Interreg North-West Europe
TRANSFORM-CE
European Regional Development Fund

# Waste Volume Analysis Report

*Factors that Affect the Future Available Volume of Plastic Waste Uptake by Businesses in Northwest European Countries*

# Waste Volume Analysis Report

*Factors that affect the future volume of plastic waste uptake by businesses in Northwest European countries*

**The aim of this report is to provide analysis of the crucial factors that affect the future volume of plastic feedstock available for AM and IEM manufacturing uses. It looks at the factors that create the single use plastic environment, to identify how to increase the circularity of plastics through recycling, thus reducing the amount that is single use.**


**Date** June 2022

**Authors** Moshe Kinn,

**Deliverable** WP.LT D1.1 Plastic Waste Volume Analysis Report



This research has been conducted as part of the TRANSFORM-CE project. The Interreg North West Europe support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Programme cannot be held responsible for any use which may be made of the information contained therein. More information about the project can be found on: www.nweurope.eu/transform-ce. TRANSFORM-CE is supported by the Interreg North West Europe programme as part of the European Regional Development Fund (ERDF).

## List of Abbreviations

| | |
|---|---|
| AM | Additive Manufacturing |
| C&I | Commerce and Industry |
| HDPE | High Density Polyethylene |
| HWRS | Household Waste Recycling Site |
| EPRS | Extended Producer Responsibility Schemes |
| EfW | Energy from Waste |
| GHG | Greenhouse Gasses |
| IEM | Intrusion Extrusion Moulding |
| kt | kilo tonnes, 1000 tonnes |
| LDPE | Low Density Polyethylene |
| MRF | Material Recovery Facility |
| MSW | Municipal Solid Waste |
| Mt/a | Million Tonnes per annum |
| NGOs | Non-Government Organisations |
| PET | Polyethylene terephthalate |
| PMD | Plastic, Metal and Drinks cartons |
| PP | Polypropylene |
| RDF | Refuse Derived Fuel |
| SPI | Society of Plastics Industry |
| SUP | Single Use Plastic |
| WfH | Waste from Households |

## Glossary of Terms

**Additive Manufacturing:**
This is the process of turning a digitised three-dimensional model into a physical object by adding layer upon layer of material to form the object.

**Commercial waste:**
Consists of waste from premises used mainly for the purposes of a trade or business or for the purpose of sport, recreation, education, or entertainment, this excludes household and industrial waste

**Misthrow**:
Waste that should not be in this waste stream, i.e., plastic put into general waste or contamination like organic matter placed in the plastic waste

**Post-Consumer waste:**
Post-consumer waste is the waste produced at the end of a consumer-product lifecycle, e.g., food and thin film packaging that tends to be dirty, within mixed wase and is difficult to recycle

**Primary packaging:**
This is the first layer of packaging, that has direct contact with the product. It is the one that the final customers interact with, like a cereal box or a wine bottle. Its purpose is to protect the actual product, but it is also an important marketing tool

**Residual waste:**
Non-hazardous waste material that cannot be re-used or recycled and needs to be sent to energy recovery or disposal in landfill.

**Secondary packaging:**
This is the middle layer of packaging, that protects the **primary packaging.** Used to pack together more individual products in an organized manner. Some examples could be the printed shrink film used for containing 12 cans of soda or the cardboard box that guards 12 jars with pickles

**Tertiary /Transport packaging**:
The outer layer of packaging placed for transportation, e.g., plastic film wrapped around a pallet

**Valorisation:**
This is a process of changing residues into energy or products with a much greater economic value, i.e., enhancing the value of the waste

**Virgin plastic:**
Plastic resin that has been newly created without any recycled materials. This type of plastic is produced (using natural gas or crude oil) in order to create brand new plastic products for the very first time

**Waste fractions:** The grouping of waste according to its properties; plastic, wood, metal, biodegradable waste, earth, stones, etc

Interreg North-West Europe TRANSFORM-CE

## Table of contents

## List of Tables



## List of Figures

## 1. Executive Summary

This report is part of the TRANSFORM-CE project. A project which aims to promote recycling and the uptake of single use plastic (SUP) waste, for use in additive manufacturing (AM) and intrusion extrusion moulding (IEM), to create innovative, new products within circular economy business models. It looks at the factors that affect present and future supply of plastic waste volumes that will be available for AM and IEM until 2030. Its focus is on Northwest European countries with concentration on Belgium, Germany, the Netherlands, and the UK.

This project identifies two risks that may affect the uptake of recycled plastic for the use in AM and IEM Manufacturing.  The first, is the lack of compatibility and high specification of existing technologies and the constraints of using recycled plastics with these technologies. The second risk is, that manufacturers presently lack the confidence to replace virgin plastics with recycled feedstocks. They are worried about continual supply of standardised feedstock and the reluctance of many consumers to buy products that they perceive as of inferior quality.

A key component of promoting the uptake of SUP and in driving business and policymaker confidence in taking up the solutions demonstrated by TRANSFORM-CE, is to provide information on the current and potential future supply of these waste materials. This report focusses on the future availability of adequate volumes of plastic recyclates. It provides analysis of the long-term availability of compatible feedstock for both the AM and IEM, as an aid to inform and support the decision-making processes of political, municipal, and industrial stakeholders.

Plastics, once used, start a long journey from the consumer until they are either reused, put in landfill, or burned. This report looks at some of the reasons why plastics don't end up as feedstocks in new products. It looks at consumer behaviour when disposing of their waste, to contamination within the waste system, and rejection at the material recycling facilities (MRF). One problem identified is lack of detailed data about how much and of what type of plastics are being collected for recycling, being processes and ultimately what happens to it after leaving the MRF.

A lack of harmonisation of polymer composition of SUPs, waste collection mechanisms, types of plastics that are recyclable, data collection, waste policy, and education about recycling, were found to exist across different municipalities and across different countries.  Introducing harmonisation where they are lacking, to increase the amount of available plastics not in the waste system, for example enhanced landfill mining or from the oceans, are identifies as possible mechanisms to increase the volume of available plastic.

It is concluded that given the vast amount of future plastic consumed each year, plastic in circulation still filled with products, and plastics in landfill, this report sees no issues for the volume of supply for the foreseeable future.

## 2. Introduction

Since about 1950, when plastics began to be produced on a large-scale, it is estimated that by 2015, 6.3 billion tonnes of plastic waste have been produced, only 9% of which has been recycled and about 79% has ended up in landfills or in the natural environment, (Geyer et al., 2017). This means that there are up to 4.97 billion tonnes of plastic waste that, given right technical and economic environment, are potentially available for recovery. Geyer et al explain, that the largest market for plastics is for packaging, with a high increase in yearly growth particularly for single-use containers.

Single use plastic (SUP) causes enormous pollution in our environment. Each year 8 Mt of SUP leaks into our oceans ending up as microplastics affecting our ecosystems. Northwest Europe (NEW) generates the biggest source of SUP (40% of Europe). The EU generates 27 Mt per year of waste plastic, of which 31% is recycled, 41% is sent for energy from waste (EfW) and 27% is landfilled. This is a loss of valuable resources to the European economy. The challenge is to reduce this 68% loss of processed plastic, by diverting it using alternative recycling options. However, uptake for recycled content in new plastic products is low.

In 2016 EU plastic production was 60Mt and only 8Mt were collected for recycling. The EU is reliant on imports of virgin plastic and there is a huge opportunity to revalue and use, low and high grade recycled SUP as an alternative to virgin plastic. The EU has set an ambitious 2025 recycling target of 65% for packaging materials, which includes SUP, with an increase to 70% by 2030. Existing lack of infrastructure capacity and viable links to secondary material markets across NWE forces pre-segregated and mixed waste plastics into landfill and or EfW. This approach is not resource efficient and will not enable EU recycling targets to be achieved and clearly does not promote a circular economy (CM) approach. There are real environmental and resource security issues, but currently NWE lacks the economic incentives to solve them.

The plastic export ban to China (2018) meant demand for recycled plastic dropped, while at the same time the supply of waste plastics continues to go up. In response, EU plastic is being stockpiled and high levels of SUP are being sent to energy-from-waste plants and in some countries to landfill. This is an economic loss to the EU and reinforces the wasteful linear economic model of ‘use once and discard’. The EU Packaging Waste Directive and Extended Producer Responsibility (EPR) policy, aims to reduce plastic production and make manufacturers more responsible for the waste they produce. Therefore, there is urgency for NWE to develop its own plastic recycling economy, to reduce reliance on import markets, to repurpose, to revalue existing SUP waste and to upcycle, while at the same time diverting valuable plastic away from EfW and landfill.

Currently, plastic packing follows a linear lifecycle, hence the label ‘single use plastic’ (SUP). A goal of the TRANSFORM-CE project is to change the linearity of the SUP lifecycle into one that is circular. This means that what is now known as SUP will be recycled multiple times, thus eliminating the term ‘single use’. This could mean that from the point of view of its original use, it may be still single use, i.e., if it is used for food, it may be used only once for the food. However, it will then be upcycled into another plastic non-food item that will be recycled multiple times before it is discard or, as will be explain later, chemically recycled for use again as new plastic. The TRANSFORM-CE project focuses on the post-consumer SUP plastics, as this is the least likely to be recycled at this time.

Since it is technologically feasible to segregate, re-engineer and repurpose SUP, the TRANSFORM-CE project uses all types of SUPs from a single waste stream. It focuses on the repurposing of post-consumer plastic packaging waste that is within the municipal waste system. NWE is a region of mixed economy, with variable levels of wealth and employment. Its consumers produce significant quantities of plastic waste in part due to affluent and urban lifestyles. The region contains some of the largest urban conurbations in Europe. Several are sufficient to provide consistent and large feedstocks for remanufacturing of SUP. The TRANSFORM-CE uses all types of SUPs for two innovative technologies. The low valued plastics such as foils i.e., thin packaging films, are moulded into products using intrusion-extrusion moulding (IEM). The higher valued plastics i.e., pre-sorted drinks and cleaning bottles, and food trays/containers, are processed into filaments to be used to make additive manufactured (AM) products. AM provides opportunity for integration into complex products, while IEM provides opportunity for simpler single unit designs.

The availability of recycled plastic for use in AM and IEM depends on several factors. Some of these are connected to the type and quality of the available feedstock, while others are associated with the uptake of recycling and how much consumers understand what can and can't be put in the recycle bin. Differences in municipal and national regulations and incentives for customers to recycle, play a role in the volume as well as the quality of available feedstock. These differences can lead to consumers causing contamination of the plastic waste by putting the 'wrong' type of plastics or even non-recyclable material in with the recyclable plastic. By doing this, this contaminates the individual's recyclables. When it is mixed at kerbside with other consumers recyclables, it is possible that a much larger volume of waste will be contaminated.

Plastics are only around 3% of all waste collected by some municipalities in the UK and therefore of low priority in directing financial assets for their recovery, especially if the cost of recovery is more than the value of the recovered plastic. The economics of plastic recycling is very dependent on the price for virgin plastic feedstocks, which itself is dependent on the price of a barrel of crude oil. Therefore, having the waste as clean as possible can help with the availability of plastic for upcycling purposes.

The TRANSFORM-CE project is transnational and includes partners in Belgium, Germany, the Netherlands, and the UK. To assess the possible future volumes of plastic, this report first looks at consumption data and then municipal collection data from across these countries. It draws on previous work carried out in work package T1. The focus is on roadside collections of waste by municipalities, and the deposit return schemes. Other waste collected by the private sector, that is not associated with municipal waste streams, is not within the scope of this report.

The goal for this project is to divert 308.25t of post-consumer municipal SUP waste over 3 years, which is an estimated reduction in CO2 equivalents of 478 tonnes, (based LCA natureline Save Plastics of 1.3kg net CO2 reduction per kg plastic diverted), to become feedstock for both AM and IEM. Long-term uptake through scaling up of the technology with industry investment has the potential to divert approximately 16,000t in 10 years using the manufacturing facilities within this project. Further increases are possible as the TRANSFORM-CE business model is taken up across NWE by the business community.

The very low amounts of recyclant ending up in new products has been identified as being due to technical unknowns, and lack of investment via government and waste companies to capture low-grade plastics for recycling. This results in a non-secure supply chain for recycled plastic feedstocks. Therefore, this project identified three risks that exit to the successful uptake of recycled plastic by manufacturing businesses. This report focuses on Risk 2 and 3. Risk 2 identifies the **lack of technology uptake** throughout the recycling process including technology like AM and IEM that can upcycle the recyclant in new products. Risk 3 is the **lack of market uptake for the recycled material**, this includes businesses worried that consumers will not want to buy products made from recycled plastics.

This report, LT 1.1, is the first of three reports that look at the long-term effects of this project. It looks at the long-term challenges involved in providing a steady stream of plastic recyclant in the volumes required by manufactures. Having a waste management system that can provide this, provides security of supply for manufacturers, and will mitigate part of Risk 3. However, not having a secure long-term supply of clean feedstocks to turn into recycled plastic, will result in lack of adoption of recycled plastics in the design and manufacturing processes for new products. This report aims to analyse the crucial factors that affect future plastic waste volume and potential harmonisation social and economic factors that affect plastic recycling. to support decision-making of political and municipal stakeholders. The objective is to provide confidence in supply for businesses to uptake recycled plastic in partner and other NWE countries.

