eunomia, 2015). There are many different technologies available for composting which include simple open-air systems (windrow composting and aerated static pile composting) to more sophisticated contained systems (Environment Agency, 2002). Figure 18 presents a schematic representation of composting inputs and outputs.

Composting facilities can only operate economically if they function at or near maximum design capacity. Therefore this implies that for every composting facility one needs to secure sufficient waste (Environment Agency, 2002). Based on their quality, waste-derived composts can be used for land reclamation and as a soil improver in landscaping, agriculture and horticulture due to its ability to improve the biological and physical properties of soil in particular of use in arid regions (Environment Agency, 2002; UNEP, 2015).

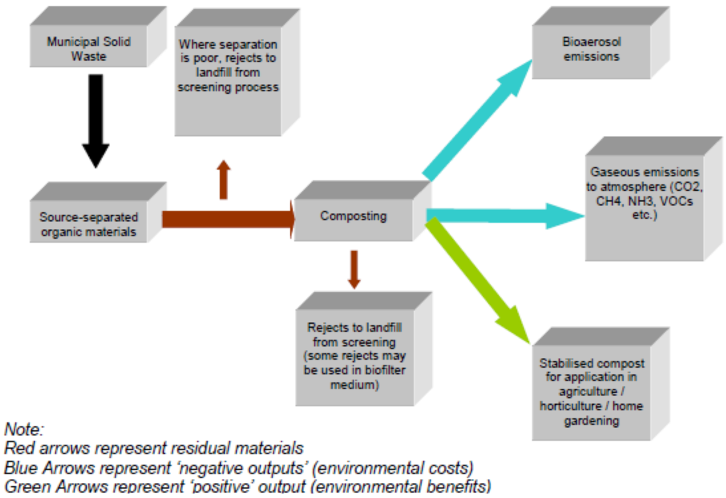

Figure 18. *Schematic representation of composting inputs and outputs (Eunomia, 2015)*

2.3.5. Anaerobic Digestion (AD)

Anaerobic digestion (AD) is the bacterial decomposition of organic material in almost anaerobic conditions whose by-products include biogas, and digestate (Eunomia, 2015). There are two main types of anaerobic digestion called thermophilic and mesophilic – the primary difference between them is the temperatures used in the process; thermophilic processes reach temperatures of up to 60 degrees centigrade and mesophilic normally run at about 35-40 degrees centigrade (WRAP, 2016).

The high degree of flexibility associated with AD is considered one of the most important advantages of the method, since it can treat several types of waste, ranging from wet to dry and from clean organics to grey waste (Eunomia, 2015). AD (Figure 19) can in comparison to composting better treat waste with a higher moisture content and can occur usually between 60% and 99% moisture content (Eunomia, 2015). Hence kitchen waste and other putrescible wastes which are high in moisture can be an excellent feedstock for AD, whereas woody wastes including a higher proportion of lignocellulosic materials are better suited to composting.

