Plastic packaging - How do we get to where we want to be?

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Cover photo: from the picture repository of the RRFW Programme

EXECUTIVE SUMMARY

Plastic waste has been recognised as a threat to the UK's environmental quality, with a range of potential impacts on ecosystems, the economy and human-wellbeing. The UK government via its 25 Year Environment Plan and the recent Resources and Waste Strategy has committed itself to eliminating avoidable plastic waste by 2050. The Government has set ambitious targets for minimising the amount of plastic packaging and improving the plastic packaging recycling rate, while increasing the recycled content of plastic packaging. Government proposals aimed at reaching these targets include the introduction of a tax on plastic packaging with less than 30% recycled plastic, a deposit return scheme for plastic drinks containers, the development of an Extended Producer Responsibility (EPR) system for packaging, and the acceleration of plans to improve consistency in the type of recyclable materials collected from all households and businesses in order to engage citizens in the processes of meeting environmental policy goals.

This report produced by an interdisciplinary team at Brunel University London and the University of Leeds in collaboration with Defra, analyses the plastic packaging system in England and identifies new metrics that can be used for monitoring and assessing progress in meeting the targets set by the Government. It does so by employing a new multidimensional systems based approach termed 'Complex Value Optimisation for Resource Recovery' (CVORR) that supports understanding of how the various policy interventions, current and planned, need to be coordinated to deliver the desired outcomes.

Analysis of the Plastic Packaging System in England

The report analyses the structures, processes, commercial opportunities and constraints that make up the current UK system for the management of plastic packaging waste. The analytical scope is restricted to the plastic packaging collected by local authorities (LAs) in England, known as local authority collected municipal waste (LACMW). The focus is on positive and negative impacts created, destroyed and distributed in the plastic packaging system in the four domains of value; environmental, economic, social and technical.

The analysis revealed that:

- Plastic packaging waste that is left uncollected can cause serious harm to ecosystems, leading to a significant net negative value creation. This is exacerbated by value loss associated with the inappropriate disposal of plastic packaging waste via littering and fly-tipping.
- A considerable proportion of plastic packaging waste including films, some pots, tubs and trays (PTTs), black plastics, and multi-layered and laminated plastics, are not recycled in some LAs in England, leading to additional value loss.

- The long-term contracts that LAs make with waste management contractors make it difficult to implement changes in waste infrastructure; the contracts effectively 'lock-in' technology and processes. For example, LAs need to consider the contractual constraints and costs involved in any changes to collection services, which may outweigh the wider benefits of those changes.
- Austerity has brought divergent implications for waste collection and management at the LA level, and Brexit is likely to bring more instability in the way waste management services are provided.
- Confronting and breaking the lock-ins to current regulations and infrastructures is key to achieving more sustainable transformations in the resource recovery systems and improving the plastic packaging system specifically.
- Investments in infrastructure required to deliver on the targets set by the government, depend on profitability, which in turn depends upon various factors along the value chain, such as sorting ability at household level, constant flows of inputs and outputs, stable commodity prices, and compliance with legislation. Each of these aspects of the system must be addressed if investments are to succeed.
- Exports of plastic packaging waste for recycling are likely to contribute to negative value creation, as destinations tend to be countries with questionable waste infrastructure and weaker, less reliable institutions to control the management of that waste.
- Ambiguities in the way regulations that govern the plastic packaging system in England are interpreted at local government level, and inconsistent implementation of fiscal instruments and enforcement have caused failures in the system that have a negative impact on the management of plastic packaging waste and associated value creation.
- The current producer responsibility system implemented in the UK overburdens LAs with the cost of collection and management of plastic packaging waste, offering very little (if any) cost compensation. It also hampers infrastructure investment due to uncertainty over cost returns leading to a growing dependence on export markets, and encourages a lack of transparency regarding the sale of evidence notes and the way income therefrom supports recycling of packaging waste.
- Volatile markets for waste products can reduce the expected revenues associated with operating a waste treatment facility and the expected investment returns, hence diminishing recycling activities.
- Consumers' decisions on how to dispose plastic packaging waste impacts on the waste management operations and the fate of the plastic packaging waste, but consumers are unaware of the true environmental costs that arise from plastic packaging waste.
- Product information and recycling symbols on packaging, as well as the different rules about what can and cannot be recycled applied in different areas in England, often leads to confusion and misinterpretation, which may impact on the quantity and quality of plastic packaging waste collected for recycling.

Identification of New Metrics for Assessing and Monitoring Government Targets

Drawing on the analysis, an initial list of proposed metrics was developed. The aim was to identify metrics that would be suitable as potential means to gain insights into the business-as-usual situation in relation to the desirable goals; as measures of progress towards the achievement of current and future policies (assessment); and as means to track the progress of new policy measures and process changes in England in the long-term new initiatives (monitoring).