This report starts by looking at past statistics about post-consumer municipal plastic packaging waste. It identifies volumes of waste across the four consortium countries that is not currently being recycled and ends up in either landfill or WFE plant. It is Informed by the Work Package T1, Activity 1 and by the outcomes of the Work Package T3 based on engagement with 20 businesses from all NWE territories and not just the 4 consortium countries. This report will feed into work package T3 Circular Economy Plastic Roadmap.

This report begins with an overview of the types of plastics available and which ones are used in AM and IEM. It then discussed the consumption of plastics with some statistics on the possible volumes that could be inputted to the waste system. It then looks at factors that affect the economics of waste plastics and factors that will affect the volumes of plastic that are recycled into ready to use recyclant.

# 3. Understanding the different types of plastic polymers

The use of waste plastic is technically challenging. Plastic comes in at least seven polymer types, and when finally used in products it contains additives and polymer combinations that could be a challenge to recycling. It is therefore important to understand which polymers can be used for additive manufacturing and which can be used for Intrusion Extrusion Moulding manufacturing.

## 3.1 The seven Plastic Industry Association plastic categories

These are the seven types of primary plastic polymers that are identified by the Plastic Industry Association.

- 1 PETE – Polyethylene Terephthalate (PETE or PET)
- 2 HDPE – High-Density Polyethylene (HDPE)
- 3 PVC – Polyvinyl Chloride (PVC)
- 4 LDPE – Low-Density Polyethylene (LDPE)
- 5 PP – Polypropylene (PP)
- 6 PS – Polystyrene or Styrofoam (PS)
- 7 OTHER – Miscellaneous plastics (includes polycarbonate, polylactide, acrylic, acrylonitrile butadiene, styrene, fiberglass, and nylon)

For many practical reasons, plastic products are not made with pure primary polymers but are mixed with other chemicals. These include additives that are, stabilizers, colorants, plasticizers, fillers and reinforcing fibres, ultraviolet absorbers, antioxidants as well as processing aids including lubricants and flow promoters, (Shamsuyeva & Endres, 2021). This adds complexity in the sorting of plastic waste. To complicate the recycling process, the EU have an identification system for all types of packaging materials that can potentially go up to 99 categories (European Commission, 1997). Furthermore, the EU numbering system is not aligned with China that have 140 numbers specifying different plastic resins, (Standardization Administration of China, 2008) thus introducing possible barriers within international trade of plastic waste fractions. Therefore, when some manufacturers want to use recycled plastics within their products, they will be constrained in the type of additives and primary plastic polymer they can use, as their manufacturing process may require very specific polymer types. The need to sort the plastic waste adds complexity to the recycling system and may even lead to some products not being able to use recycled plastic. This is due to the costs and present technical abilities of the sorting machinery to provide a specific uncontaminated steam of plastic fraction. However, for many uses of plastic, the specificity of chemical makeup may not be too complex, allowing for the use of recycled plastics.

## 3.2 Types of plastic used in additive manufacturing (AM)

The TRANSFORM-CE project mainly looks at post-consumer single use plastics from within the food and packaging industry. The plastics are recycled from municipal and commercial waste. The filament types used within this project are PET, ABS and PLA. PLA is made from renewable resources such as corn or sugarcane and is a very versatile bioplastic that can be recycled or, under specific conditions, be composted. PLA works well in AM, and is a good type of plastic to start with in order to gain confidence using these recycled materials. The PLA used in this project was from coffee cups and lids that were sourced from municipal waste. The PET came from water and drinks bottles and clean punnets, which were of high quality non contaminated plastic. The ABS was from car dashboards obtained from a commercial recycler.

Polymers like polypropylene, HDP, LDP are not very readily taken up by additive manufacturing, because of the challenges of using these materials with the current available technology. Problems include warping, stringing, poor adhesion of layers, etc. One of the key outputs that this project wanted to achieve is, to develop new formulas for plastic polymers, and to identify the conditions and settings for the printers to successfully print with these newer formulations. For AM printing, the recycled plastics have to be of high-quality materials. The list below makes up the types of plastic filaments used in AM (Geyer et al., 2017; Simplify3D, 2022).

### 3.2.1 **ABS (Acrylonitrile Butadiene Styrene)**

It is a low-cost material with good mechanical properties. It is tough and impact resistance, and therefore good for printing durable parts that will hold up to extra usage and wear. It can withstand much higher temperatures before it begins to deform. This makes ABS products good for outdoor or high temperature applications. When printing with ABS, good ventilation is necessary, as the material tends to have a slight odour. ABS also tends to contract quite a bit as it cools, so controlling the temperature of the environment can have major benefits.

### 3.2.2 **High-Density Polyethylene (HDPE)**

It is light, flexible, easy to dye and mould, has good insulating property, and has a non-absorbent property that can be used for everyday materials. However, Garmulewicz et al. (2018, p. 118), explain that the thermal properties of HDPE make it hard to work with, and as of 2018 HDPE "… *commercially available HDPE filament from recycled materials is still hard to find*."

### 3.2.3 **Low-density polyethylene (LDPE)**

It is a polymer used in many different types of packaging. It can be used when wear resistance is a critical issue; for example, the soles of shoes also require hardness, plasticity, elasticity, and more. LDPE can also be used as a near-surface filler or in creating products like sliding pads (commonly used with furniture).

### 3.2.4 **Polyethylene Terephthalate (PET)**

It is used to manufacture water bottles. It is a semi-rigid material with good impact resistance, but it has a slightly softer surface which makes it prone to wear. The material also benefits from great thermal characteristics, allowing the plastic to cool efficiently with almost negligible warpage.

### 3.2.5 **Polylactic Acid (PLA)**

It is the filament of choice for many extrusion-based AM, because it is used at a low temperature and does not require a heated bed. It is inexpensive and creates parts that can be used for many applications. It is derived from crops such as corn and sugarcane, it is biodegradable and is therefore considered one of the most environmentally friendly filaments. For the PLA to be compostable it must be able to compost according to the European standard EN 13432. However, the conditions for composting under this standard are only suitable for commercial or industrial type composting and not ordinary ambient temperature garden composting.

### 3.2.6 **Polypropylene (PP) – used in AM**

It is a semi-rigid and lightweight material used in storage and packaging applications. It is a challenging metrical to use for AM, however it is tough and has a good fatigue resistance making it ideal for low strength applications like living hinges, straps, leashes, etc.

## 3.3 Types of plastic used in Intrusion Extrusion Moulding (IEM) manufacturing in Save Plastics

A low-grade mix of plastics is used for IEM in Almere, the Netherlands. It consists of mixed plastic foils, with a high fraction of polyolefin-based materials (DKR310 and DKR350 for NL nomenclature). This mix mostly includes materials with reference numbers 4 (LDPE) and 5 (PP), however, and 2 (HDPE) can also be present. If PVC and PET are present in the waste recyclant, they are removed as much as is possible, due to their different melting temperature. A high quality recyclant may have about 15% PET or PVC that needs to be removed, but for general mixed recyclant that have not been pre-sorted, there can be between 20 to 60% of waste fractions that have to be removed before the plastic is ready for IEM manufacturing. The reason for high polyolefin content specification is due the different processing temperatures of plastics. Trying to produce a product from two types of plastics that have different processing temperatures can lead to the different plastics not mixing and sticking together. This can lead to the production of a poor-quality product that can easily fracture.

The aim of the TRANSFORM-CE project is to divert plastic waste from the current linear recycling model to one where the plastics are upcycled within a circular economic modal. The central question this report seeks to answer is, in the future will there be enough plastic available to supply the envisages growing AM and IEM markets?

## 4. An overview of what affects the current and future volumes of available plastic

The first process that single use plastics go through after manufacture, is they are used by consumers, after which they get discarded. There are multiple routes the plastic takes through the waste system until a small portion is recycled back into use. The rest gets rejected into the residual waste system and ends up in landfill or as refuse derived fuel. Therefore, to ascertain the volumes of plastic available for AM and IEM, this report looks at consumption, collection, recycling and rejection data.

Work package deliverables T1.1.1 'Statistical Harmonisation', identified plastic waste streams rich in single use plastics in each of the four TRANSFORM-CE partner countries. The plastic content, as well as the composition of the plastic fractions found in the respective waste streams, as described in this section, were derived from data provided by work package deliverable T1.1.2 (Buchhorn, 2022). Depending on the availability of data, the quantities were taken from national and regional waste statistics. Since composition analysis are usually only available on a national level, the quantities of the waste fractions were extrapolated to the regional level.

One of the main objectives of TRANSFORM-CE is the diversion of plastic waste from landfills or waste to energy plants, to a higher-value material utilisation. Therefore, in Buchhorn's report, plastic waste not intended for material recycling, which was categorised as residual waste, was considered "available for TRANSFORM-CE pilot plants". To understand the future volume of plastic available for AM and IEM, there is a need to identify how much plastic used in packaging is actually consumed and then to contrast that with the amounts actually inputted into the recycling system. It is also important to understand why so much of the plastic is not making it into to the recycling system.

### 4.1 Consumption of plastic packaging – potential inputs to the recycling system

This project uses post-consumer plastic packaging waste as input feedstock for AM and IEM manufacturing. The type of plastic use is either low-grade mixed plastics that is rejected by the recycling system and ends up either in landfill or burnt as refuse derived fuel, or high quality none recycled sorted and washed single polymers. Waste, like high grade PET that is not from bottles, yet is not recycled in many parts of Europe, makes up this single polymer high-grade waste. The none recycled plastics make up a waste fraction that is labelled 'residual waste', as it is residual to the recycling system. The most important polymers for packaging are low density polyethylene (LDPE, e.g., used for films and bags) and high-density polyethylene (HDPE, e.g., food packaging, crates), polypropylene (PP, e.g., food packaging, bottle caps) and polyethylene terephthalate (PET, e.g. bottles). Each of them has a higher market share than all other polymers combined, see Table 1 below.

Table 1Estimated plastic consumption for packaging in kt in Germany (Conversio Market & Strategy GmbH, 2020), the Netherlands (Snijder & Nusselder, 2019), Belgium (essencia, 2019) and the UK (Valpak, 2020)

**Plastic consumption for packaging in kt**

| | Germany | Netherlands | Belgium | UK | total |
|---|---|---|---|---|---|
| LDPE | 966 | 183 | 212 | 637 | 1,998 |
| HDPE | 679 | 81 | 90 | 415 | 1,264 |
| PP | 696 | 86 | 94 | 563 | 1,440 |
| PET | 585 | 136 | 99 | 502 | 1,321 |
| other | 295 | 37 | 54 | 174 | 560 |
| total | 3,220 | 523 | 549 | 2,290 | 6,582 |

According to these figures, more than 6 Mt of new plastic packaging is put into the market in the four TRANSFORM-CE partner countries every year. With 2 Mt/a, LDPE is the most important polymer for packaging, followed by PP (1,4 Mt/a), PET (1,3 Mt/a) and HDPE (1,3 Mt/a). All other polymers used for packaging add up to 0.6 Mt/a. Most of the packaging that is put on the market each year will be used and discarded ending up in a waste stream, however there will be a proportion that stays with its contents and will be stored for future use.

## 4.2 Defining waste fractions within waste streams

Waste streams and waste fractious are contextual to the subject under discussion. **Waste streams** are about the pathways within the waste system that the waste takes until it is either reused or discarded. In EU official literature waste streams mean either materials or products for disassembly. This report looks at plastic waste stream from when it is picked up at the kerbside until its reuse. It focuses on mixed plastics going through the waste recycling system. **Waste fractions** are the grouping of the waste into components of interest. Therefore, when looking at general waste, plastic may be one fraction among other materials, for example plastic as compared to glass wood, metal etc. However, when we are looking at plastic the waste stream is the plastic waste and the waste factors are the different types of plastic for example PET, PP, PE etc.

Finding data, about the composition of the waste fractions in different waste streams, from municipalities and the waste management companies was difficult. However, there were some published studies that were found that provides the details used for the data gathering within this project. There arose a question of semantics and a difference in the nomenclature in different regions as to the contents of waste streams. This means that due to regional differences, the plastic fractions in the same labelled wate stream were different. This is because across the four regions covered by this project, waste is governed by national and EU legislation. Further to this, each municipality within each region has its own regulations as to what can and what cannot be recycled. While the general definition of what waste is, is generally defined across all regions as '*article or objects that are discarded after use*', there exists some discrepancy as to the content of a specific waste stream. This means that the general composition of waste fractions that make up each waste stream differs for each waste stream in each region. Much of this is rooted in the sorting and collection mechanisms of the plastic waste by consumers at the beginning of the waste cycle.

For example, the most recent classification in Wallonia Belgium for the sorting of the so-called P+MC collected waste (household recyclable packaging waste including extended range of plastics 'P+', metals 'M' and cartons for beverage 'C') includes 14 categories, 10 of which being for plastics. Those are listed as follows (source: calls for tenders for sorting facilities): 1. Aluminium – 2. Steel – 3. Cartons for beverage – 4. PET H: uncoloured bottles – 5. PET B: blue bottles – 6. PET C: coloured bottles – 7. PET T: formed PET packaging (trays) – 8. HDPE bottles and other packages – 9. PP bottles and other packages – 10. PS – 11. PE films (including P+MC collecting bags) – 12. Other plastic films – 13. MPO: mixed plastics with high rigid polyolefins content – 14. Residue, (Talon, 2020). While in the Netherlands, a policy measure of the national government and municipalities was the Introduction of recycling centres with minimal 20 types of waste to be separated, (Mul, 2020).