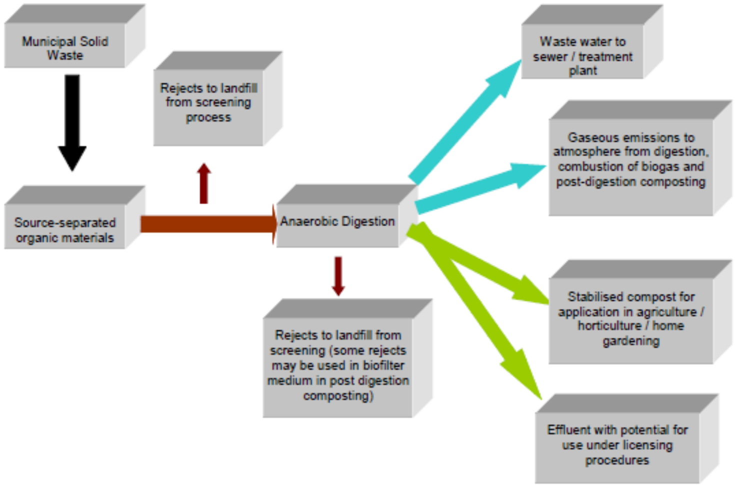

Figure 19. *Schematic representation of AD inputs and outputs (Eunomia, 2015)*

The process of AD provides a source of renewable energy, since the food waste is broken down to produce biogas (a mixture of methane and carbon dioxide), which can be used to produce energy. The biogas can be used threefold: to generate electricity, to power on-site equipment and any excess electricity can be exported to the National Grid. A further by-product of the process is the biofertiliser, which is rich in nutrients such as nitrogen, phosphorus and other elements essential for healthy plant growth and fertile soil (WRAP, 2016).

2.3.6. Recycling

Recycling refers to the systematic collection, processing and reuse of materials, which include the following categories: paper, glass, plastic, wood, aluminium products and iron (Halkos, 2013). Recycling entails many benefits which include amongst others the following (EPA, 2016):

- Reduces the amount of waste sent to landfills and incinerators
- Conserves natural resources such as timber, water, and minerals
- Prevents pollution by reducing the need to collect new raw materials
- Saves energy
- Reduces greenhouse gas emissions that contribute to global climate change
- Helps sustain the environment for future generations
- Helps create new well-paying jobs in the recycling and manufacturing industries.

Also there is clearly a correlation between increasing recycling rates and declining rates of landfilling, as in countries with high MSW recycling rates, landfilling seems to be declining much faster than recycling is growing, because waste management strategies usually move from landfill towards a combination of recycling and incineration, and in some cases also MBT (European Environmental Agency, 2015b). An overall picture of the treatment options across Europe expresses in kg/capita can be seen in Figure 20. As it is obvious there is a strong difference between countries in the North and South of Europe.

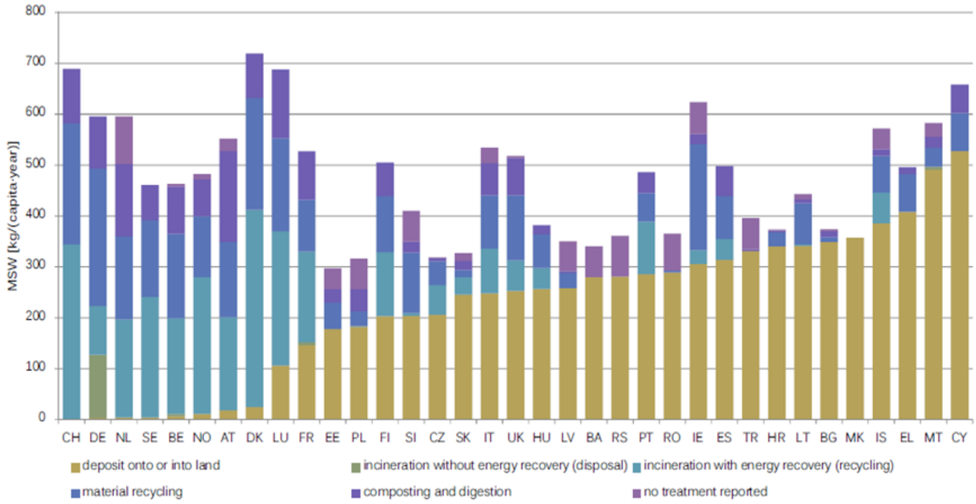

Figure 20. *Treatment of MSW across Europe – kg per capita in 2011 (FhG-IBP, 2014)*

3. Conclusion: closing the loop

As it has been presented in the previous sections, waste is an issue that has been raising awareness in recent years. Regulations and directives around it are trying to find new and effective ways to manage it appropriately and efficiently. Yet implementation of these rules differs by country and sometimes even by region. The fact is that waste arisings continue to rise and our world cannot sustain the uncontrolled disposal of waste anymore. New and improved technologies are emerging which can help manage waste in a more efficient way which is more beneficial in the long run as well. The model that used to run up until today is that of the linear economy when it comes to waste management, whereas natural resources were extracted and used and then disposed of usually at landfills.