A total of 12 metrics were proposed. Each metric was categorised as falling within a particular value domain, measuring either environmental value (4 metrics), technical value (3 metrics), economic value (2 metrics) or social value (3 metrics). The initially proposed metrics were presented at an expert workshop that aimed at reducing the proposed list down to a final list of four selected metrics; one from each domain of value. As a result of the expert workshop, the following metrics were selected:

- ***Reprocessing efficiency*** **(environmental domain)** - measures the proportion of plastic material that is reprocessed into secondary material within the UK
- ***Percent losses for sorting facilities*** **(technical domain)** - measures the losses and rejections of plastic packaging waste sent to sorting facilities (i.e. MRFs and PRFs)
- ***Cost efficiency*** **(economic domain)** - measures the cost that can be avoided and/or the revenue that can be captured at an increased recycling rate
- ***Inequality*** **(social domain)** - measures the allocation of costs (and incomes) produced by the recycling process in the overall system, in order to identify the misalignment between cost-bearing (e.g. government) and revenue allocation activities

These metrics were selected on their merits to capture systemic aspects that are otherwise overlooked, especially in regards to changes in the design of plastic packaging and investments in upgrading the technologies used in material and plastic recovery facilities, both of which are reflected by improvements in sorting and reprocessing efficiency. Other aspects that the selected metrics anticipate to capture are insights on the costs that can be avoided and/or the revenue that can be generated if recycling of plastic packaging waste is increased.

The expert workshop also made the following two general suggestions regarding metrics:

- Disaggregation of the analysis to polymer types, and into primary and secondary plastic, would make the assessment more useful.
- Economic metrics used by the government should provide insights into which stakeholders in the value chain bear the actual costs of plastic packaging waste management and who profit from it in order to put in place the right instruments to support change and allocation of benefits.

Concluding reflections: the need for a holistic and coordinated approach to policy intervention

The use of the CVORR approach in the report highlights that understanding the processes, stakeholders and complex value involved in the plastic packaging system aids in identifying ways to better connect the downstream with the upstream part of that system. By contrast siloed-thinking that promotes change in one or two parts of the system only, or that focuses only on one value domain (e.g., economic) but not others (e.g., technical) cannot bring systemic change, but may lead to problem shifting elsewhere in the system.

Interventions need to be done through orchestrating the flows of complex value across the plastic packaging system as a whole. This requires regulators and local government to work together with brand designers, manufacturers, importers, wholesalers, retailers, waste management companies, recyclers, consumers and other organisations (e.g. trade-unions, associations, NGOs) to coordinate their actions and make it feasible to maintain progress achieved in waste and resource management sector; promote technological innovation and investment; implement transparent environmental policies; and use information based instruments to raise the social responsibility of businesses and individuals.

The one thing that this report highlights is that there is no one perfect solution, but many well-targeted and informed ways of addressing the multidimensional impacts, as revealed by our system based approach. In our view, assessing and improving the plastic packaging system as a whole across the political, economic, social, environmental and technical domains of value, is the only viable pathway to achieving the desired sustainability goals.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

According to recent statistics, in 2017 UK households and businesses generated around 2.63 million tonnes (Mt) of plastic packaging waste, which reflects the amount of plastic packaging placed on the market (POM) (WRAP, 2018). Other reports suggest that the amount of plastic packaging waste generated is likely to be around 3.5 Mt (a figure estimated based on a range of assumptions), or 67% of the 5 Mt of plastic placed onto the UK market each year (Elliott and Elliott, 2018). This data discrepancy can be allotted to poor data availability, evident also by the lack of robust information on the sources and types of plastic packaging waste generated and reported (WRAP, 2018).

The principle formats of plastic packaging are bottles, films (incl. carrier bags), and pots, trays and tubs (PTTs). According to the source plastic packaging waste can be categorized into *consumer* and *non-consumer* plastic packaging waste. Non-consumer plastic packaging waste refers to all plastic packaging found in the commercial and industrial waste streams, as well as in other sectors such as in agricultural and construction, (e.g. drums, pallets, crates, pipes, shrink wrap) (WRAP, 2013). Consumer plastic packaging waste is the packaging discarded by consumers *in the household*, *at places of work* and *on the go*[1]*,* which includes any packaging taken from cafes, shops or from home and those disposed of in the street bins as litter. Consumer plastic packaging accounts for 68% of plastic packaging used in the UK (Valpak, 2011).

The collection and management of plastic packaging waste is a complex matter. It involves multiple stakeholders, and operates under a combination of different interventions, from collection and taxation schemes, to legislation, infrastructure and commercial viability that currently influences and sometimes hinders improvements in the plastic packaging recycling rate. To improve the plastic packaging waste recycling rate, there is a need to examine the way the plastic packaging system operates and the role of various stakeholders within. This can generate useful insights on broader systemic aspects that govern and control the amount of plastic packaging waste produced and used, discarded, collected, sorted and managed in order to improve and promote sustainable resource recovery.