In the UK there are at least two kerbside recycling containers. However, one authority had nine different containers for a household, which has now been deemed to be too difficult for the householder to manage, (Greenfield, 2020). This means that in the UK there will be at kerbside either two mixed paste fractions or up to nine. This leaves the sorting of the mixed recyclables for the municipal recycling facility to sort into its constituent fractions. Therefore, the collection systems and the rules about what can be put into the recycle bins, as well as the types of plastics put into the systems for reuse, varies across the UK. There is a lack of harmonisation including, a large private sector parallel system. This disjointed way of processing waste inevitably leads to losses due to contamination, and makes it in many cases, uneconomic to recycle the plastics.

Municipal and national statistics, across the four regions in focus, show that there is a wide range in the labelling systems of types of plastics waste streams. This issue introduces a difficulty in direct comparison between for example household waste in a German municipality and one in the UK. In Germany there is a bottle return scheme, while in the UK there isn't one. This implies that more PET will be found in the household waste stream in the UK than in Germany. However, the quality of the PET under the return scheme in Germany, will be of higher quality than that which is found from UK kerbside collections. Nonetheless for this project, what is in focus is the total available quantity of different plastic waste fractions that will be available for AM and IEM purposes.

### 4.3 Routes into the recycling system

As explained, collection systems, such as those dedicated to plastics, differ between countries and even among neighbouring municipalities. A commonly used collection method is via kerbside, which is organised by local authorities. Kerbside collection includes, from households, from bins in public areas, as well as street cleaning that ends up in the same MRF. There are different types of kerbside collection, all dependent on the local authority, or municipality.

For example, in the UK the Department for Environment Food & Rural Affairs (Defra) is responsible for setting waste and recycling policy, most of which is from the EU waste directives. Waste from Households (WfH) was introduced for statistical purposes by Defra in 2014. Wfh includes waste from the following: Regular household collection, Civic amenity sites, 'Bulky waste' and 'Other household waste'. Local authorities are responsible for household and business waste collection services, waste disposal, enforcing waste legislation, and encouraging good waste management in their areas. In England and Wales, 376 Waste collection authorities are charged with the collection of municipal waste. All collection systems require residents to separate their recyclables from their residual waste and place each in a designated container (box, bin or sack) and to present the container for collection on the specified collection day.

### 4.3.1 **Residential waste**

Across the four regions that this report focuses on, there are between three and fourteen different containers for all residential waste collection. The first type of sorting of the plastic waste is carried out by residents, who sort materials into different material types. Secondly, a single stream or co-mingled method collects all materials into the same waste truck which then gets sorted at a Materials Recovery Facility (MRF). Lastly, a two-stream co-mingled method asks residents to sort materials into two containers which are kept separate but collected at the same time. Furthermore, plastic waste can be taken to recycling centres, such as a Household Waste Recycling Site (HWRS), whereby residents can dispose of waste into designated bins. Despite plastics being theoretically highly recyclable, post-consumer plastic packaging recycling rates remain low and this is mainly associated with their quality, (Hahladakis & Iacovidou, 2018). Therefore, municipalities that require residents to sort their waste at kerbside experience less rejection and contamination, hence, more material can be sent to high quality recycling, increasing its circularity. (Burrell & Greenfield, 2021)

Contamination of the plastic waste is a problem that leads to the inability to recycle or upcycle the plastic. In Manchester UK, there are currently only two types of plastic allowed to be put into household recycling bins, PET (Number 1) and HDPE (Number 2). The allowed PET must be from bottles and not from trays however clean they are. In Manchester it was found that contamination begins at the Kerbside. (Burrell & Greenfield, 2021). Given the fact that in all regions it was found that consumers put the wrong, or contaminated items into recycling bins, (this is called misthrow) which introduces contamination into the recycling system.

### 4.3.2 **Commercial and industrial waste**

Commercial wase by itself can be household-like waste that comes from offices and public buildings. Commercial and Industrial (C&I), is mainly from the manufacturing and service industries, most of it collected by local authorities. It is important to note that in Germany there is no strict separation between household and business waste, (Buchhorn, 2022). Therefore, there is a difference in the nomenclature used in different partner countries. This means that what would be specified in the UK as commercial waste would be waste collected from offices, commercial and industrial premisses. However much of this UK designated 'commercial wates' would be classified in for example Germany as municipal waste. The difference in use of terminology can sometimes make it unscientific to compare statistical data from different north-eastern European countries.

This project focuses on packaging waste that is collected by municipalities, however there is a parallel collection, processing and recycling system run by the private sector for commercial and industrial waste. The C&I system will have a large volume of single use plastic waste which is not in the statistics given below, in section 6.6. This does not mean that C&I plastic wate will not end up in municipal recycling systems. This implies, that the total potential available plastic for AM and IEM, while unknown, is larger than that shown below.

Factory waste, also known as industrial waste, is already quite readily recycled, either returned to the same process where it's generated within a factory or readily taken up by big recyclers because it's very clean, pure material. Industrial waste comes directly from manufacturing processes should not be confused with packaging waste, which is generated from industrial and construction activities, for example transport packaging.

Once the waste enters the MRF it goes through a mechanical sorting process. But is all of it actually recycled for future use, or does a large amount end up destroyed or discarded?

### 4.4 Waste rejected from recycling that end up in residual

The collected waste is taken to a materials recovery facility (MRF) where it is sorted into 10, 12 or 13 different waste fractions depending on the country (Buchhorn, 2022). Of these waste fractions only some are the different plastics associated with this project. In some municipalities the MRF bails up the waste and sends it to a waste processing facility which is a different company, many of which are privately owned. In some municipalities especially in large cities, the MRF contains onsite processing facilities. Where the MRF and processing facility are municipality owned it was easier to gather the data for this project. Where the plastic waste comes into the MRF co-mingled or as the general waste, it is sorted. However, at this stage the plastic is either mixed with different other waste fractions or different types of plastic are mixed together, this renders the plastic as contaminated. The contaminated bails of plastic are either rejected at the MRF or the processing plant and are designated as 'residual' waste. The TRANSFORM-CE project therefore seeks to divert some of this residual waste for upcycling via AM and IEM manufacturing.

So far in this report the use of the term 'residual waste' has been used to describe plastic that either ends up in landfill or is burned in waste to energy facilities. No distension has been made about the origin of the plastic. It could have come directly from a non-recyclables bin which in the UK would be called the general waste bin or could have been contaminated bails of plastic that came via the recyclables bin route. However, in Germany the use of the term 'residual waste' with reference to plastic, means plastic that has been put in the general waste bin and ends up outside the plastic recycling system. Therefore, when this report will be discussing statistical data about national volumes of different waste streams, as the data has been compiled according to the nomenclature used in Germany. The 'residual waste' plastic data will be in in accordance to how it is defined in Germany.

Therefore, it should be noted that the pathways to and composition of the residual waste differs in each one of the partner countries. For example, in Belgium, according to the 27/06/1996 Walloon decree, residual waste is waste material that is not collected separately and would not be recycled, and thus will undergo energetic valorisation in a waste to energy facility. In Belgium, household waste collection is performed by a series of intercommunal companies. In Germany, residual waste is supposed to contain only waste fractions that are not collected separately in another waste flow, such as hygiene products. In reality, false throws of plastic, paper and organic waste are also included. It is usually collected at the kerbside in black bins. Companies are obligated to entrust household-like commercial waste to the public waste management authority. Thus, the residual waste in Germany also comprises household like commercial waste. Partly, this household like commercial waste is recorded in a separate waste stream. According to the National Waste Management Plan (LAP3), residual waste (*Restafval*) is a mixture of components of household waste, that differ by nature and composition and arises after sub-flows, such as organic waste, paper and cardboard, glass, etc. are kept separate and be collected and disposed of separately.

Understanding how much plastic ends up rejected out of or not making it into the plastic recycling system, helps to identify the future volumes of waste that will be available as feedstock to a growing AM and IEM industries.

As has been described above, the waste nomenclature differs from country to country, see Appendix 1 of this report. This makes it difficult for data analysis across partner countries as the national and local statistics will be in the local nomenclature. As the waste volumes data in this report has been compiled by our German partners, they overcame this problem by using German nomenclature and where such data was not available, they have left it blank. All this means is that the plastic waste stream that is individually labelled in one country, for example 'packaging waste' in Germany, the Netherlands and Belgium, would be included under a different label, for example in the UK under 'residual waste'. This is due to the difference in data gathering, where some countries gather more detailed data about more waste streams than others.

### 4.5 Volumes of plastic from residual waste

The residual waste in Germany for 2018 consists of thirteen different waste fractions totalling 13.5Mt. 6.7 % of this residual waste fraction was plastic, more than half of which was packaging waste. In total, about 40 kt of plastic waste in Rhineland-Palatinate or 900 kt of plastic waste in Germany are disposed without material recovery,(Dornbusch et al., 2020). In Germany, a high caloric fraction is often sorted out of the residual waste and incinerated in waste-to-energy plants. This Refuse Derived Fuel (RDF) is known to contain high amounts of plastic waste.

Residual waste in Germany is usually not sorted for material recovery of recyclables (except for metals). This is probably because of economic reasons, since the plastic fraction in this waste stream is contaminated. But there is a lot of potential good plastics for the IEM industry. The TRANSFORM-CE sub partners of the district Rhein-Lahn-Kreis are testing further treatment options of the RDF fraction, instead of directly incinerating this waste fraction. For that, TOMRA Sorting GmbH carried out a sorting test with the RDF fraction (32 % of the original quantity of residual waste), which resulted in a mixed plastics fraction (9 %) after the first step and a PE and PP fraction

(5 %) after a second sorting. The resulting fraction was delivered to Save Plastics for further treatment and input for a TRANSFORM-CE pilot plant, (Buchhorn, 2022). This exercise showed that, plastic put into the general waste bin, that would usually be designated as residual waste, was able to be upcycled out of residual waste and put into a circular economy.

In the Netherlands, the Directorate-General for Public Works and Water Management, (Rijkswaterstaat, 2021), designates ten different waste fractions for residual waste. The total residual waste was averaged to 2.98Mt over the three years 2018 to 2020. About 12 % of the residual waste fraction was plastic, more than half of which was packaging waste. In total, on average, about 357,000 tons of plastic waste in the Netherlands is disposed of in the residual waste each year.

England includes the residual waste into its residential and commercial recycling streams. The total figure for residential was about 13.1 Mt WfH (WRAP, 2019b) According to the Waste and Resources Action Programme, (WRAP, 2019), both the residential and the commercial residual waste consists of twelve waste fractions, two of which are plastics. Of the 13.1 Mt of household waste 13% was plastics and of the 11.9Mt of commercial residual waste 19.4% was plastics. This translates into 1.7 Mt of household plastic waste and 2.3 Mt of commercial waste.

RECOUP (2021) give the 2019 UK values at 828 kt of plastic not collected for recycling, i.e. put into the general waste bin (black/grey bin) of which 290 kt went into landfill and 538 kt went into energy recovery. This implies that none of it made it back into the circular economy.

### 4.6 Plastic from Packaging waste

> "Currently only circa 5% of material value of plastics packaging is captured after one use cycle. As such, industries are continuously investing in R&D activities and innovation to develop new technologies that can support and maximise the recovery of plastic packaging material and its embedded value." (Hahladakis & Iacovidou, 2018)

The data from each of the four areas covered by the TRANSFORM-CE provide different fractions for the plastic waste and includes packaging and non-packaging plastics. Packaging does not only consist of plastics, there are also metals used for strapping and corner protections, wood, carboard and cartons that make up packaging materials. It was found that there was a high proportion of waste that did not belong in the plastic fractions, this was labelled misthrow.

It is worthy to note that the statistics given in the next few subsections bring out the differences each country have in the breakdown of the plastic waste fractions. These differences show the need for harmonisation of data collection systems.

### 4.6.1 German statistics

Table 2: Packaging waste in RLP/Germany in 2019

| Waste fraction | weight per cent [%] | waste per capita [kg/(capita*a)] | total amount RLP [t] | total amount Germany [t] |
|---|---|---|---|---|
| PE | 3.5% | 1.2 | 4,900 | 193,600 |
| PP | 7.0% | 2.4 | 9,700 | 387,200 |
| EPS | 2.5% | 0.9 | 3,500 | 138,300 |
| PET | 1.5% | 0.5 | 2,100 | 83,000 |
| ABS | 3.5% | 1.2 | 4,900 | 193,600 |
| films LDPE | 18.0% | 6.1 | 25,000 | 995,800 |
| films PP | 6.0% | 2.0 | 8,300 | 331,900 |
| other plastics | 8.0% | 2.7 | 11,100 | 442,600 |
| non plastic packaging product residues misthrow | 50% | 17.0 | 69,400 | 2,766,000 |
| **total** | **100%** | **34.0** | **138,900** | **5,532,000** |

About 50% the packaging waste is made of plastic, of which in 2019 about 58 % was recycled, (Stiftung Zentrale Stelle Verpackungsregister, 2020) which equates to approximately 1.6 Mt. About 40% was not recycled for economic reasons, because of contamination, or it may of ended up in the sea. In total, about 29 kt of plastic packaging waste in Rhineland-Palatinate or 1.1 Mt of plastic packaging waste in Germany were disposed of without material recovery.