Lately systems analysis techniques have been applied to handle MSW streams through a range of integrative methodologies, with a total of five system engineering models and nine system assessment tools in this field (Chang et al., 2011). These models contain, among others, systems engineering models like cost and benefit analysis (CBA), prediction and simulation models, optimization models (OM), and integrated modelling system (IMS). Similarly, they may comprise system assessment tools embracing management information and decision support/expert systems, the development of scenarios, life cycle assessment or inventory, risk and environmental impact assessments, strategic environmental and socioeconomic assessments and sustainable assessment (Pires et al., 2011).

Thus with these techniques, nowadays the focus has moved upstream, addressing the problem from the beginning; this starts at the point designing of waste, preventing it, reducing both the quantities and the uses of hazardous substances, minimising and reusing resources, and, where residuals still occur, keeping them concentrated and separated to preserve their potential value for recycling and recovery and prevent them from contaminating anything else with economic value after recovery (UNEP, 2015). The main idea is to move away from 'waste disposal' to 'waste management' and from 'waste' to 'resources' (UNEP, 2015).

Moving towards a circular economy as presented in Figure 21 creates a challenge of its own, as it demands changing our way of thinking and managing waste. Landfill is and needs to be considered as the last possible resort for waste. As the figure illustrates the biological and technical nutrients should be kept in separate loops in order to maintain high quality and make it possible to circulate effectively; the smaller the cascading loop the higher the value kept in the resource and with less need for adding energy and other resources to keep it circulating (Berndtsson, 2015).

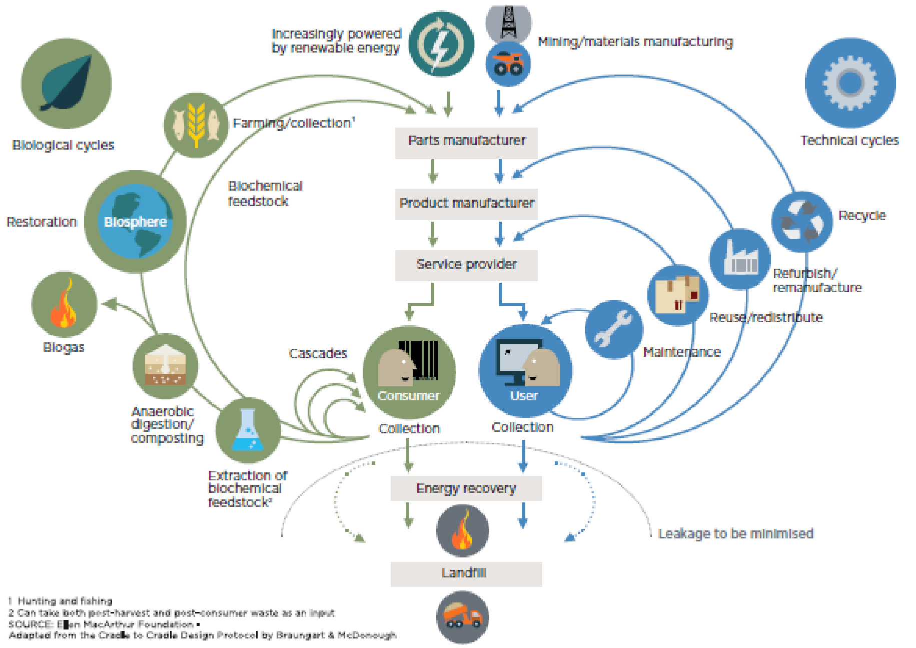

Figure 21. *Moving towards a circular economy (UNEP, 2015)*

Regulations already exist in the EU and worldwide in most cases on those regards, the only thing left to do is put them in practice. As it has been presented in the previous sections, prevention and resource efficiency are two of the main drivers towards the circular economy. However the uniqueness of the Circular Economy comes from two interrelated ideas, the closed-loop economy and ‘design to re-design’ approaches, demonstrating new concepts of system, economy, value, production, and consumption (Murray et al., 2015). Therefore the idea of the circular economy is highly related to waste management under the umbrella of resources management at the same time and needs further research.

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