How circular are plastics in the UK?: Findings from Material Flow Analysis

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Globally, consumption of plastics has increased rapidly, reaching 350 Mt in 2017[1]. Trends in the UK have followed a similar pattern. Total consumption of plastics in the UK is around 6.3 Mt (own estimation), considering plastic products and plastic contained in other products. A large share of this, is disposed as waste. Concerns around the use of plastics and its disposal have emerged linked to inadequate end-of-life management of plastics and increased evidence of important leakage to the natural environment, suggesting the need to better align use of plastics to the principles of the Circular Economy. Lebreton et al[2] estimated that globally mismanaged plastic waste represent 60-99 Mt and estimation of leakage in Europe may be around 3.3%. In the UK, still a large fraction of plastics is sent to landfill (31%) or being incinerated (35%). A number of studies have already been undertaken to quantify plastics flows in the UK. Wrap[3] provides an overall picture of plastic flows in the UK, concluding that better capturing residual plastic flows could provide cost savings in the region of £82 million. A recent study by Eunomia[4] provides detail of plastic flows in key sectors of the economy. All these studies highlight important data gaps and uncertainty. Building on previous contributions, the present study has developed a comprehensive Material Flow Analysis for the UK addressing prior data gaps. The MFA provides detail of sector, waste composition and final destination. The aim of the MFA is to estimate current level of circularity of the plastic system and identify areas of inefficiency and leakage to natural systems. Preliminary findings from the analysis are presented in this paper. This work sets the basis for the definition of to measure the impact of alternative intervention pathways at different stages of the plastic life cycle, as future research steps. The analysis has highlighted important data gaps with regards to production, inter-sectoral consumption and plastic waste arisings. Estimations of plastic content in other products (textiles, electronics, etc.) relies highly on assumptions around plastic content. Data fragmentation and lack of consolidation across different databases results in increased uncertainty in the quantification of plastics flows, and, importantly plastic leakage to the environment, and thus calls for a better harmonization of production and waste data. Preliminary results from the analysis indicate that a large share of plastic waste is generated by industrial and commercial sectors (51%) while post-consumer waste, from households, also represents very important fraction of plastic waste (43%). While recycling of plastics has increased, a large fraction of plastics still ends up in landfill or incineration without energy recovery (around 53%) and this is likely to be an underestimation as plastics may also be mixed in unsorted fractions of waste not recovered. The paper concludes with a discussion of main areas of opportunity to increase circularity of plastics in the UK and some recommendations on data harmonisation.

Introduction

Rates of plastic use have grown exponentially since the 1950's, reaching 350 million tonnes (Mt) globally in 2017. In Europe, production of plastics has been estimated at 60 million tonnes in 2018, which is around a 17% of world's plastic production[1]. Most sectors in the economy consume plastics, being packaging, construction, textiles, EEE and automotive among most important applications. The advantages of plastics are many, being a cheap and versatile material, which has increasingly become present in numerous consumer goods, leading price reductions, better protection of goods, enabling trade, preservation of food, reducing food waste or improved health & safety linked to use of disposable plastic products in sectors such as health care. This increased use has raised issues around end-of-life management and waste leakage to natural ecosystems. A large share of plastic products are single-use or have short life spans, leading to increasing volumes of plastic waste. Mounting evidence of the damage created by leakage of plastic waste into the natural environments have raised concerns around sustainability of plastics. This paper aims to contribute to a comprehensive mapping of plastic flows in the UK, using Material Flow Analysis (MFA) as a main methodological approach. The MFA covers the whole cycle of plastic from primary polymers and fibres to consumption and end of life. It provides detail of sector, waste composition and final destination, and the scope encompasses all main sectors of the economy and all main applications of plastic. The paper has been organised as follows: section 2 summarises current state of the play in the

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literature with regards to the estimation of plastic flows; section 3 describes the methodological approach used and defines the model; section 4 summarises key preliminary findings from the research, and section 5 discusses implications for circularity from main findings and draws some conclusions and next steps.

Literature review

Growing concerns around the use of plastic and destination of plastic waste have resulted in numerous papers and reports in the area. The literature tends to focus on the destination of plastic waste, plastic entering the ocean and policy measures to increase circularity. MFA has been used in some of the recent contributions to measure the circularity of plastic flows at different levels of analysis and varied scopes.