Transport and secondary packaging are, at least in part, captured in a separate waste stream. This waste stream consists of about 7 % plastic materials. Unfortunately, there is no specific data regarding recycling of this plastic fraction. Since this waste stream has very little contamination, a high recycling rate can be assumed.

Table 3: Transport and secondary packaging in RLP/Germany 2019

| Waste fraction | weight per cent [%] | waste per capita [kg/(capita*a)] | total amount RLP [t] | total amount Germany [t] |
|---|---|---|---|---|
| glass | 0.1% | 0.1 | 269 | 214,000 |
| paper and cardboard | 55% | 37.2 | 151,845 | 2,946,100 |
| metals | 2% | 1.7 | 6,745 | 48,800 |
| plastics | 8% | 5.3 | 21,793 | 329,900 |
| wood | 14% | 9.7 | 39,594 | 526,100 |
| compound | 0.5% | 0.4 | 1,473 | 58,100 |
| not sorted by type | 19% | 13.0 | 53,235 | 608,800 |
| contaminated waste | 0.2% | 0.1 | 506 | 13,200 |
| **total** | **100%** | **67.4** | **275,460** | **4,745,000** |

In total, about 330 kt of plastic waste are captured in this waste stream in Germany in 2019.

### 4.6.2 The Netherlands statistics

The Netherlands have adopted the European Packaging Waste Directive. Companies that market packaged products in the Netherlands pay a tax on their packaging to the Packaging Waste Fund (Afvalfonds Verpakkingen). With these taxes, Afvalfonds Verpakkingen compensate municipalities and waste companies for the costs incurred for collecting, sorting, transporting and marketing of sorted plastics.

In the Netherlands about 12 % of the residual waste fraction is plastic, more than half of which is packaging waste. In total, about 36 kt of plastic waste in Flevoland and Utrecht or 357 kt in the Netherlands are disposed of in the residual waste and are therefore potentially available for recycling. The Netherlands provides a breakdown of the plastic waste into the categories in Table 4.

Table 4: Composition of packaging waste in the Netherlands 2019 (Afvalfonds Verpakkingen, 2020)

| Waste fraction | weight per cent [%] | waste per capita [kg/(capita*a)] | total amount Flevoland + Utrecht [t] | total amount Netherlands [t] |
|---|---|---|---|---|
| Alu | 2% | 0,5 | 900 | 8.200 |
| Tinplate | 6% | 1,4 | 2.500 | 22.600 |
| PP | 5% | 1,3 | 2.200 | 20.000 |
| Films | 10% | 2,3 | 4.100 | 37.000 |
| PE | 3% | 0,7 | 1.300 | 11.400 |
| PET | 10% | 2,5 | 4.500 | 40.000 |
| Mix plastics | 20% | 4,8 | 8.600 | 76.600 |
| carton for beverage | 8% | 1,9 | 3.400 | 30.000 |
| Misthrow | 36% | 8,8 | 15.600 | 139.300 |
| **total** | **100%** | **24,2** | **43.100** | **385.000** |

From this it is noted that the largest fraction, 36%, is misthrow, which acts as a contaminant to the plastic waste.

### 4.6.3 Belgium statistics

In Belgium, household waste collection is performed by a series of intercommunal companies. In In Wallonia, 64 kt of plastic and all over Belgium more than 200 kt were disposed in the residual waste (RDC Environment SA, 2019)

Fost Plus, a non-for-profit association, is responsible for the collection and recycling of household packaging waste in all regions. It provides kerbside collection using yellow light-weight bags or alternatively in some cities yellow waste bins for packaging waste made of plastic, metals, and composite materials. In Belgium, about 70 % of the packaging waste is made of plastic. The different forms of PET (PET H: uncoloured bottles; PET B: blue bottles; PET C: coloured bottles; PET

T: formed packaging / trays), are the biggest fraction at approximately 25%, this is because there is no deposit return system in place in Belgium. According to Fost Plus, the packaging waste in Belgium consist of the fractions in Table 5.

Table 5: Packaging waste in Wallonia and Belgium in 2018

| Composition of packaging waste | weight per cent [%] | waste per capita [kg/(capita*a)] | total amount Wallonia [t] | total amount Belgium [t] |
|---|---|---|---|---|
| steel | 20% | 3,0 | 11.200 | 33.900 |
| films | 19% | 2,8 | 10.700 | 32.200 |
| PET H | 13% | 1,9 | 7.300 | 22.000 |
| PET B | 5% | 0,7 | 2.800 | 8.500 |
| PET C | 2% | 0,3 | 1.100 | 3.400 |
| formed PET | 5% | 0,7 | 2.800 | 8.500 |
| PP | 10% | 1,5 | 5.600 | 17.000 |
| HDPE | 8% | 1,2 | 4.500 | 13.600 |
| carton for beverage | 6% | 0,9 | 3.400 | 10.200 |
| PS | 3% | 0,4 | 1.700 | 5.100 |
| other plastics | 5% | 0,7 | 2.800 | 8.500 |
| Alu | 4% | 0,6 | 2.200 | 6.800 |
| **total** | **100%** | **14,9** | **56.100** | **169.500** |

For commercial and industrial packaging, Valipac is the accredited organisation responsible for collection and recycling of the packaging waste. In 2019, more than 116 kt of plastic were collected via commercial and industrial plastic packaging waste system (Valipac, 2020), most of which was plastic films (70 %), see table 6 below.

Table 6: Plastic fractions in commercial and industrial packaging waste in Wallonia and Belgium in 2019

| Waste fraction | weight per cent [%] | waste per capita [kg/(capita*a)] | total amount Wallonia [t] | total amount Belgium [t] |
|---|---|---|---|---|
| plastic film | 70% | 6,0 | 15.500 | 68.200 |
| rigid plastic | 28% | 4,0 | 6.200 | 45.800 |
| expanded PS | 2% | 0,2 | 400 | 2.500 |
| **total** | **100%** | **10,2** | **22.100** | **116.500** |

### 4.6.4 **United Kingdom statistics**

In the UK About 7.3 % of the household residual waste fraction consists of dense, plastic (952 kt), another 5.7% consist of plastic films (752kt). In total, about 85,700 tonnes of plastic waste in Greater Manchester or 1.7 Mt of plastic waste in England are disposed in the residual waste. The largest share of the plastics fraction in residual waste consists of packaging film with 25 % and other dens plastic e non packaging with 22 %. Bottles make up about 10 % of the plastic waste.

Table 7 Plastic fractions in household residual waste

| Waste fraction household waste | weight percent [%] | total Greater Manchester [t] | total amount England [t] |
|---|---|---|---|
| PET Bottles | 5% | 4,285 | 85,247 |
| HDPE Bottles | 4% | 3,428 | 68,198 |
| Other plastic bottles | 1% | 857 | 17,049 |
| Pots, tubs& trays | 15% | 12,855 | 255,742 |
| other dense plastic packaging | 7% | 6,000 | 119,346 |
| other dense non-plastic packaging | 22% | 18,853 | 375,089 |
| Polystyrene | 2% | 1,714 | 34,099 |
| Carrier Bags | 6% | 5,142 | 102,297 |
| Other packaging plastic films | 25% | 21,425 | 426,237 |
| Non-packaging plastic film | 13% | 11,141 | 221,644 |
| **total** | **100%** | **85,700** | **1,704,948** |

About 8.5 % (1Mt) of the commercial residual waste fraction consists of dense plastic, another 10.9 % (1.3 Mt) consist of plastic films. In total, about 116 kt of plastic waste in Greater Manchester or 2.3 Mt of plastic waste in England are disposed in the commercial residual waste. The largest share of the plastics fraction in residual waste consists of packaging film with 37 % and non-packaging plastic film with 16 %.

Table 8 Plastic fractions in commercial residual waste in England

| Waste fraction commercial municipal residual waste | weight percent [%] | total Greater Manchester [t] | total amount England [t] |
|---|---|---|---|
| PET Bottles | 7% | 8,141 | 161,949 |
| HDPE Bottles | 5% | 5,815 | 115,678 |
| Other plastic bottles | 1% | 1,163 | 23,136 |
| Pots, tubs& trays | 14% | 16,282 | 323,899 |
| other dense plastic packaging | 5% | 5,815 | 115,678 |
| other dense non-plastic packaging | 12% | 13,956 | 277,627 |
| Polystyrene | 0% | 0 | 0 |
| Carrier Bags | 3% | 3,489 | 69,407 |
| Other packaging plastic films | 37% | 43,031 | 856,018 |
| Non-packaging plastic film | 16% | 18,608 | 370,170 |
| **total** | **100%** | **116,300** | **2,313,562** |

### 4.6.5 **Rejection rates**

Plastic that is in the recycling system, yet does not meet the correct standard for reuse, is rejected. This could be because it is itself contaminated or it is mixed up in a bale with containments. The rejected plastic is designated residual waste.  In the Netherlands, different municipalities had different rejection rates for plastic packaging, from 10% to 40%. This has been calculated by looking at the tonnage into the processing facility from the MRF and the tonnage out.  For the input and output rate of all municipalities in Altenkirchen Germany and in Manchester UK, a 100% output rate from the processing plant was observed. It is thought that this is due to the cleaner collection pathways and better sorting at the MRF which must have sent to the processing plant very good quality plastic without any contamination.

### 4.6.6 The total aggregated amounts of waste plastic in the whole system

The total aggregated amounts of waste plastic across all four regions was approximately 9.5 Mt per year, and is shown in Table 9 below.

Table 9: Total plastics in waste streams

national plastic waste streams [kt/a]

| Waste stream | Germany | Netherlands | Belgium | UK | total |
|---|---|---|---|---|---|
| residual | 906 | 357 | 201 | 1.705 | 3.170 |
| commercial residual | 247 | | | 2.314 | 2.561 |
| packaging | 2.446 | 185 | 119 | | 2.749 |
| packaging commercial | 349 | | 117 | | 466 |
| deposit return | 467 | 42 | | | 509 |
| **total** | **4.416** | **584** | **437** | **4.019** | **9.455** |

Germany 2018  (Dr. Dornbusch et al., 2020), Netherlands, composition is three years average over 2018 - 2020 (Rijkswaterstaat, 2021),residual Belgium (RDC Environment SA, 2019) Belgium, packaging  (Valipac, 2020), Residential England 2017 (WRAP, 2019b)  Commercial England 2017(WRAP, 2019a)

Municipal and national statistics, across the four regions in focus, show that there are differences in the labelling of types of plastics waste streams in each region. This can be seen, from Table 9, that Germany has five waste streams for plastic, Netherlands and Belgium have three and the UK has two. This is partly because of the EPR scheme, as countries are mandated to operate a separate collection for packaging, therefore, they have a separate packaging waste stream.  Given that the plastic fractions in each waste streams are different in each country, it would be incorrect to make a direct comparison between the countries. Furthermore, it would be erroneous to make conclusions based on comparisons.  What this data tells us is, that there are potentially millions of tonnes of plastic waste that are ending up either being burned as a fuel, going into land fill or into the oceans, that could be diverted into a circular economy, some of which could be used in the AM and IEM industries.

## 4.7 Plastic available for TRANSFORM-CE AM and IEM projects

### 4.7.1 **Availability of feedstock for the AM filaments for this project**

The requirement for the AM project was to use single-use municipal plastic waste that has been sorted, processed and washed, and available at scale. This took considerable time and effort. Only three companies could provide the required plastic. The project was able to acquire approximately 3 tonnes of plastic in total consisting of PET, PLA and ABS, all from recycled plastic from municipal waste streams. The PLA was particularly hard to find from municipal waste. This is because the market for PLA recyclant is very underdeveloped. Therefore, as a very small waste fraction, PLA is not singled out in municipal waste for collection and recycling and usually ends up in general waste. The criterion for this project is that municipal waste must be used and not waste from private sector recyclers. However, PLA coffee cups lids were eventually sourced from municipal waste in Italy. The PET and ABS were sourced from within the UK. The making of filament from municipal recycled plastics is a technical challenge. There are very few companies in the world who have the expertise, equipment, and capacity to do it. Through the use of additives, this project was able to successfully produce filaments that can be used in 3D printing. (Work Package. i2, 2021)

### 4.7.2 **Availability of feedstock for the IEM Save Plastic plant**

The project required low grade mixed polymer plastics that are normally not recycled. It was possible to get the plastic from the local municipality in Almere in the Netherlands. The type of mix used was DKR310 and DKR350 , see Section 4.3 above for more details. There was a need to screen out any of the other plastics like PVC. The municipality was able to supply more than what was needed for the project. In the Netherlands 40% of the packaging waste is DKR310 and DKR350, (email from P. Mul). Therefore, at the time of writing this report, there is potential for up to 125 kt of DKR310 and DKR350 to be available per year for IEM production from the municipality in Almere. Therefore, there should be adequate locally sourced plastic for the foreseeable future to supply the Save Plastic manufacturing facility.

For the UK in 2019 there was approximately 415kt of plastic films from non-consumer plastic packaging which are not placed on the market (RECOUP, 2020b, p. 33) only a small amount of which is recycled. Therefore, the rest will be potentially available for any future IEM facility. The exact amounts of feedstock available in the other two regions is not known. However, given the total amount of plastics ending up in the residual waste stream, it is estimated that there are more than one million tonnes available per annum that could be inputted to a circular economy for use in the IEM industry.