In the UK, waste management is a devolved matter. Scotland, Wales and Northern Ireland are each responsible for the waste and packaging policy, and the respective governments of Scotland and Wales have set ambitious targets in the area of plastic waste. In England, the Department for Environment, Food and Rural Affairs (Defra) is responsible for waste and packaging policy as well as for monitoring the overall progress against the UK-wide packaging

[1] This does not include plastic packaging waste disposed of in commercial buildings such as offices or through hospitality operations back of store.

recycling targets. The Environment Agency (EA) is responsible for enforcing the regulations (National Audit Office, 2018). Under the Environmental Protection Act 1990, local authorities (LAs) in England have the legal responsibility of waste collection and management (UKELA, 2018, LARAC, 2018).

In its 25-year Environment Plan, published in 2018, the UK government has placed increased attention on plastics, making commitments to encourage the recycling of plastic in the UK and eliminate avoidable plastic waste by the end of 2042 (HM Government, 2018). This has recently been strengthened in the Waste Strategy for England where ambitious targets have been set for increasing the plastic packaging recycling rate via a number of proposals, such as introducing a tax on plastic packaging with less than 30% recycled plastic, a deposit return scheme, and consistency in the type of recyclable materials collected from all households and businesses, amongst others (Defra, 2018d).

In 2018 the UK Plastics Pact, a voluntary agreement to tackle the issue of plastic waste through collaboration across the entire supply chain, has set a number of ambitious targets to be reached by 2025. Among these targets, are the need to increase the recycling and composting of plastic packaging to 70% by 2025, and increasing the average recycled content in all plastic packaging to 30% by 2025. Meeting these targets may require considerable changes in the way that plastic packaging is produced and used, and managed when it becomes waste.

As a result, the UK government wishes to understand the way the plastic packaging waste system operates in England and make long-term improvements to recycling efficiency. To that end, the identification and/or development of metrics that can help the government to better measure and monitor changes in the plastic packaging system, is considered to be amongst their key priorities. This project will support the local and national government's challenge to assess and monitor the plastic packaging production and plastic packaging waste management system in England, using the Complex-Value Optimisation for Resource Recovery (CVORR) approach.

CVORR is a novel, conceptual framework for understanding systems and aiding transitions towards a resource-efficient future, developed by a group of academics at the University of Leeds (Iacovidou et al., 2017a). In this report we apply CVORR to support public policy improvements and processes at national and local government, helping the UK become a "zero avoidable waste" economy by 2050.

2. BACKGROUND

Current waste management policy and practice needs to depart from the linear approach of make-use-dispose and move towards more efficient ways of recovering value from waste that promote sustainability. Efforts are largely concentrated on the recovery of resources from waste based on the consideration of environmental and/or economic values. This is influenced by the national and trans-national environmental legislation and its desirable and undesirable impacts on the economy, which poorly account for unwanted effects in other domains of value (i.e. social and technical) (Iacovidou et al., 2017a).

CVORR addresses this issue by going beyond the individualistic abstractions of standard economic theory, to recognise that value is created and destroyed in a social process in which production, consumption and resource recovery are integrally linked. This helps to prevent unintended consequences and problem-shifting, and it can benefit concurrently the society, economy and the environment by delivering global optimal resource recovery solutions (Iacovidou et al., 2017a).

In essence CVORR is a systems thinking approach that helps in understanding and reforming resource and waste management patterns throughout supply chains. It describes, monitors, forecasts and evaluates all significant values and trade-offs in an integrated and holistic manner. This approach provides a less abstract, more realistic and practical appreciation of economic, societal and governance processes as materially conditioned by technical and environmental conditions. It catalyses the development of new business opportunities that exploit previously overlooked residual value hiding in waste material, component and product systems. It looks beyond end-of-pipe solutions, examining both upstream and downstream parts of the waste producing system.

In the CVORR approach, complex value refers to the positive and negative changes in the social, environmental, economic, and technical domains of value, as influenced by political and organisational aspects (Iacovidou et al., 2017b). The political, institutional and organisational aspects that govern resource recovery systems, represent the landscape where processes, stakeholders and values are situated in, and thus do not represent a domain of value.

The complex nature of the waste-producing systems makes it difficult to keep all values in focus. Selecting a few, key values to assess resource recovery systems, and representative metrics with which they can be measured, is important for enabling the tracking and assessment of a system's performance over time.

In the CVORR approach, the metrics that are used to represent values must be selected from all four domains (i.e. environmental, economic, social and technical), to account for the economic, social and technical structures required to support policy interventions in the

analysed resource recovery system. This multi-dimensional evaluation of a resource recovery system uncovers critical interrelationships between different parts of the system, which can be exploited to optimise the system as a whole, and identify, attribute and distribute the multi-dimensional value generated to all stakeholders involved.

In addition to the above principles, it is important to note that engagement with policy makers, industry and citizens is fundamental for a successful implementation of the CVORR approach. It reveals ill-understood factors arising from micro-scale practices of individual production or waste management facilities, and peoples' consumption and disposal patterns. It helps to uncover misleading messages conveyed to businesses, policy and decision-makers that often lead to the implementation of ineffective measures (Iacovidou et al., 2017a).

As a result, in CVORR the metrics selection process is both system- and stakeholder-specific and support the measurement of key environmental, social, economic and technical values for systemic assessment and evaluation. In this report we provide our first insight into this selection process.