Geyer et al[5] present an analysis of all plastics ever manufactured world-wide, combining plastic production data with product lifetime distributions for eight industrial sectors. They estimate that 8300 Mt have been produced as primary plastics up to 2015 since the creation of this type of material. From this, 30% is currently in use, 76% (6300 Mt) became plastic waste, and around 9% of which was recycled, 12% incinerated, and 79% was accumulated in landfills or leaked into the natural environment. A yearly approximation is given for 2015 by the same authors, where 407 Mt of primary plastics were manufactured from virgin materials and 302 Mt of plastic waste was generated. Lebreton et al[2] use country-level data on waste management and combine it with distributions and long-term projections of population and gross domestic product. They conclude that between 60 and 99 Mt of mismanaged plastic waste was produced globally in 2015, and this figure could triple to 155 – 265 Mt by 2060. Jambeck et al[6] associate solid waste generation data for 2010 with waste characterization information and estimate that 11.6% of global plastic waste is mismanaged and 1.7% to 4.6% of this waste entered the ocean, mostly leaked through rivers[2,7]. Modelled estimates show that over 0.25 Mt of microplastic particles have been accumulated in the world's ocean up to 2014[8,9].

At European level several recent studies have investigated the flows of plastics in the EU economy. Kawecki et al[10] use a probabilistic approach through Bayesian distributions to conduct an MFA for seven key plastic polymers in Europe, where PP represents the largest share of consumption, followed by LDPE, PET, HDPE, PVC, PS and EPS. Based on data of plastic mass flows and average plastic contents of semi-finished and final products, Van Eygen[11] report that about 1.3 Mt of total primary plastics were consumed in Austria in 2010, where 1.1 Mt were produced locally. Roughly one third of the consumed amount materialised as net additions to stock, and about half of this increase occurred in the construction sector, while packaging waste comprised around half of the total post-consumer waste. The Danish Environmental Protection Agency[12] provides a preliminary assessment of plastic flows in Denmark for 2016, based on existing data. They report that no synthetic polymers were produced in that country, and the difference between exports and imports resulted in a primary plastic consumption of 0.61 Mt. Landfill and incineration were reported as the prevailing waste treatments in Europe for all polymer types across all industry sectors[10], and a recycling rate of 31% and 22% were calculated for Austria and Denmark, respectively[11,12].

For the UK, recent years have also seen an increase in the number of reports studying plastic flows. Eunomia[13] provides an estimate of plastic packaging waste generation and suggests that current reported recycling rates for plastic packaging are overestimated almost by a factor of two. Root causes of this lie in how current EPR systems are organised, which create incentives to under-report plastic packaging put on the market and distort recycling rate calculations as the ratio from plastic packaging put on the market (in clean and dry form) and waste volumes sent to recycling (with higher moisture and cross-contamination). Also, Eunomia[4] produced a report tracing plastic flows covering the main sectors of plastic application (for macro-plastics) and estimated the release of micro-plastics into the environment from tyre wear and textiles. WRAP[3,14,15] has produced a number of reports focusing on plastic waste and plastic waste treatment in the UK. While much of the focus is on plastic packaging, the reports also provide some data on arisings and waste destinations of non-plastic packaging. Although the scope of these studies is similar to the current research, they do not provide a full life cycle overview of plastic flows. Methods and calculations also differ, especially with regards to the analysis of plastics content in products.

Methodology

Material Flow Analysis (MFA)

The methodology is based on a static Material Flow Analysis (MFA).MFA is a systematic analysis of the interactions between natural and socio-economic systems in a specific time and space boundary governed by the mass conservation principle[16]. MFA provides a description of flows and stocks in a system and, thus, helps to identify areas of potential inefficient use of resources. In the context of the circular economy, MFA has been used to assess the degree of linearity/ circularity of a system by tracking the flows of materials from extraction to final treatment and disposal. Typically, MFA of a specific material covers the full life cycle from primary extraction, to manufacturing, consumption, recovery and disposal[17].