## 4.8 Future Availability of feedstock for both AM and IEM

It is understood that not all plastic recyclant should be a target for AM and IEM. For AM high quality feedstock is required. This does not mean that this project is targeting for example high grade PET or wanting to divert food grade plastic for AM. The best option is for food grade plastic to be recycled into new food grade packaging. However, it could be argued, that where the AM products are seen as durable multi use long life, it would be prudent to upcycle food grade plastics when there is an excess of food grade plastic. Also, since the food safety standards are high, a small amount of contamination in a large amount of plastic may render the whole lot unusable for food and therefore can be diverted to AM. An example is when high grade PET drinking bottles are removed from rivers the quality may be high enough to use for AM but not for food grade. Similarly in places, like Manchester UK, where trays and punnets are not recycled and go straight into the general waste, they could start to be collected for AM or even IEM.

The potential volume of available plastic is given in Table 9, however much of this is already recycled and does not end up in landfill or waste to energy facilities. The remainder, which is not currently recycled, is identified as potential feedstocks for AM and IEM.  IEM has a very high potential to recycle most of the lowest grade plastics not recycled today. PVC due to its chemical characteristics, especially its melting temperature, is an exception and is not currently used in AM or in the Save Plastic IEM Plant.

From Table 9; of the 4.4 Mt of plastic waste that was identified in Germany, more than 2.1 Mt of plastic were not intended for recycling and thus ere available as a potential input for the TRANSFORM-CE demonstration plants. For the Netherlands out of the 600 kt identified, 285 kt were not intended for recycling and is also potentially available.  Similarly for Belgium, 300kt was available out of 465 kt and for the UK, 3.2 Mt was available out of 6.3 Mt, see Table 10.

Table 10: Plastic waste available for pilot plants

| national plastic waste available for pilot plants [kt/a] | | | | | |
|---|---|---|---|---|---|
| **Waste stream** | **Germany** | **Netherlands** | **Belgium** | **England** | **total** |
| residual | 906 | 197 | 201 | 1.356 | 2.660 |
| commercial residual | 247 | | | 1.930 | 2.177 |
| packaging | 964 | 89 | 26 | | 1.079 |
| packaging commercial | unknown | | 70 | | 70 |
| deposit return | - | - | | | - |
| **total** | **2.117** | **285** | **298** | **3.286** | **5.986** |

The PET collected from the bottles in Germany and the Netherlands is high quality plastic that is recycled, however, what is not known is what happens to the labels, that are usually PP (type 5) and the lids which can be either HDPE (type 2) or LHPE (type 4).  Therefore, there is a potential that this waste, which should be highly uncontaminated, can be a source of feedstock for the IEM industry.

All the statistics in this section are taken from municipal waste data, however, there is also the waste collected by private commercial waste management companies. This waste adds to the total future amount of waste plastics that will be available for both AM and IEM.

Most countries in Europe are not reaching the recycling target set by the EU for overall recycling. As a commodity the amount of plastic recycled is very low. Over the years there has been many schemes to incentive the increase in recycling and the use of recyclant. However, as of 2022 targets are still not being met and the development of a market that makes things from all types of recycled plastic, including that which is of low grade, has not developed enough to form a circular economy for plastics. This report will now look art different policies, regulations and possibilities to increase the volume of available plastic recyclant.

## 5. What will affect future volumes available for AM and IEM

Many of the reasons why only a small amount of plastic is actually recycled are understood, now this report will look at what changes may affect the future volume of plastic available for AM and IEM. The volume of waste plastic available for AM and IEM is proportional to the amount and value of recycled plastic. This means, any driver that increases the amount of recycled plastic will in effect reduce the amount of plastic in residual waste and therefore available for AM and IEM. Similarly, any economic driver that affects the value of recycled plastic in an upwards direction, will increase levels of recycling and increase the cost of feedstocks. However, as long as plastic continues to be consumed, and taking into consideration plastics in circulation and in landfill, there will be a plentiful source of material for AM & IEM.

### 5.1 Policy, regulations, and national and local incentives

#### 5.1.1 Policy changes and investment in capital projects

One example of policy change is Manchester UK. From the Greater Manchester Council (GMC) waste recycling website (April 2022), it is obvious that only PET bottles are being recycled, and all other PET from clean punnets etc. are going into residual waste. Furthermore, GMC are only recycling clean bottles and soiled bottles are not being recycled. However, the policy is changing, and GMC have already given the go-ahead for a new plastic recycling plant. When this comes online less PET feedstock may be available for the AM industry.

Public policy that leads to new investment in plant will impact the volume of low-grade plastics available. Policy to increase capital investment in better sorting equipment may in fact increase the volume of sorted low grade plastic feedstock available for the IEM industry.

### 5.1.2 Taxation - The Packaging Waste Fund in the Netherlands

For many years, countries all over the world have used taxes as a means to 'force' companies and consumers to be more ecological and to increase the amount they recycle. For example, the Netherlands have adopted the European Packaging Waste Directive. Companies that market packaged products in the Netherlands pay a tax on their packaging to the Packaging Waste Fund (Afvalfonds Verpakkingen). With these taxes, the fund compensates municipalities and waste companies for the costs incurred for collecting, sorting, transport, and marketing of sorted plastics. Packaging waste is collected in the PMD (Plastic, Metal and Drinking Cartons) waste stream. Some regions are switching to a PMD+ waste stream, in which non packaging plastic is also allowed to dispose of.

### 5.1.3 Plastic Packaging Tax in the UK

> "*In the UK from April 2022, you need to register for the Plastic Packaging Tax if you've manufactured or imported 10 or more tonnes of finished plastic packaging components within the last 12 months, or will do so in the next 30 days. From 1 April 2022 to 30 March 2023, the 12 months threshold will be worked out differently. You will need to pay Plastic Packaging Tax if you have manufactured or imported plastic packaging components which contain less than 30% recycled plastic. The tax came into force on 1 April 2022 and is charged at a rate of £200 per tonne.*"(GOV.UK, 2022b)

As this is a tax on production it is not known how this will affect future availability of plastics.

### 5.1.4 Charging for general waste pay-as-you-throw (PAYT) schemas

Morlok et al. (2017), conclude that PAYT could make an important contribution towards material reuse and recycling objectives for the new circular economy. Other types of waste collection have so far failed to achieve the same levels of landfill diversion and waste recycling, like PAYT. This therefore implies that if PAYT schemes become widespread across Northeast Europe, something that is unlikely in the near future, less contamination will occur as consumers will be less likely to put plastic in the general waste system. A problem for this scheme is that it leads to more dumping of waste on private and public land, and more contaminants being hidden in the recycling bins to reduce the weight of the general waste they have to pay for.

### 5.1.5 Price incentive for residential customers to sort their waste

In the Netherlands, the Environmental Protection Act states that municipalities are responsible for collecting and processing household waste. As municipalities can choose their own preferred collection system for household waste, there are many different types of systems in place. The national VANG policy (VANG is translated "from waste to resource") sets ambitious targets for the reduction of residual waste and waste separation. To meet these targets, municipalities introduced a high service for waste separation and a low service for residual waste, accompanied by the introduction of a price incentive to separate waste.

### 5.1.6 **Deposit return schemes for single use plastic bottles**

A deposit scheme charges an upfront cost to the customer who received this back once the bottle has been returned to a designates recycling machine. This type of incentive works well in some counties like Germany and the Netherlands but seems to underperform in some affluent cities. This can be noticed by the amounts of plastic bottles collected by the homeless in these cities where a proportion of the population don't see the necessity to get their deposit back.

Even in countries that have a successful returns scheme, the volume of plastic bottles is so high that a small percentage not recycled adds up to many tonnes. For example, in the Netherlands, approx. 620 million bottles larger than 0.75 litres were sold in 2017. With a return rate of 95 %, 23,560 tonnes of PET were collected via the deposit return system. This implies that 1,240 tonnes were not returned. Since July 2021, the deposit system also includes bottles from 0.1 to 0.75 litres. Assuming a return rate of 80 % of 900 million bottles, another 18,000 tons of PET are now collected per year (Bergsma et al., 2017). This is another 4,500 tonnes not returned. It must be presumed that some of this will have ended up in the recycling system, however how much is unknown.

Similarly in Germany, about 467,000 tons of PET (net share) were disposed via the deposit return system, of which about 94 % were recycled. 34 % of the recycled PET is used for producing new PET bottles, although more than 90 % of all recycled bottles are suitable for bottle-to-bottle recycling (Gesellschaft für Verpackungsmarktforschung mbH, 2008). This is due to the high quality of the plastic, which is taken up by manufacturers other that bottle producers.

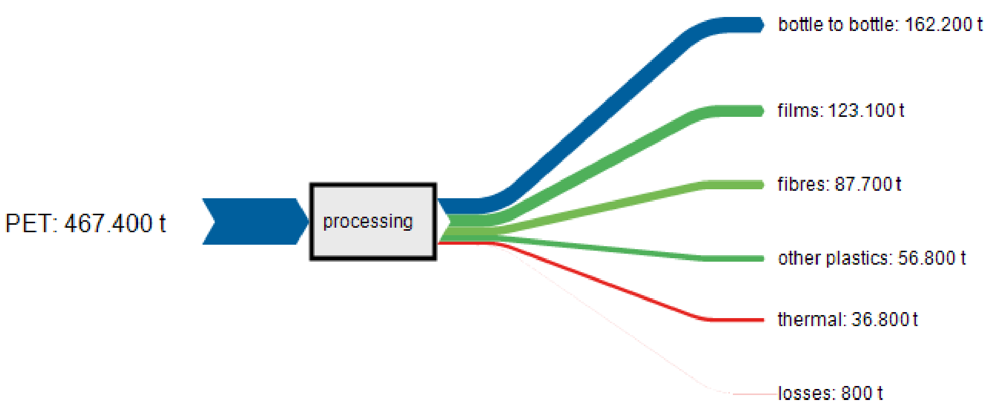

Figure 1: Recycling of PET fraction in deposit return Germany, (Buchhorn, 2022)

There is a large amount of films and HDPE lids etc. that can be of use in AM and IET but it is not know at this time what happens to them.

However, to date 2022, in Belgium and the UK there is no deposit return system in place for PET bottles. But, in the UK the Government is at the second consultation stage for implementing such a scheme which is scheduled to be introduced sometime in 2023. So while a return scheme increases the amount of clean PET recycled there is still many thousands of tonnes of plastic that could potentially be used in AM and IEM.

### 5.1.7 **Having set targets for recycling the Extended Producer Responsibility Schemes**

The EU directive 94/62/EC on packaging and packaging waste sets recycling targets for packaging and requires EU member states to set up a system to return, reuse and recover used packaging from the consumer. The TRANSFORM-CE partner countries, Germany, Netherlands, Belgium and the UK delegate this legal obligation to the producers and importers of packaging through the setting of Extended Producer Responsibility Schemes (EPR). To ensure the effectiveness of the schemes, the market for packaging is monitored closely. Such a scheme increases the amount of plastic collected. However, what is not known is how much of the plastic still ends up in the residual waste stream and therefore how such a scheme affects the availability of plastic for AM and IEM.

### 5.1.8 **Data collection**

The TRANSFORM-CE Project is focused on municipal waste and on the plastic packaging stream that can be used for AM and IEM. Gathering aggregated volume date about plastic waste streams, and more detailed data date broken down into the different types of plastics, was a difficult task. The general information was hard to find due to the lack of open channels of communication between the researchers and the municipality and the waste management facilities. However, as Almere is a partner in this project, information was much easier to obtain.

In the statistics provided by Statbel for Belgium, *"plastic waste" is one out of fifty-one different categories regardless of the chemical type or the application of the plastic. It does not therefore give the opportunity to identify whether the waste may have a particular interest for the TRANSFORM-CE project that focuses on single use plastics, and more specifically about polyolefins and PET*", (Talon, 2020). For the UK, "*it should be noted that some of the data, especially in the data gathering excel spreadsheet, is not comparable. This is due to the variation in waste data reporting systems and accessibility to such data*" (Burrell & Greenfield, 2021)

The responsibility for waste collection differs in each country and in some parts of the same country. In Germany, the packaging waste is collected by the public authority and then handed over to a repossessing facility that comes under the EPR, this makes it difficult to gather recycling data. The public authority knows how much was collected, but do not know details about volumes and types that are put into the recycling system, and how much ends up being burned for fuel or put inland fill. Other public authorities do both the collection and are responsible for the repossessing for the packaging waste, like in the UK the local authority is responsible to put the recycled plastic into the market.

Different municipalities in the same country as well as different countries collect different plastics and in different collection schemas. This makes gathering detailed information about specific plastic types difficult. Those countries signed up to the EPR for packaging waste have a specific recycling system for just packaging waste. Some municipalities add to this and have the facilities to collect other plastic waste separately or comingled with metal recyclables. While some only collect packaging plastic, and all other plastic goes into general waste. Therefore, these was a challenge to easily find accurate information about volumes of the different plastics that this project is focused on. Notwithstanding this problem, data was available in the public arena from previously peer reviewed published studies and from NGOs reports. The same is true about the countries that have a bottle deposit return system, the data available is easily obtained.