2.1. SPECIFIC OBJECTIVES

Using England as a case study, this report focuses on understanding the plastic packaging system's performance. Specifically, it will:

- Apply the CVORR approach to uncover the social/behavioural, economic, environmental and technical drivers and the role of key stakeholders in the production, use and end-of-life management of plastic packaging, and identify metrics that can be used to support multi-dimensional valuation of the plastic packaging system;
- Aid the selection of key metrics for the plastic packaging system evaluation using the CVORR metrics selection framework, supporting waste policy changes that generate long-term impact in the UK.

3. APPLYING THE CVORR APPROACH

To apply the CVORR approach a number of key steps are required for developing a dynamic, flexible, fully transparent valuation as outlined in the CVORR framework. The purpose of the framework is to streamline the process of connecting upstream and downstream processes involved in resource recovery systems, making trade-offs explicit and eliminating partial and/or double-counting. Through this novel way of assessment, CVORR provides guidance as to where successful interventions (i.e. changes to, elimination of, or collaboration between processes) can be made, in order to enable the transition to more sustainable and long-sighted systems of production and consumption.

Continuous understanding of environmental, technical, economic, societal and governance processes and their interdependencies led to improvements on the CVORR framework. Since its first publication (Iacovidou et al., 2017a), CVORR has evolved (Figure 3-1) to make sure that it captures all aspects that have to be taken into account in resource recovery systems assessment. In the following sections we describe how this is used to guide us though unpacking the specificities of the plastic packaging system in England.

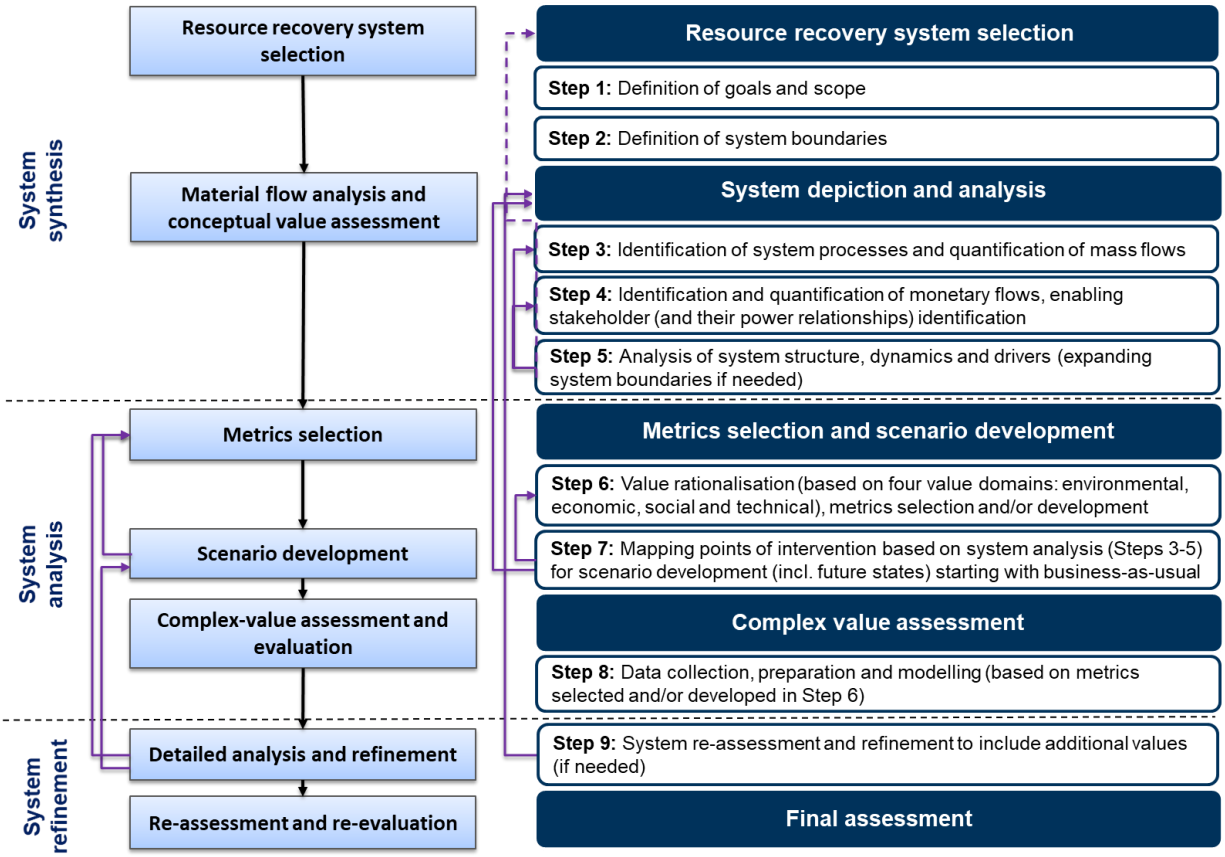

Figure 3-1 The CVORR framework; the original version of the framework (adapted by Iacovidou et al. 2017) is presented on the left, and its evolved, current form is presented on the right

The CVORR framework can guide the end-user through the process of mapping the main processes and flows - both mass- and monetary-based flows – related to plastic packaging. This is useful in gaining insights into the system structures, dynamics and drivers, and informative in understanding who are the key stakeholders involved in the system. The steps included in the system synthesis part of the framework (Steps 1-5) constitute the CVORR *baseline analysis*; mandatory for a holistic resource recovery system analysis.