System description

In this study we follow the flows of all plastic polymers from initial production of plastic polymers and fibres to final disposal and treatment. The system considers six main stages: production of primary polymers and fibres, manufacturing of semi-finished products, manufacturing of plastic products and plastic containing products, consumption by sector, waste collection and waste treatment. Trade movements, imports and exports, are considered at every stage of the plastics life cycle. Figure 1 describes the system boundary of the study. The temporal boundary is 2016, as the last most up-to-date and comprehensive statistical data year. The geographical boundary is the UK as a whole although data has also been compiled at local and regional levels to assess degree of completeness of national level data. From the production side, the scope of the study considers the production of primary polymers which will then be transformed into semi-finished products. Both semi-finished products and fibres are then transformed into plastic and plastic containing products. Consumption is calculated as the addition of all plastic products and plastic containing products manufactured in the UK plus net imports. Although there would be a small fraction of material lost at different stages during initial production of primary polymers and, more importantly, during manufacturing processes, these have been computed in the waste stage which differentiates between household (HH) post-consumer waste and industrial, construction and commercial waste. The consumption stage differentiates application of plastics by main sectors. A sector of 'other´ plastic products has been defined to group other smaller in share product categories. Imports and exports have not been computed at the consumption stage as are reflected in the trade of finished products. For the estimation of plastic contents in different product categories, data from previous reports[18-25] has been combined with own estimations based on market data (amazon, manufacturer websites, Environmental Product Declarations, etc.). The end of life stages have been divided between waste arisings (i.e. waste collection) and waste treatment, which indicates how the waste has been managed, what methods have been used for its recovery (i.e. recycling and energy recovery) and how much has been incinerated or disposed of without recovery (i.e. landfill). Similar to what was done for plastic-containing products, plastic fraction coefficients have been estimated from different academic and industrial sources[26-33] for the estimation of plastic fractions in waste types by NACE sector.. A number of uncertainties arise from these estimations as, for example, plastic content in textiles or EEE have grown considerably in recent years. Plastic fraction in waste is also a source of considerable uncertainty in the study as there are likely to be important local and regional differences in waste characterisation by sector and region.

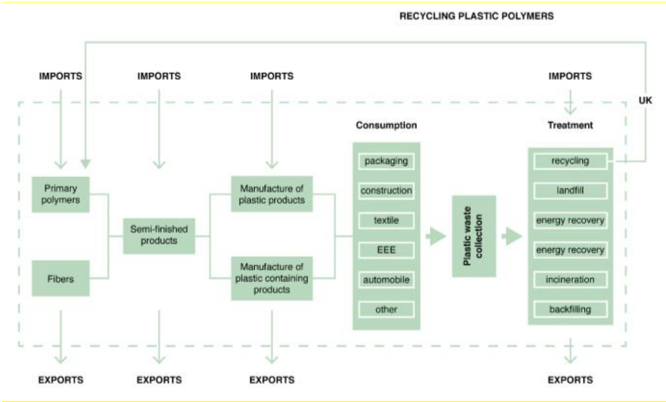

Figure 1: System boundary of the study.

Data sources

Main data sources in the analysis have been collated in the table below by MFA stage.

Table 1: Key data sources by MFA stage.

Life-cycle stage	Concept	Eurostat database
Production and Consumption	Primary plastics	Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data
	Fibres	
	Semi-finished plastic products	
	Finished plastic products	
	Plastic-containing products	
Disposal	Waste generation	Generation of waste by waste category, hazardousness and NACE Rev. 2 activity
	Waste import/export	Trade in recyclable raw materials by waste
	Waste treatment	Treatment of waste by waste category, hazardousness and waste management operations

Analysis

The overall MFA for the UK is represented in the Sankey Diagram below (Figure 2). The material flow diagram provides an aggregated representation of the plastic system in the UK, covering both the production, consumption and end of life phases. The analysis of each of these phases is briefly reported in the sections that follow.

Plastic production in the UK

In the UK, primary plastic polymers and plastic fibres are dominated by imported materials. Over 50% of primary polymers were imported, with negligible internal plastic fibre production. Around 3.6 Mt of raw materials were used for the production of semi-finished products. Semi-finished products group around 50 different product categories of semi-manufactured goods that will then be incorporated into different categories of finished products. Trade of semi-finished products results in positive net imports of almost 0.5 Mt.