The data does not give information about the quality and level of possible contamination of the mixed waste plastic. Therefore, it is not possible to determine the volume of plastic available for AM as it must be of high quality. Similarly, while the IEM can use low grade mixed types of plastics it cannot use all the types at the same time, e.g. PVC must be removed from the mixed plastic feedstock. All that can be determined about the volume of plastics, is how much exists that could possibly be fed into a circular economic model within the AM and IEM industries. These are the statistics given above in section 6.

Having a harmonised and more detailed data about plastic waste could help to identify types of plastics not being recycled. This could lead to answering why they are not being recycled and then to policies that could either reduce the use of the amount or type within future products or incentivise more recycling. Also having arcuate data about which types of plastic are in the system could incentivise the plastic processing industry to focus resources to produce higher volumes of all types of plastics. For example, PLA is a low volume plastic and is good feedstock for AM, yet date about volume or recycling is not available.

## 5.2 Changes in the material science of plastics

Plastics for packaging contain many different types of polymers, either within the same product or when they get mixed together in the waste streams. Much of it is thin, and difficult to sort with manual systems. There is a move in Europe to harmonise the polymers that go into the plastic packaging, so that they will be easier to recycle. Therefore, in the future there will be changes to the makeup of plastic types, new composites will be developed, and substitution of plastic for other materials.

### 5.2.1 **Elimination of multi-layer films**

The use of multi-layer films, that act as a functional barrier, has been an important plastic for the safe packaging or foodstuffs. While there is a move to reduce the use of such packaging materials, for the foreseeable future, these complicated multi-layer plastic films will still be used. There is a discussion about using virgin plastic on the surface that comes in contact with the food and recycled plastic for the outside layer, (BPF, 2020). If this happened, it opens the possibility for large volumes of recycled plastic to be used in a circular way even as multi-layer films.

### 5.2.2 **Chemical recycling of plastics**

> "*Can plastics be recycled indefinitely? The mechanical recycling of polymers will allow multiple cycles to be achieved, but not an infinite number of cycles due to the impact on the properties of that material. However, the continuous addition of*

*virgin material acts to counterbalance this effect. .... Chemical recycling, where the material is returned back to monomers offers the opportunity for an infinite number of cycles to be achieved without the necessity to incorporate a virgin element. There are different types of chemical recycling processes, including pyrolysis, gasification, solvent dissolution and chemical depolymerisation, and other specialist processes which are evolving. The process of breaking down collected plastics into monomers and other basic chemical elements ("depolymerization") offers the opportunity to process difficult to recycle materials and remove contamination. These monomers can be used as virgin material alternatives in manufacturing new polymers*." (BPF, 2020)

This seems to indicate that changes in the material science of plastics will see a reduction in the availability of feedstock for AM and IEM over time. However, if the total amount of plastic ever produced, and the small amounts that are actually being recycled, are taken into consideration, the volume data suggests that there will be ample feedstock for use in AM and IEM for many decades to come.

## 5.3 The economics of oil

The future market price for crude oil effects the price of virgin plastic. Ironically the cheaper a barrel of crude oil is, the less recycled plastic is worth. This is because the price of virgin plastic becomes much cheaper than recycled plastic. Conversely the more expensive crude oil is, the more recycled plastic is in demand and the less ends up as low-grade in residual waste. The problem with this is, that the price cycle of crude oil is shorter than the capital investment cycle for recycling plastics. Many companies that put capital investment into plastic recycling when the price of crude oil reached over $60 a barrel, withdrew from the industry as the price dipped below $40. Twice since 2002 it has fallen to below $20 a barrel. Many analysts believe that Peak Oil has been reached and therefore in the future the price of oil will stay at a high level. However, on the other side, is the move away from fossil fuels to electric and hydrogen transportation, which will reduce the demand for oil. This oil price cycle will have effects on the future availability of recycled plastics as private business, who understand the oil price fluctuations, refrain from investing in the capital expenditure needed to process plastic waste. This conundrum was highlighted by many companies across Europe that attended the different workshops carried out through work package T1. Some suggestions were to tax the use of virgin plastics.

## 5.4 The economics and CO2 of recycled plastic for AM and IEM

### 5.4.1 The economic argument for using recycled plastic instead of virgin plastic

For the IEM industry that is focused on non-food grade plastics and makes outdoor items for the garden or façade of buildings, the grade of plastic can be of low-grade and of mixed types of plastics. Plastic foils and mixed plastics like the DKR310 and DKR350 grade of mixed plastic from the Netherlands, are well suited for this. Usually there is a cost to the waste management company of up to €200 per tonne for disposing of DKR350 grade waste, however this can be saved by diverting this waste to the IEM industry. In the UK, SUEZ (2021) concluded that "*for many of the* *options for collection and treatment, costs were equal to or less expensive than placement to landfill or energy-from-waste*." For the IEM industry virgin plastic costs around €1000 per tonne, so using DKR350 grade plastic as part of a circular economy business model is economical.

Regardless of the discussion if food grade plastic should be used for AM, the use of high-grade plastics for AM offers opportunities for upcycling rather than just bottle to bottle recycling. AM can produce products from single use plastic that are durable, long lasting, and can be used many times. Such upcycling increases the economic value of the plastic as AM produces higher value products than single use plastic packaging. Therefore, both AM and IEM provide economic opportunities to increase the monetary value of waste plastic by upcycling them.

#### 5.4.2 **The reduction in CO2 using recycled plastic instead of virgin plastic**

> "*To demonstrate the level of environmental benefit of using recycled materials a study by (Accorsi et al., 2015) is detailed. The study demonstrated the carbon saving of a PET bottle for olive oil with levels of 0 to 50% recycled material. The carbon footprint per kg $CO_2$ equivalent per 1 litre of 0% recycled content is 0.225, compared with 0.155 for 50% recycled content, a saving of 31% kg $CO_2$ equivalent*. (BPF, 2020)"

Using recycled polymers in products significantly reduced greenhouse gas (GHG) emissions. using 30% in PET packaging on average results in a reduction in GHG by 15.25%, for HDPE it is 10.23% and in PP it is 6.38%, (BPF, 2021 from How2Recycle Recycled Content Calculator). Around three quarters of the individual life-cycle assessments studies assessed in WRAP (2010) found that the global warming potential associated with plastics recycling was, at a minimum, half of that associated with incineration or landfilling. The displacement of virgin plastics by their recycled equivalents is one important reason for the relative desirability of plastics recycling, (oecd, 2022, p. 6). Recycling saves between 30% and 80% of the carbon emissions that virgin plastic processing and manufacturing generate, (Voulvoulis et al., 2020). These environmental benefits become a selling point for producers and therefore recycled plastics are highly sort after. When substituting virgin plastic for recycled feedstock in AM and IEM, the environmental gains, of making things out of low-grade waste, is a selling point that will help municipalities and companied reach their carbon reduction goals.

### 5.5 Plastics from general waste

It has been shown, that recycled waste collected at the kerbside as part of a designated recycle system, included plastics that are either not yet recyclable or are not recycled by that specific municipality. Also included are contaminants that are household waste that is not plastic and should never have been placed in the plastic recycle bins. This is called misthrow. This stream of plastic ends up in residual waste which is disposed of as either waste-to-energy or in landfill. However, what was not looked at by this project and which perhaps has not been quantified before, is the amount of recyclables that should have been put in the plastics recycle bin, but are 'misthrow' in the general waste bin. In many municipalities across Europe, a lot of the general waste is never sorted. The general waste that goes to energy-from-waste facilities is burned as is, without any level of sorting. The same is with the general waste that goes form kerbside directly into landfill.

In the future if this general waste was sorted then there could possibly be enormous amounts of both high-grade PET for AM manufacturing and low-grade plastics for the IEM facilities. The possible volume of plastic that could be available is left for future research projects, but it should be in line with the volumes that have been quantified as existing in already closed landfills that are now being considered for Enhanced Landfill Mining (ELFM).

## 5.6 Mining of old landfill sites

Since plastics began to be mass produced in the 1950s, global plastic waste is estimated to be 6.3 billion tons, of which 79% has accumulated in landfills or the natural environment (Geyer et al., 2017). In Europe over 5.25 billion tonnes of waste has been landfilled between 1995 and 2015. Among this large amount of waste, plastic represents typically 5-25wt% which is significant and has the potential to be recycled and reintroduced into the circular economy, Canopoli et al. (2018). For Europe this is at least 262.5 million tonnes of plastic that is not available today for recycling.

Enhanced Landfill Mining (ELFM) is the process of mining legacy municipal or private landfill sites for material recovery. The value and availability of precious and rare-earth metals will necessitate and make it economically viable, to open these landfill sites for mining of metals. ELFM will inevitably recover millions of tonnes of all types of plastic that will have to be dealt with. The plastics will be a by-product of the metal mining business and as such will be a source of plastic to feed into the industry Cappucci et al. (2020). Cappucci et al. report that "*over 500,000 landfills have been reported in the EU, of which 90% operated before the introduction of specific directives (1993/31/EC) and thus potentially unsafe*". As such, this may be a reason why in the future, there may be a need for ELFM. The thought at this time is, that the plastics will go through a process that will turn the solid plastic into liquid polymers which will then be reprocessed into new sold types of plastic. This will use pyrolysis (Zhang et al., 2021), a cost effective alternative option to conventional recycling, it produces an oil that is expected to have similar characteristics to petroleum diesel oil Canopoli et al. (2018). As explained above, there are other chemical recycling methods to produce clean monomers form the plastic waste.

There is potential, depending on the quality of the plastic, that some of the plastics from landfill sites could be able to go directly into the IEM industry.

## 5.7 Reducing contamination by changing the way waste is deposited by consumers

Municipalities that require residents to sort their waste at kerbside, experience less rejection and contamination, hence, more material can be sent to high quality recycling, thus increasing productivity. It has been shown form Germany that 94% of all recycled plastic bottles are of high quality and can be used for bottle-to-bottle recycling. Therefore, implementing a Deposit Return Schemes would increase the amount of high quality PET available (Burrell & Greenfield, 2021),

Plastic that is currently contaminated at the kerbside, is rejected and ends up being burned, mostly as fuel to generate electricity, or put in landfill. Some of this could in the future be available for repurposing. It is understood that this is not because it is technically impossible to sort all plastics by polymer type, treat it, and therefore recycle, rather it is due to the economics and final value of the materials compared to the cost of processing. Given the human condition that creates high volumes of 'misthrow' that leaves contaminants in the waste, and given the volumes of waste generated, it is very likely that there will still be significant amounts of low-grade plastics for IEM purposes for the foreseeable future.

### 5.8 Sources of plastic from private waste management companies

This project only looked at municipal waste. However, across the world, there is a parallel collection and processing system run by private contractors that service the commercial and industrial sectors. In the UK kerbside waste collection is a 'paid for service' for the commercial sector. This included large offices, schools, SMEs, religious establishments etc. For the UK, where a EPR scheme is not in operation, the private sector offers a stream of plastic from packaging that is not captured by this project and can therefore add to the volume of plastic available for AM and IEM. However, for countries that are part of the EPR scheme, the packaging that is collected by the private pay scheme, is still captured by this project. Volumes of plastic available from the private sector that is outside the ERP scheme, is not known at this time and can be part of future research.

## 6. Findings and recommendations for policy and decision makers

These recommendations have been derived from the work carried out by many different work packages across this project. The aim of these recommendations is to provide insights as to what needs to be done to increase the uptake of recycled plastics for the AM and IEM industries. Decision makers should note that each individual recommendation can only achieve incremental changes. In order that a circular economy model can be implemented there is a need to see improved changes in all these recommendations. Also, some of the recommendations, for example, education, data gathering, and investment are important throughout the circular business model for AM and IEM.

### 6.1 The need for harmonisation of polymer composition of single use plastics

Plastics for packaging contain many different types of polymers, much of which is multi polymer thin films which have different specifications across Europe. It is recommended that the policy of harmonising this type of packaging so that it will be easier to recycle should be implemented as soon as possible. Doing this will provide larger volumes of the same type which will make it easier to sort, process and ultimately recycle.

### 6.2 Labelling plastics for easy identification by future recyclers.

Many SUPs made outside the EU do not have the polymer types embossed on them. Some have the polymer type in alphabetic presentation, like PET or PP, while other have the different standards of numerical identification, (see section 4 above). All this is confusing for the consumer. Therefore, to increase the correct sorting of plastics by consumers there is a stronger need for regulations that harmonise the identification labelling on all plastics consumed.

For the IEM industry it is possible to make products from a mix of different polymers. Depending on the melting point of groups of polymers, the products made will not be able to be recycled together with other IEM products if they have a wide difference in their melt points. It is recommended that further work is carried out to produce a set of alpha and numeric symbols for these new composites. By tagging all recycled plastics with a symbol that is universally recognised, it will be easy for future recyclers to sort the streams of waste plastic to maximise the financial value of the waste. Harmonising this will be helpful, as at this time SME manufacturers are using their own symbols, and the use of a QR code or a barcode is being touted.

### 6.3 Harmonisation of collection and kerbside sorting mechanisms

Across the regions that this project looked at there were many different amounts of bins, bags and containers for the recyclables, at the kerbside and different mechanisms used by the vehicles used to collect the waste. The more effort that goes into pre-collection sorting the greater the chances of having less contamination, misthrow and larger quantities of cleaner usable plastics. Therefore, it is recommended that a plan for harmonising the collection methodologies should be implemented.