Understanding the system structure, dynamics and drivers of current practices, or the change thereof, helps to understand changes in value related to physical entities and their relationship with space. This is critical in conceptualising the importance of governance and political support in facilitating resource recovery and enabling waste producing systems to become circular where feasible and sustainable in the long-term.

Circularity of materials, components and products in resource recovery systems is not necessarily sustainable. Therefore attention is needed in the selection of values critical in assessing the sustainability of the resource recovery system under assessment. Understanding which values need to be measured for assessing and monitoring progress in the plastic packaging system's performance and sustainability, can help us rationalise and select the metrics that are best suited to achieve that goal.

4. UNPACKING THE PLASTIC PACKAGING SYSTEM IN ENGLAND

4.1. RESOURCE RECOVERY SYSTEM SELECTION

Recycling is considered to be the most sustainable option for the management of plastic packaging waste that cannot be avoided. According to WRAP, in the UK, a third of post-consumer plastic packaging is considered to be currently recycled (WRAP, 2018b). This figure is in line with the figures reported in a recent WWF report where 29% of single-use plastic packaging waste generated is estimated to be collected for recycling (Elliott and Elliott, 2018). In the latest UK Waste Digest report plastic packaging recovery/recycling rate is reported to be 39.4% in 2015, and provisionally up to 44.9% in 2016 (Defra, 2018a). The latter figure is in line with the recycling rate reported by the British Plastics Federation (BPF) reports which is 45% (1,015,000 tonnes) of all plastic packaging used in the UK in 2016 (BPF, 2018). However, a distinction between recovery and recycling appears to be unclear or unaccounted for.

In the EU recycling is defined as any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes and may include composting or digestion. This definition excludes energy recovery or reprocessing into materials that are to be used as fuels (EU, 2011). Nonetheless, variations in the calculation methods employed by each member state, can lead to deviations in the actual amount of waste reported as recycled (EEA, 2019). For example, the amount (weight) of material lost or rejected during the recycling process is often included in the recycling figures, whereas the recovery and recycling rates may be reported under one figure making it difficult to distinguish between the two (Defra, 2018b).

For the UK to improve the plastic packaging recycling rate, there is a need to investigate how much plastic packaging waste is actually collected for recycling, i.e. amount of plastic packaging collected for conversion into secondary plastic material, and how much is eventually reprocessed into products within the UK, or exported for recycling into products elsewhere. This investigation is crucial in the design of viable and sustainable interventions, and for policy improvements in increasing the recovery of value from plastic packaging waste. Table 4-1 outlines the focus and scope of the work presented in the report.

Table 4-1 Resource recovery system selection details

DESCRIPTION	*COMMENT*
PROBLEM DEFINITION	Low plastic packaging recycling rates and loss of value
OBJECTIVES	Based on the targets set by the UK Plastics Pack, UK to increase the: • Recycling of plastic packaging waste to 70% by 2025, • Average recycled content in all plastic packaging to 30% by 2025.

DESCRIPTION	*COMMENT*
SYSTEM SELECTION/ BOUNDARIES	Plastic packaging system in England
FOCUS	Plastic packaging that is collected by local authorities (LACMW)
SCOPE	Propose metrics for the plastic packaging system assessment and monitoring

Using England as a case study, the project will estimate the recycling rate of plastic packaging and investigate its fate from the point of its disposal, to its final destination (Table 4-1). It is important to note that this report focuses on petrochemical-based plastic packaging; yet small amounts of biobased polymers are also likely to be present in the system.

In the following sub-sections we will attempt to examine the interlinkages between the different stages in the plastic value chain and consider multi-dimensional issues relating to resource recovery from waste, as well as broader issues occurring within and outside of England. This analysis will support the scope of proposing new metrics for assessing and monitoring progress in improving the plastic packaging recycling rate.

4.2. SYSTEM DEPICTION AND ANALYSIS

In the CVORR *baseline analysis*, the 'system depiction and analysis' is a crucial stage in ensuring the successful assessment of the system. It is highly dependent on a clear definition of the problem at hand, the objectives that are to be met and the scope of the analysis, and clear system boundaries as outlined in section 4.1.

System depiction and analysis involves three (3) steps (Steps 3-5, as in *Figure 3-1*). The order of the steps is not predetermined, but contingent upon the user-knowledge and context-specific details of the system. For example, in informal recycling system, understanding the stakeholders is imperative to get an insight on the processes involved, and thus step number four (4) may precede step number three (3), whereas in formal system depicting the processes involved in the system and quantifying the mass flows can be revealing in terms of the stakeholders involved. Moreover, it must be emphasised that step number five (5) in the CVORR framework, i.e., *'Analysis of system structure, dynamics and drivers'*, can occur in tandem with the previous steps as a means for efficiently depicting the system's processes and stakeholders involved, quantifying the relevant flows, and capturing the stakeholders power relationships.