In the case of finished manufactured products, the analysis distinguishes between plastic products (where the totality or a larger part of the product is made of plastic) and plastic containing products, which represents all other product categories which an important plastic fraction. Plastic-only products include around 110 categories of plastic products. Production of final manufactured plastic products in the UK is around 4 Mt, while total consumption (production + imports -

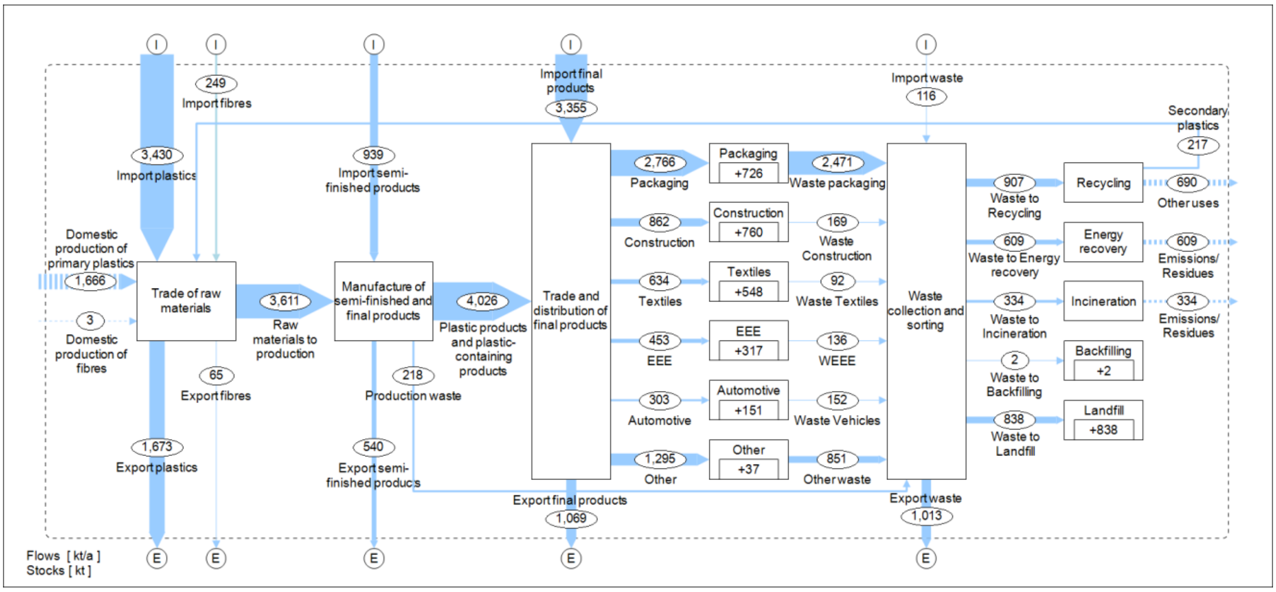

Figure 2: Material flow diagram of plastics in the UK for 2016.

exports) is estimated at 6.3 Mt. Endogenous production clearly dominates for plastic products, especially in the categories of packaging products, with an important UK production of plastic bottles and flasks, and construction plastic ware products.

For the calculation of plastic contained in other product categories, over 374 product categories were considered. Assumptions based on the literature, industrial and commercial reports were made to estimate plastic fraction for each product categories. These include textile products, luggage and handbags, footwear, paper products, paints and varnishes, tools, EEE and other electronic and IT equipment, specialised instruments and equipment, machinery, motor vehicles, sports goods, toys and furniture. Total plastic contained in these products has been estimated at 2.09 Mt. All these categories are clearly dominated by imports which represents around 94% by weight of total plastic contained in these products. UK production is only relevant in the case of motor vehicles (0.16 Mt), paints and varnishes (0.18 Mt) and electrical equipment (0.11 Mt).

Consumption of plastic in the UK

The consumption stage considers UK inward plastic applications by sector of activity. As shown in the material flow diagram above (Figure 2), leading sector of plastic applications are packaging (33%) and construction (10%), followed by textiles (7%), electronics (5%) and automotive and transport equipment (4%). All other applications across different sectors have been grouped in 'others' (15%), this includes among others agriculture plastics (see Figure 3 below).