For packaging waste, it was found that there is a lack of harmonisation in the content of this waste fraction across different municipalities and regions. This means that there is a need for sorting of waste into as many categories as necessary to reduce kerbside contamination and increase the volume of clean plastic available for recycling.  Change begins through education and empowerment of consumers to be pivotal in increasing the amount of usable recyclable material. It starts with the consumer having adequate knowable about what how and why types of plastics can and cannot be recycled. Providing the correct containers to place the different plastics in. The goal is to drastically reduce misthrow that comminates plastic waste.

RECOUP conclude that "Consistency *in household and business recycling collections would increase the quantity and quality of the material collected for recycling by having a core set of materials and products that should be presented in the same way for recycling regardless of where you live or travel to in England*." (RECOUP, 2020b) This has been found to be true across all partner counties.

### 6.4 Deposit retunes scheme for bottles

During the research for this report a conclusion was reached that the UK would gain from implementing a bottle deposit return scheme.  This would increase the availability of labels and lids for the IEM industry.   The British government have finally, after many years, published their strategy for such a system for 2023 (Gov.UK, 2022a).  It is recommended that the collection machines be upgraded to be able to remove the labels, caps, and rings so that the shredded PET from the bottle does not have any other plastic polymers mixed in.  However, this process has now been made harder with the EU rules that forces manufacturers to make the cap stay on after it is opened (European Commission, 2021). Future work will have to ascertain how these EU rules will affect the purity of the PET recyclant as there has in the past been a small percentage of HDPE from the caps that ended up mixed with the crushed and washed PET.

## 6.5 Extended Producer Responsibility scheme

The UK is not signed up to the EPR or a deposit retunes systems for bottles so packaging waste is not collected as a dedicated waste stream. Harmonising the EPR scheme or a similar scheme, that moves the cost of waste disposal from the consumer to the producer, can be an effective incentive to increase the volume of plastic material collected for recycling. It also may have the added effect of reducing the illegal dumping of such waste.

## 6.6 Education

In general waste is looked at as a 'problem to be delt with', especially when the price of virgin plastic is low. Consumers, policy makers, and decision makers within the waste management business, should look at plastic waste as a finite non-renewable resource for which humanity cannot for the foreseeable future do without. It is therefore very important to educate everyone about the circular economic benefits of properly recycling plastic waste.

### 6.6.1 **Schools and further education institutions**

Because there is little harmonisation across the waste collection systems as to what should or should not be put into which recycling bin (RECOUP, 2021), there is a need to better educate consumers of all ages.  Also, consumers need reasons why a clean plastic food tray cannot not be recycled and in their particular municipality has to be put into the general waste. RECOUP found that when people moved to a different municipality in the UK, they still thought that the recycling rules in their old home were the same in their new one.  This caused them to inadvertent misthrow and contaminate the recyclables.  Municipalities have to be transparent with consumers about the limitations of their recycle system. RECOUP found that some consumers gave up as they felt that recycling was a "waste of their time". Consumers need to understand how not to contaminate the recycling with nonrecyclables, misthrow of general waste and therefore what the environmental cost is to their noncompliance to the rules is.

However, in an environment where general waste is not collected every week, consumers could find that their general waste bin is too small, and in the UK, they could have problems if the bin does not close due to overloading. They may be compelled and perhaps wilful in putting all plastics even non recyclables into the recycle bin to alleviate their problem of not having enough room in the general waste bin. For such consumers education about waste may be meaningless and only moving back to a weekly general bin removal service will change their behaviours.

## 6.7 Data gathering mechanisms

Different waste management companies, municipalities, and aggregated country data, use different methodologies to collect data. They report and present different datasets which use different nomenclature. This is not only between different countries but even different municipalities.   This makes comparing the availability of plastics across municipalities and regions difficult. As there is a difficulty in identifying where waste plastic fractions originate from, this makes it difficult to know where and how to direct policies to increase the amounts that can be used in the future for AM and IEM industries.

There is ample information, from national statistics, as to the volume of wase entering the reprocessing centres in all four regions. However, it is very difficult. but not impossible, to find detailed data about different waste plastic fraction within the waste system. Due to the lack of precise data, there is a difficulty identifying the actual reason why so much of the plastic has been rejected and ends up in residual waste. To increase the circularity of the plastics, especially that of low-grade, there is a need for more data as to why plastic is being rejected. This rejected plastic is nominally a future stream of plastic for the IEM industry.

For the private sector, that collect commercial and industrial waste plastics, there is almost no publicly available data, there is a need for more transparency and publicly available data about what they collect and volumes available for the circular economy. Companies use commercial confidentiality as a reason to not provide detailed statistical data about the plastic factors they handle. Therefore, this report recommends that policymakers create data collection mechanisms that harmonise details about SUP, from consumption and across the whole waste management system.

## 6.8 Capital investment in the waste processing facilities

Notwithstanding the fact that when the recyclables enter the MRF, the goal is that the waste should be correctly sorted and uncontaminated, there is also a need to put capital investment into cutting edge technology for sorting within the MRF and plastic processing facilities. These include new types of optical sorters and artificial intelligent robotic equipment. There are many reasons why people may continue to misthrow and contaminate the waste streams, modern technology should be used to mitigate for this.

### 6.8.1 **The need for more investment in more sophisticated sorting and processing machines**

Much of the UK,s plastic recyclables are exported to third countries for reprocessing. If the UK and EU were to have better recycling facilities, there would be an increase in the availability of a valuable commodity to feed into our circular economy, thus saving resources and increasing GDP. The technology for sorting plastics by polymer and colour exists, therefore there is a need for more investment in this type of technology to increase the volume of plastic available for the circular economy and therefore for the AM and IEM industries.

Many parts of the waste management system do not have the technical infrastructure to sort the plastic into high quality single polymer bails. This means that many bails of plastic have a conservative estimate of at least 15% of the wrong types of plastic. This leads to many bails being rejected and therefore available for the IEM industry. With investment in more sophisticated sorting technology more of the low-quality grade films could be diverted away from EfW plants or landfill to IEM.

### 6.8.2 **Facilitating small and medium sized recycling plants**

Transportation of waste plastic over long distances to a manufacturing site adds monetary and environmental costs. It is not economic for large scale municipal and private waste management facilities, to deal with small manufacturers, who may require a few tens of tonnes a year of specific polymer type/s per order. Therefore, having small scale local collection facilities near to production facilities would be beneficial. It would incentivise SMEs to locally sourced feedstock to make locally produced products. This business model feds into the concept of a circular economy for plastics. However, for this business model to take off there will need for financial incentives by way of grants, low interest loans and tax breaks to encourage the setting up of these facilities. Policy makers will have to make the waste management regulation easier and cheaper for SMEs to operate.

### 6.8.3 **Building of large-scale recycling plants**

The bigger the plant, the more able it is to handle waste that smaller plants would throw into residual waste for burning or landfill. A massive plant that has the ability to sort thousands of tonnes using sophisticated electronic sorting machines may be able to sort low grade plastics. It also operates with economy of scale, so that is able to spread its fixed overheads across many more tonnes of output. For example SUEZ (2021) found that the cost to sort plastic packaging, varied between 14 pence and 45 pence per kg, with one of the aspects that affect this cost is the amount of volume handled by the MRF. Therefore, large facilities create streams of SUP recyclant that cannot be economically processed by smaller facilities. As these are very expensive, in the many millions of pounds, they will need the same financial incentives available for the small-scale facilities. At these facilities the latest optical equipment can be installed. An example is the recycling of black plastics. Conventional near infrared optical sorters are not able to sort black plastic. Manufacturers have gone through great effort to include special pigments into the plastic to help facilitate sorting (recoup, 2020a). However, new AUTOSORT technology from Tomra (2022) is now able to sort ordinary black plastic. At this scale only a few strategically placed facilities around a country will be needed, the best place would be near to large urban areas to reduce transportation distances. It is recommended that policy makers place mechanisms to make sure that large facilities do not lead to the closure of smaller ones, or the inability of the industry to operate at smaller scale.

## 6.9 Take-up of products made from the AM and IEM industries by public authorities.

One reason why the types and volumes of plastic are not optimally recycled is due to the lack of demand side pull from manufacturers who are reluctant due to lack of demand side pull from consumers. Therefore, since public authorities are large precures, they have the buying power to provide this demand side pull that could catalyse the AM and IEM industries. The volumes consumed by public authorities could create economies of scall for small producers that will help them grow their business. When consumers hear, through the media, that public authorities are using the products from recycled plastic, it gives them confidence to also opt for products from recycled plastic. Economies of scale also reduce the cost of production which therefore make the end product cheaper. Demand side pull increases the demand for plastic rtecylents from the recycling system which thus reduces the amount of plastic in the liner economy and transposes it into the circular economy.

### 6.10 Harmonisation of government policy

The lifecycle of plastics varies per polymer type and is affected by many different policy issues. Waste policy is identified by Oluwadipe et al (2022) as one of the most important aspects in influencing recycling rate. This report has many recommendations, many of which are under the stewardship of different governments departments. Policy that emanates from a single government department, can have the nature of being very siloed. There is therefore the possibility of incompatible policies disseminating from different government departments. This report recommends a new government department should be created. The focus of the department should be on complicated cross departmental societal problems, like plastic waste. It could be named the Department for the Circular Economy. (It will also look at all aspects of the circular economy). Its remit, regarding plastic waste, would be as a conduit through which other departments would pass through it policies that effect plastic waste to see how each policy would affect and be affected by policy from other departments in central and local government. Such a department would see the wider picture with is outside the remit of a single department and should bring together the different stockholders for joint up thinking on the problem.
Extended Producer Responsibility scheme

## 7. Conclusion

Summary of critical factors that affect the volume of recyclant available for AM and IEM.

1. A lack of harmonisation of polymer composition of SUPs
2. An educated and informed consumer focused on optimal recycling behaviours
3. A clean/uncontaminated supply of post-consumer plastic waste
4. A harmonised collection system across the whole of Europe – bin and bag colour
5. A harmonising of types of plastic collected to include mechanisms for all types
6. Lack of capital investment in materials handling and processing systems
7. A strong harmonised regulatory system
8. A growing demand for plastic recyclant will push supply side growth

Summary of recommendations

1. To harmonise/reduce the complexity of the polymer composition of SUPs
2. To introduce across Europe harmonised polymer identification marks on all recycled plastic
3. To harmonise kerbside sorting and collection mechanisms across the whole country
4. To introduce a bottle deposit return scheme across all EU countries
5. To introduce an Extended Producer Responsibility scheme across all EU countries
6. To better inform and educate consumers about waste recycling
7. Harmonisation and more transparency of data gathering processes and of the type detailed data gathered
8. An increase in capital investment in both small local and large central waste processing facilities to include state of the art technology that can handle thin plastic films

9. Governments and public authorities should only buy things that are made with recycled plastic, as this can create the demand for large volumes of recycled plastic and catalyse the AM and IEM industries.
10. There is a need for joint up thinking, harmonisation of government policy

Many of the reasons why only a small proportion of plastic is actual recycled are understood. The volume of plastic available for AM and IEM is proportional to the amount and value of recycled plastic. This means, any driver that increases the amount of recycled plastic will in effect reduce the amount of plastic in residual waste and therefore available for AM and IEM. Similarly, any economic driver that affects the value of recycled plastic in an upwards direction, will increase levels of recycling and reduce the availability of low-grade plastics, and vice versa if the value goes down.

It was estimated that there is approximately 6 Mt of waste plastic per year that could be available for AM and IEM in the four partner countries. Given that the pilot plant, after an upgrade, has a maximum capacity of 2000t per year, 6 Mt could in theory feed either 3000 IEM plants, many more thousands of AM printers, or a combination of both. Adding volumes available from other countries the potential for IEM and AM is huge. Due to lack of data gathering mechanisms across northwest Europe, it has been difficult to ascertain projected volumes that will be available in five and ten years after the completion of this project. This should be future work. However, given the vast amount of future plastic consumption, plastic in circulation and in landfill, if this is compared to the very small percentage now used for AM and IEM, this report sees no issues for the volume of supply for the foreseeable future.

## References

Accorsi, R., Versari, L., & Manzini, R. (2015). Glass vs. Plastic: Life Cycle Assessment of Extra-Virgin Olive Oil Bottles across Global Supply Chains. *Sustainability*, *7*(3), 2818-2840. https://doi.org/10.3390/su7032818

Afvalfonds Verpakkingen. (2020). *Monitoring Verpakkingen - Resultaten inzemeling en recycling 2019*.

Bergsma, G., Warringa, G., & Schep, E. (2017). *Kosten en effecten van statiegeld op kleine flesjes en blikjes*.

BPF. (2020). *Recycled content used in plastic packaging applications*.

BPF. (2021). *British Plastics Federation Roadmap*.

Buchhorn, T. (2022). *NWE plastic waste Inventry*.

Burrell, A., & Greenfield, D. (2021). *D.T1.2.1 - Collection Systems*.