4.2.1. Description of system material flows

The system's starting point is the point where plastic packaging is produced and placed on the market (POM) for consumption. It is assumed that the useful life of plastic packaging is less than a year. Based on this assumption the plastic packaging POM becomes waste in the same year and is either littered or placed in the bin. It is then collected and distributed to the various waste management facilities for further processing, as depicted in Figure 4-1.

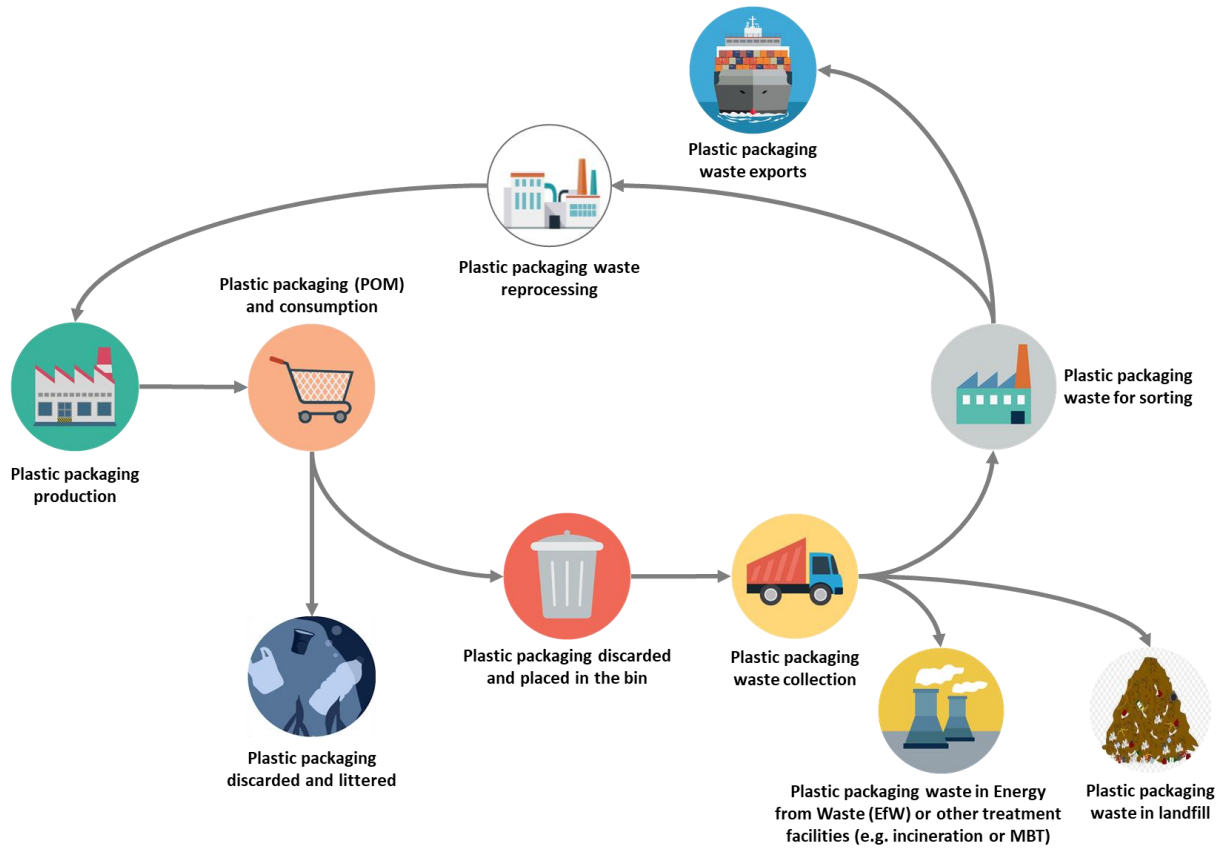

Figure 4-1 A simplified preliminary description of the principle plastic packaging flows in the UK economic system; POM: Placed on the market

4.2.2. Identification and quantification of material flows

To quantify the plastic packaging and plastic packaging waste flows we used data and information from a number of reports, and via expert input on data related to plastic packaging POM, plastic packaging waste generation, collection and management in England. The principle source of plastic packaging consumption data was the PackFlow 2017 report and the Plastic Packaging Composition 2011 report. For plastic packaging waste generation, distribution and management we used data on local authority collected municipal waste

(LACMW) in England, which date from 2010/11 (Defra, 2012). Although this dataset is considered to be outdated, it was at the time of the analysis the most detailed available in England in terms of plastic packaging waste format.