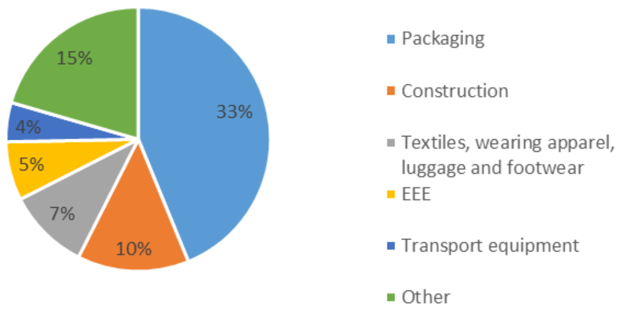

*Figure **Error! No text of specified style in document.**Plastic consumption by sector in the UK.*

In the case of packaging goods, most consumed applications include plastic bottles and plastic caps, capsules and other closures. Applications in construction include windows, doors and their frames and plastic shutters and blinds. Although the study did not consider the specific polymer composition of the products, building on the literature[10], it is possible to infer dominance of PP, PET and PE for packaging goods and PVC for construction applications.

The analysis also shows important additions to stock for plastic applications. This is especially important for the construction sector, as one would expect, and also for textiles, EEE and automotive. However, the analysis also computes around 25% additions to stock in the case of packaging. This can represent packaging of goods that are still in inventory but also reveal possible leakages of plastic packaging to the environment.

End of Life of Plastics in the UK

The end of life of plastic in the UK provides a good overview of the degree of circularity of plastic flows. The calculation of plastic waste arisings considers the plastic fraction for each waste type generated by NACE activity. The total plastic waste arisings are estimated at 5.3Mt, from which around just under

50% of it corresponds to plastic packaging. This figure is considerable higher than previous estimates (see[3]) which estimate plastic waste arisings at around 3.3 Mt (for 2013). This is partly explained by the scope of the study (as this one includes sectors like textile and health care), which were not considered in previous studies, as well as methodological differences, mainly linked to uncertainties in the calculation of plastic content in products and different plastic fractions in waste. Plastic applications were data available is better, such as packaging, provide similar estimates. Commercial and HH waste make up the large majority of plastic waste, followed by manufacturing, construction and agriculture (see Figure 4).

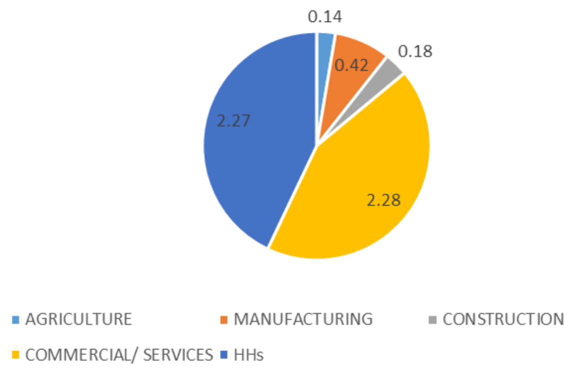

Figure 4: Waste generation (Mt) by waste source.

Waste undergoing treatment in the UK amounts to 2.7 Mt. These preliminary results report a very important difference between waste generation (current estimate at 5.3 Mt) and waste treatment (2.7 Mt), which may be explained by a number of factors: 1) waste treatment includes only waste treated in the UK, however a fraction of the waste will be exported to third countries for further processing (as discussed below) and therefore is not included here; 2) cross-contamination and differences in moisture content may explain differences between waste arisings and waste entering treatment operations; 3) treated waste will have gone through processes of sorting and drying, which would have reduced cross-contamination and volume; 4) another fraction of plastic waste may be included in other waste categories entering treatment and not accounted as plastic waste; 5) sectors with documented increasing use of plastics, such as construction, may result in accumulation in stock which will become waste in the future, and this may have led to overestimation of plastic waste arisings in sectors such as C&D and EEE and 6) a fraction of plastic waste will be leaked to the environment or lost in transit.

From the plastic waste entering treatment, around 34% is sent to recycling, followed closely by landfill (31%) as main route for non-recovery disposal. Energy recovery operations (R1) is after recycling the most common recovery route (at around 23%). Incineration of plastics is the option for around 12% of the plastics entering treatment (see Figure 5).