Canopoli, L., Fidalgo, B., Coulon, F., & Wagland, S. T. (2018). Physico-chemical properties of excavated plastic from landfill mining and current recycling routes. *Waste Manag*, *76*, 55-67. https://doi.org/10.1016/j.wasman.2018.03.043

Cappucci, G. M., Avolio, R., Carfagna, C., Cocca, M., Gentile, G., Scarpellini, S., Spina, F., Tealdo, G., Errico, M. E., & Ferrari, A. M. (2020). Environmental life cycle assessment of the recycling processes of waste plastics recovered by landfill mining. *Waste Manag*, *118*, 68-78. https://doi.org/10.1016/j.wasman.2020.07.048

Conversio Market & Strategy GmbH. (2020). *Kunststoffrelevante Abfallströme in Deutschland 2019. BKV GmbH*.

Dornbusch, H. J., Hannes, L., Santjer, M., Böhm, C., Wüst, S., Dr. Zwisele, B., Dr. Kern, M., Siepenkothen, H.-J., & Kanthak, M. (2020). *Vergleichende Analyse von Siedlungsrestabfällen aus repräsentativen Regionen in Deutschland zur Bestimmung des Anteils an Problemstoffen und verwertbaren Materialien*.

Dr. Dornbusch, H.-J., Hannes, L., Santjer, M., Böhm, C., Wüst, S., Dr. Zwisele, B., Dr. Kern, M., Siepenkothen, H.-J., & Kanthak, M. (2020). *Vergleichende Analyse von Siedlungsrestabfällen aus repräsentativen Regionen in Deutschland zur Bestimmung des Anteils an Problemstoffen und verwertbaren Materialien*.

essencia. (2019). *The Belgian plastics industry and the circular economy - How far have we come?*

European Commission. (1997). Establishing the identification system for packaging materials pursuant to European Parliament and Council Directive 94/62/EC on packaging and packaging waste, .

European Commission, D.-G. f. E. (2021). *Turning the tide on single-use plastics*. Publications Office. https://doi.org/doi/10.2779/800074

Garmulewicz, A., Holweg, M., Veldhuis, H., & Yang, A. (2018). Disruptive technology as an enabler of the circular economy: what potential does 3D printing hold? *California Management Review*, *60*(3), 112-132.

Gesellschaft für Verpackungsmarktforschung mbH. (2008). *Gesellschaft für Verpackungsmarktforschung mbH. „Aufkommen und Verwertung von PET-Getränkeflaschen in Deutschland 2019." Mainz, 2008.*

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science advances*, *3*(7), e1700782. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5517107/pdf/1700782.pdf

Gov.UK. (2022a). *Introducing a Deposit Return Scheme (DRS) in England, Wales and Northern Ireland: Executive summary and next steps*. https://www.gov.uk/government/consultations/introducing-a-deposit-return-scheme-drs-for-drinks-containers-bottles-and-cans/outcome/introducing-a-deposit-return-scheme-drs-in-england-wales-and-northern-ireland-executive-summary-and-next-steps

GOV.UK. (2022b). *Plastic Packaging Tax: steps to take*. https://www.gov.uk/guidance/check-if-you-need-to-register-for-plastic-packaging-tax

Greenfield, D. P. (2020). *D.T1.1.1: The UK waste management system*.

Hahladakis, J. N., & Iacovidou, E. (2018). Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity? *Science of the Total Environment*, *630*, 1394-1400. https://doi.org/10.1016/j.scitotenv.2018.02.330

Morlok, J., Schoenberger, H., Styles, D., Galvez-Martos, J. L., & Zeschmar-Lahl, B. (2017). The Impact of Pay-As-You-Throw Schemes on Municipal Solid Waste Management: The Exemplar Case of the County of Aschaffenburg, Germany. *Resources-Basel*, *6*(1). https://doi.org/ARTN 8
10.3390/resources6010008

Mul, P. (2020). *D.T1.1.1: The Dutch waste management system*.
oecd. (2022). *Improving Plastics Management: Trends, policy responses, and the role of international co-operation and trade*. https://www.oecd.org/environment/waste/policy-highlights-improving-plastics-management.pdf
Oluwadipe, S., Garelick, H., McCarthy, S., & Purchase, D. (2022). A critical review of household recycling barriers in the United Kingdom. *Waste Management & Research*, *40*(7), 905-918. https://doi.org/Artn 0734242x211060619
10.1177/0734242x211060619
RDC Environment SA. (2019). *Analyse de la composition des ordures ménagères brutes et des déchets organiques collectés sélectivement en Wallonie Année 2017-2018*.
recoup. (2020a). BLACK PLASTIC PACKAGING FORUM Options for improving the recycling of black plastic packaging.
RECOUP. (2020b). *UK Household Plastic Packaging Sorting and Reprocessing Infrastructure*.
RECOUP. (2021). *The UK Household Plastics Collection Survey 2021*.
Rijkswaterstaat. (2021). *Samenstelling van het huishoudelijk restafval,sorteeranalyses 2020 - Gemiddelde driejaarlijkse samenstelling 2019*.
Shamsuyeva, M., & Endres, H.-J. (2021). Plastics in the context of the circular economy and sustainable plastics recycling: Comprehensive review on research development, standardization and market. *Composites Part C: Open Access*, *6*, 100168.
Simplify3D. (2022). *Ultimate 3D Printing Materials Guide*. https://www.simplify3d.com/support/materials-guide/
Snijder, L., & Nusselder, S. (2019). *Plasticgebruik en verwerking van plastic afval en Nederland*.
Standardization Administration of China. (2008). Marking of Plastics Products, . https://www.chinesestandard.net/PDF.aspx/GBT16288-2008
Stiftung Zentrale Stelle Verpackungsregister. (2020). Trendwende erreicht - Jahresbericht zur Transparenz beim Verpackungsrecycling. www.verpackungsregister.org/fileadmin/Auswertungen/Unterlagen_Pressekonferenz_ZSVR_18.11.2020.pdf
SUEZ. (2021). *Mapping the value chain for flexible plastic packaging in the UK*. https://www.suez.co.uk/en-gb/news/list-of-publications
Talon, O. (2020). *D.T1.1.1: The Belgian waste management system*.
Tomra. (2022). *AUTOSORT® The most powerful multifunctional sorting system worldwide*. https://www.tomra.com/en/solutions/waste-metal-recycling/products/autosort
Valipac. (2020). *Report annuel 2019*.
Valpak. (2020). PackFlow Covid-19 Phase I: Plastic.
Voulvoulis, N., Kirkman, R., Giakoumis, T., Metivier, P., Kyle, C., & Vicky, M. (2020). *Veolia Plastic White paper*. https://doi.org/10.13140/RG.2.2.12793.70241
Work Package. i2. (2021). *Deliverable 2.1: Municipal waste plastic diversion*.
WRAP. (2010). *Environmental benefits of recycling – 2010 update*. https://wrap.org.uk/sites/default/files/2021-02/WRAP-environmental-benefits-recycling-2010-update.pdf

WRAP. (2019a). *National municipal commercial waste composition, England 2017*.
WRAP. (2019b). National municipal waste composition, England 2017.
Zhang, F., Zhao, Y., Wang, D., Yan, M., Zhang, J., Zhang, P., Ding, T., Chen, L., & Chen, C. (2021). Current technologies for plastic waste treatment: A review. *Journal of Cleaner Production*, *282*, 124523.

## Appendix 1: Catalogue of Definitions from work package WT1 D1.1

| Definition | Country | |
|---|---|---|
| | Germany | UK |
| Waste *(Abfall)* | materials or objects which the owner discards, or intends to or is required to discard | (a) any substance which constitutes a scrap material or an effluent or other unwanted surplus substance arising from the application of any process; and<br>(b) any substance or article which requires to be disposed of as being broken, worn out, contaminated or otherwise spoiled |
| MSW *(Siedlungsabfälle*) | consists of wastes from private households as well as household-like commercial wastes and wastes from household-like institutions, such as law offices, administrative buildings, schools and kindergartens | "Regular" waste from non-industrial sources, such as residential homes, restaurants, retail centres, and office buildings. Typical MSW includes paper, discarded food items, and other general discards. Green waste is considered MSW and includes garden clippings, leaves, trees, etc. |
| Household waste *(Haushaltstypische Siedlungsabfälle, vorher Haushaltsabfälle)* | consists mainly of waste flows collected at private households including packaging and household-like commercial wastes when collected in the same collection system | WfH includes waste from:<br>• Regular household collection<br>• Civic amenity sites<br>• 'Bulky waste'<br>• 'Other household waste'<br>WfH excludes waste from:<br>• Street cleaning/sweeping<br>• Gully emptying<br>• Separately collected healthcare waste<br>• Soil, Rubble, Plasterboard & Asbestos waste |

| | | |
|---|---|---|
| | | It is a narrower measure than 'municipal waste' and 'council collected waste'. It was first published by Defra in May 2014. It was introduced for statistical purposes to provide a harmonised UK indicator with a comparable calculation in each of the four UK countries and to provide a consistent approach to report recycling rates at UK level on a calendar year basis under the Waste Framework Directive (2008/98/EC). |
| Residual waste *(Hausmüll oder Restmüll)* | consists of waste materials that are not collected separately in another waste flow, such as hygiene products, includes plastic, paper and organic contents due to false throws, waste originates from private households and partly C&I (household-like commercial waste), when collected in | |
| Household-like Commercial waste *(Überlassungspflichtige hausmüllähnliche Gewerbeabfälle)* | consists of commingled waste, which in its composition is very similar to residual waste from private households, it is legally obligatory to hand this waste over to public waste management authority | Commercial and Industrial waste. This is waste from mainly manufacturing and service industries. |
| Packaging waste *(Leichtverpackungen & Kunststoffe)* | separately collected packaging waste at household level including commercial share, consists of plastic, metals and composite materials and contamination, including bottles from deposit return system, excluding paper and cardboard | |
| Yellow bag waste *(Gelber Sack)* | All of the above-mentioned packaging waste except for bottles in the return deposit system | |
| Deposit return system *(Pfandsystem)* | collection system for mainly PET bottles with collection (machines) in supermarkets and other points of sale, surcharge on a product when purchased and a rebate when it is returned | |

| | | |
|---|---|---|
| Organic waste *(Abfälle aus der Biotonne)* | consists of food and kitchen wastes, small quantities of greenery and animal wastes, non-contaminated wood, in reality false throws of plastic and paper, collected at household level (kerbside collection) | Avoidable waste: Food and drink that is thrown away untouched or opened/started but not finished (e.g. whole apples, yoghurts, half loaves of bread, unused slices of bacon etc.) or food and drink we cook or serve too much of Possibly Avoidable waste: Food that some but not all people would eat (e.g. bread crusts) or that can be eaten when a food is prepared in one way but not in another (e.g. potato skins). Unavoidable waste: This is elements of food that has not been edible under normal circumstances, such as bones, cores, peelings eggshells, banana skins and teabags |
| Greenery waste *(Garten- und Parkabfälle)* | consist of larger quantities of biodegradable wastes from gardening activities such as parks and cemeteries, collected in bring system to central collection points | consist of larger quantities of biodegradable wastes from gardening activities such as parks and cemeteries, collected in bring system, kerbside systems or Household waste recycling Sites |
| Public waste management authority *(öffentlich-rechtlicher Entsorgungsträger)* | public authorities on the city/municipality level responsible for collection, treatment and valorisation of household wastes and household-like commercial wastes | Unitary Authority |
| System operator *(Systembetreiber)* | private companies responsible for collection, treatment and valorisation of packaging waste, activities defined in the German Packaging Law | Commercial contractor |
| Recovery | | 'any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function. |
| Recycling | | a subset of recovery and means 'any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material (e.g. composting, anaerobic digestion etc.) but excludes the use as fuels and the use for backfilling operations.' |

## About the project

The problems associated with plastic waste and in particular its adverse impacts on the environment are gaining importance and attention in politics, economics, science and the media. Although plastic is widely used and millions of plastic products are manufactured each year, only 30% of total plastic waste is collected for recycling. Since demand for plastic is expected to increase in the coming years, whilst resources are further depleted, it is important to utilise plastic waste in a resourceful way.

TRANSFORM-CE aims to convert single-use plastic waste into valuable new products. The project intends to divert an estimated 308.25 tonnes of plastic between 2020 and 2023. Two innovative technologies – intrusion-extrusion moulding (IEM) and additive manufacturing (AM) – will be used to turn plastic waste into recycled feedstock and new products. To support this, an R&D Centre (UK) and Prototyping Unit (BE) have been set up to develop and scale the production of recycled filaments for AM, whilst an Intrusion-Extrusion Moulding Facility, the Green Plastic Factory, has been established in the NL to expand the range of products manufactured using IEM.

Moreover, the project will help to increase the adoption of technology and uptake of recycled feedstock by businesses. This will be promoted through research into the current and future supply of single-use plastic waste from municipal sources, technical information on the materials and recycling processes, and circular business models. In-depth support will also be provided to a range of businesses across North-West Europe, whilst the insights generated through TRANSFORM-CE will be consolidated into an EU Plastic Circular Economy Roadmap to provide wider businesses with the 'know-how' necessary to replicate and up-scale the developed solutions.

**Lead partner organisation**
Manchester Metropolitan University

**Partner organisations**
Materia Nova
Social Environmental and Economic Solutions (SOENECS) Ltd
Gemeente Almere
Save Plastics
Technische Universiteit Delft
Hogeschool Utrecht
Hochschule Trier Umwelt-Campus Birkenfeld Institut für angewandtes Stoffstrommanagement (IfaS)
bCircular GmbH

**Countries**
UK | BE | NL | DE

**Timeline**
2019-2023

www.nweurope.eu/transform-ce