According to PackFlow 2017, the total plastic packaging flow into the UK market in year 2011, was between 2,409 and 2,660 kt; the low and high flow growth rates represent the projections for year 2011. This variation is based on the differing growth rates and/or base tonnes used for the projection, and illustrates the uncertainty caused by the information available (Valpak, 2011). Specifically, PackFlow 2017 reports that, in 2011, the UK consumed an average of 2,535 kt of plastic packaging, with 1,724 kt deriving from the consumer stream and 811 kt deriving from the non-consumer stream. The non-consumer flow represents all packaging from the commercial and industrial streams as well as agricultural and construction & demolition (C&D) plastic packaging. This can include primary, secondary and tertiary packaging.

In the same year, the total plastic packaging waste collected by LAs (known as LACMW) in England was estimated to be approximately 1,829 kt. This estimate is the one used in our analysis and includes both plastic packaging produced in the household sector (i.e. consumer), and plastic packaging produced by the commercial sector that is of similar nature to household (i.e. both consumer and non-consumer plastic packaging waste). The figure also includes elements of contamination from products contained within the packaging that lead to an over estimate of the actual plastic packaging waste collected. Using data and information from PackFlow 2017 (Valpak, 2011) and PlasFlow 2017 (WRAP, 2013) reports and official statistics on LACMW destination, we made some rational assumptions regarding the collection and fate of plastic packaging waste for calculating its flow in the system (see details in *Appendix I*).

To estimate the amount of plastic packaging waste discarded as litter or disposed in the bin and distributed in the various waste management options available in England we consulted experts on plastic marine litter apportionment, and used data from various existing reports. These include, a report on plastic consumption and management in the UK (Elliott and Elliott, 2018) and the local authority collected municipal waste (LACMW) data for 2010/11 (Defra, 2012). It must be noted, that the amount of plastic packaging littered in England, as well as other flows estimated in this study, represent modelled estimates with associated uncertainty. Therefore, they should be interpreted with caution.

In reality, the fate of plastic packaging waste depends and varies according to the type of materials it contained, the behaviour of the consumer while discarding the packaging waste, the type of collection system implemented by each LA in England as well as the existing contracts that the LA may have with waste collectors and management companies. 'Collection' refers to *"the gathering of waste, including the preliminary sorting and preliminary storage of waste for the purposes of transport to a waste treatment facility"*

(WRAP, 2014b). It takes place when waste discarded by a householder or business is transferred from their control to the collector's, or is deposited directly to the bring sites, household waste recycling centres and street litter bins (WRAP, 2014b).

Deciding on the collection scheme, LAs need to make reasonable estimates of the composition of the waste arising within the area they are responsible for. Compositional information (usually from national/regional reports) or local sampling are key in helping LAs to decide which waste streams to collect separately, and how effective their current collection systems are (WRAP, 2014b). Then LAs need to understand how the waste is actually collected and how it is managed (e.g. reprocessed, composted, separated in a MRF, incinerated, or sent to MBT). LAs that currently do not undertake waste management services themselves they can exercise control and gather relevant information on waste compositions from the waste management contractors with whom they have contracts with.

According to our calculations and based on the data available, the majority of plastic packaging waste generated, comes from households (89%), whereas around 8% and 3% comes from commercial and street cleaning activities, respectively. In the households, dense plastic packaging waste (incl. PTTs) dominates over bottles (drink and non-drink) with 664 kt over 452 kt, yet it is the bottles that dominate in the recycling stream, with 58% collected for recycling. Indeed, drink bottles account for 37% of total plastic packaging waste collected for recycling, 98.5% of which comes from households, 0.5% from street cleaning and 1% from commercial activities. PTTs account for 23.5% of total plastic packaging waste collected for recycling, the majority (99%) of which comes from households.

For the quantification of plastic packaging recycling, we used data from the National Packaging Waste Database (NPWD), Recoup's Household Recycling report, PackFlow 2017 and various publicly available non-consumer plastics reports. In 2011, the NPWD reports that the UK recycled (domestically and internationally, i.e. sent abroad for recycling) 610 kt of plastic packaging, of which approximately 427 kt was assumed to be coming from the consumer stream and the rest (~184 kt) was from the non-consumer stream. The principle sources of plastic sorting and reprocessing data were the NPWD, the Online Recycling Information System (ORIS), WRAP's Recycling Market Sentiment 2012 report and internal knowledge by industry.

Based on the available data and other relevant information in year 2011 the UK/England had:

- 3.2 - 4 Mt of Material Recovery Facility[2] (MRF) capacity, of which around 360 kt is believed to be focussed on plastics;
- 350 kt of Plastic Recovery Facility[3] (PRF) capacity in 2011, rising to around 400 kt (as in 2012);

[2] Also known as Material Recycling Facility
[3] Also known as Plastic Refining Facility

- 260 kt of plastic packaging reprocessing capacity in 2011; and
- exported 70% of plastic packaging for reprocessing with the remainder 30% reprocessed in the UK.

Figure 4-2 depicts the flows of the plastic packaging system in England in year 2010/11.