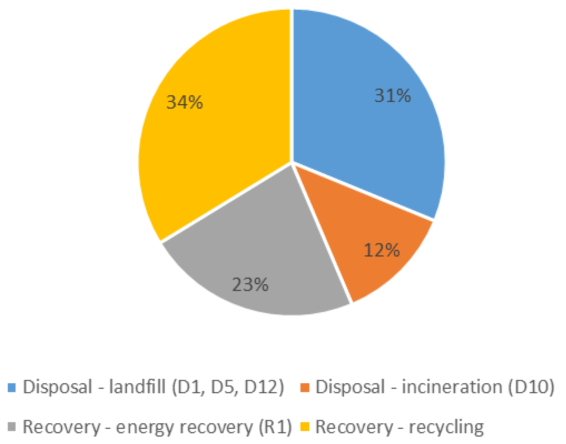

Figure 5: Waste treatment by waste managament operation.

An important fraction of plastic waste is sent for recovery outside the UK. This is segregated plastic waste, which complies with Waste Shipment Regulation requirements[18]. Net exports of plastic waste account for just under 1Mt (0.9 Mt), according to EUROSTAT data, which is just slightly higher than the plastic waste exports computed for 2020 for UN Comtrade database (0.8Mt). China and Hong Kong are still the main two destinations of plastic waste both by mass and value, but Malaysia and Vietnam have also evolved as major destinations of UK plastic waste. In the EU, the Netherlands and Germany are also very important destinations of plastic waste, mostly as feedstock for overcapacity of energy recovery operations in those countries.

Circularity and secondary markets

Preliminary findings of the analysis indicate that around 0.9Mt of plastics may enter recycling processes. Considering recycling losses of around 10-20% and a recycling efficiency of 90-95%, available secondary plastics for reprocessing could be in the region of 0.6-0.8 Mt. This is less than 10% of the total plastic consumed and around 6% if we include semi-finished products. This is close to other recent estimates such as EEA[19] which estimate that use of secondary plastics in the EU economy would be in that region.

Discussion and conclusions

Preliminary findings from the MFA above point to a largely linear plastics flow in the UK. Plastic waste sent to recycling processes makes only a small fraction of total plastics consumed (14%) and considerably smaller than what reported recycling rates seem to suggest. Plastic recycling rates are calculated for the packaging fraction and based on products on the market, providing an artificially larger percentage of recycling[13]. Around a tonne of plastic waste is exported; some of which may be recycled but traceability is difficult to follow. Evidence also suggest that plastic waste exports can be considerably higher considering exports of other waste which may contain plastic fractions (e.g. WEEE).

Recycling rates of plastics are not straightforward to calculate as plastic content by type of product differs and there is a lack of harmonised methodologies to monitor plastic waste. Only for the UK, recent estimates of plastic arisings and recycling rates differ. Our study provides an estimate of plastic waste arisings considerably higher than the figure estimated by WRAP[3]**.** This can be explained through differences in the scope and assumptions around plastic fractions in products. There is also considerably uncertainty with regards to the final destination of plastic waste. While traceability of plastic packaging subjected to Extended Producer Responsibility schemes is better monitored, plastic fractions in other waste streams are more difficult to trace, possibly leading to overestimation of plastic recycling.

The difference between plastic consumption (6.3 Mt), waste arisings (5.3 Mt) and plastic waste treated (3.8 Mt considering exports) estimated for the UK, is high but also consistent with other studies published at the EU level[36]**.** The gap between waste arisings and waste treated is partly the result of how data is collected and the fact that segregation and drying processes take place between different fractions that are sent to treatment operations.

In terms of plastic waste destinations, the UK estimates are also consistent with EU destination of plastic waste. The share of plastic waste sent to landfill is both 31% for the EU and the UK, while energy recovery in the UK is significantly lower than the EU average (39%). This is partly explained by the treatment capacity mix differences between EU and the UK, with important energy recovery capacity in Northern European countries.

Increasing recycling rates faces several barriers ranging from: low profitability of plastic recycling, due to weak demand for recyclate plastic; high uncertainty linked to volatile price of primary plastics; and technical difficulties in managing and dealing with complex composite designs and the wide range of plastic polymers on the market. This leads to a loss in the material integrity and value of plastics at the end of their first life, which has been estimated as an economic loss of between EUR 70-105 billion annually[36]**.**

From a circular economy perspective, solutions to plastic waste should consider simultaneously: material traceability; design of products; end-of-life management; and final treatment. EU policy respond to increasing concerns around plastic waste led to the adoption, in 2018, of European Strategy for Plastics in a Circular Economy, which lays the foundations for better design, production, use and recycling of plastics[36]. Among its key measures, it introduces a binding target for all packaging to be recyclable by 2030, and also increases the target for plastic waste recycling to 50%. The current BREXIT process, poses questions around the commitments for plastic waste, but the DEFRA 'our waste, our resources: A strategy for England' suggest that the UK will match EU commitments in this area with the aim to eliminate 'avoidable plastic waste' in the timeline of the 25 year Environment Plan. This is partly supported by the 'UK Plastic Pact' which proposes a collaborative framework across supply chain stakeholders to achieve very ambitious targets for plastic packaging including increasing recyclability (100% reusable, recyclable or compostable), improving recycling (70% high quality recycling) and promoting use of secondary markets through recycled content targets. This certainly provides incentives into the right direction to improve circularity but also requires investments to increase recycling capacity, further work in the development and consolidation of a secondary market for recycled plastics, and requires further action to improve end of life of biodegradable and compostable packaging.

To conclude, the analysis has shown that there are still important gaps in measuring the circularity of plastic flows. Data gaps increase uncertainty in the calculation of plastic consumed, additions to the stock and waste arisings. Treatment data is based on inputs to the different treatment routes but outcomes of treatment processes are not well understood. The circular economy for plastics requires a comprehensive and holistic approach to rethink the production (including sources of feedstock), use, recovery and final disposal, to create systems that minimize not only resource use, but also importantly, environmental impact of the overall system.

Conflicts of interest

There are no conflicts to declare.

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References

1 PlasticsEurope, *Plastics–The Facts 2019. An analysis of European plastics, production, demand and waste data*, 2019.
2 L. Lebreton and A. Andrady, Future scenarios of global plastic waste generation and disposal. *Palgrave Communications*, 2019, 5(1), 1-11.
3 H. Thomson and P. Sainsbury, *Plastics Spatial Flow–An assessment of the quantity of un-recycled plastic in the UK*, 2016.
4 J. Royle, B. Jack, D. Hogg, T. Elliot and A. Bapasola, *Plastic Drawdown: A new approach to identify and analyse optimal policy instruments to reduce plastic pollution in UK rivers and seas*, 2019.
5 R. Geyer, J.R. Jambeck, and K.L. Law, Production, use, and fate of all plastics ever made. *Science advances*, 2017, 3(7), e1700782.
6 J.R., Jambeck, R. Geyer, C. Wilcox, T.R. Siegler, M. Perryman, A. Andrady, R. Narayan and K.L. Law, Plastic waste inputs from land into the ocean. *Science*, 2015, 347(6223), 768-771.

7 L. Lebreton, J. Van Der Zwet, J.W. Damsteeg, B. Slat, A. Andrady, and J. Reisser, River plastic emissions to the world's oceans. *Nature communications*, 2017, 8, 15611.
8 M. Eriksen, L.C. Lebreton, H.S. Carson, M. Thiel, C.J. Moore, J.C. Borerro, F. Galgani, P.G. Ryan and J. Reisser, Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PloS one*, 2014, 9(12), e111913.
9 E. Van Sebille, C. Wilcox, L. Lebreton, N. Maximenko, B.D. Hardesty, J.A. Van Franeker, M. Eriksen, D. Siegel, F. Galgani and K.L. Law, A global inventory of small floating plastic debris. *Environmental Research Letters*, 2015, 10(12), 124006.
10 D. Kawecki, P.R. Scheeder and B. Nowack, Probabilistic material flow analysis of seven commodity plastics in Europe. *Environmental Science & Technology*, 2018, 52(17), 9874-9888.
11 E. Van Eygen, J. Feketitsch, D. Laner, H. Rechberger and J. Fellner, Comprehensive analysis and quantification of national plastic flows: The case of Austria. *Resources, Conservation and Recycling*, 2017, 117, 183-194.
12 K. Pivnenko, A. Damgaard and T.F. Astrup, *Preliminary assessment of plastic material flows in Denmark–Technical Report*, 2019.
13 Eunomia, *Plastic Packaging–Shedding light on the UK Data*, 2018.
14 H. Thomson, K. Illingworth, H. McCoach, M. Jefferson, S. Morgan, *PlasticsFlow 2025–Plastic Packaging Flow Data Report*, 2018.
15 WRAP, *Plastics Market Situation Report 2019*, 2019.
16 P.H. Brunner and H. Rechberger, *Practical Handbook of Material Flow Analysis*, CRC press, 2004.
17 P.C. Deshpande, G. Philis, H. Brattebø and A.M. Fet, Using Material Flow Analysis (MFA) to generate the evidence on plastic waste management from commercial fishing gears in Norway. *Resources, Conservation & Recycling*, 2020, X 5, 100024.
18 N. Kanari, J. L. Pineau and S. Shallari, End-of-life vehicle recycling in the European Union. *Jom*, 2003, 55(8), 15-19.
19 Swedish Chemicals Agency, *Commodity Guide*, 2007. http://webapps.kemi.se/varuguiden/varugruppermaterial.aspx
20 D. Panaitescu, M. Iorga, A. Ciucu, S. Serban, A. Crucean and C. Bercu, New methods for recycling plastic materials from end-of-life vehicles. *WSEAS Transactions on Environment and Development*, 2008, 4(12), 1009-1108.
21 L. D. Whigham, D. A. Schoeller, L. K. Johnson and R. L. Atkinson, Effect of clothing weight on body weight. *International Journal of Obesity,* 2013, 37(1), 160.
22 M. C. Vats and S. K. Singh, Assessment of gold and silver in assorted mobile phone printed circuit boards (PCBs). *Waste management*, 2015, 45, 280-288.
23 A. Asayesh, F. Mirgoli and A. Gholamhosseini, An investigation into the effect of fabric structure on the compressional properties of woven fabrics. *The Journal of The Textile Institute*, 2018, 109(1), 32-38.
24 "Forti V., Baldé C.P., Kuehr R. (2018).
25 V. Forti, K. Baldé and R. Kuehr, *E-waste Statistics: Guidelines on Classifications, Reporting and Indicators*, 2018.
26 M. L. Casares, N. Ulierte, A. Mataran, A. Ramos and M. Zamorano, Solid industrial wastes and their management in Asegra (Granada, Spain). *Waste Management*, 2005, 25(10), 1075-1082.
27 T. L. Tudor, C. L. Marsh, S. Butler, J. A. Van Horn and L. E. T. Jenkin, Realising resource efficiency in the management of healthcare waste from the Cornwall National Health Service (NHS) in the UK. *Waste Management*, 2008, 28(7), 1209-1218.
28 D. Knapman, *Construction, demolition and excavation waste arisings, use and disposal for England 2008*, 2010.
29 C. Bartlett, I. McGill and P. Willis, *Textiles flow and market development opportunities in the UK*, 2012.
30 A. Villanueva, P. Eder, *End-of-waste criteria for waste plastic for conversion. Institute for Prospective Technological Studies*, 2014.
31 A. Buekens, J. Yang, Recycling of WEEE Plastics: A Review. *Journal of Material Cycles and Waste Management,* 2014, 16(3), 415–434.
32 J. Havukainen, S. Heikkinen and M. Horttanainen, Possibilities to improve the share of material recovery of municipal solid waste in Finland. *LUT Scientific and Expertise Publications/Tutkimusraportit–Research Reports*, 2016.
33 W. Mashek, K. Holmes and K. Martin, *Automotive Recycling: Devalued Is Now Revalued*, 2016.
34 Commission Regulation 1013/2006 on shipments of waste, *Official Journal L 190*, 2006, 1.
35 C.H. Wilts and I. Bakas, *Preventing plastic waste in Europe*, 2019.
36 HM Government, *Our Waste, Our Resources: A Strategy for England*, 2018.

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