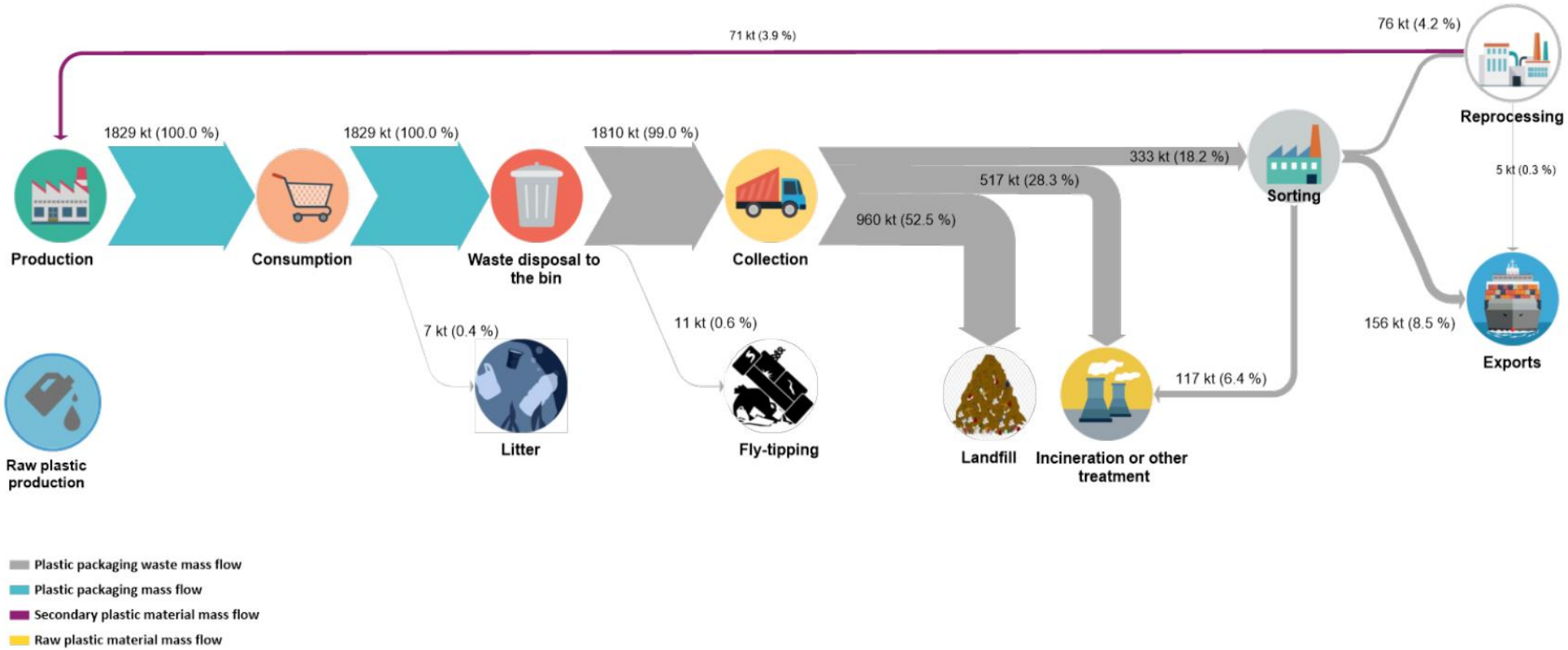

Figure 4-2 Quantification of the local authority collected plastic packaging waste flows in England, based on data from year 2010/11. A 100% collection coverage across England was assumed.

As shown in Figure 4-2, around 80% of plastic packaging waste generated in England in 2010/11 is estimated to end up in the residual waste stream. We consider residual waste to be either treated in energy from waste (EfW) facilities, in mechanical and biological treatment (MBT) facilities, or to be disposed of to landfills. Of the 19% of plastic packaging waste collected at the time for recycling only 4.4% is estimated to be reprocessed within the UK. This signifies that approximately 9% of the plastic packaging collected for recycling was exported in Asian or European countries, such as Malaysia, Vietnam, Indonesia, Turkey and Poland, whereas around 6% is estimated to be leakages from the sorting facilities.[4]

While plastic packaging waste exports count in the recycling rate, some of the exported plastic packaging waste will contain contamination. As a result, a small volume of the exported plastic packaging waste is likely to be too expensive to sort and recycle, and is either dumped or illegally burnt (National Audit Office, 2018). This creates implications from a political economy perspective, because the mismanagement of waste outside the UK system boundaries is rarely taken into account. As a result plastic packaging waste exports are being considered as wholly beneficial, partly due to the impression that all the material is being recycled and due to the 'out of sight, out of mind' mentality.

In our system, leakages at MRFs were estimated based on the material output of material recovery facilities only. This leakage rate was estimated based on quarterly data from 2018 retrieved from WRPA material facilities (MFs) reporting portal (WRAP, 2018a). Leakages at MRFs can occur as a result of contamination both designed and created, as well as due to mechanical unit performance and advancement (for definitions see Iacovidou et al. 2019).

Designed contamination can be due to the labelling of plastic packaging that often prevents near infrared (NIR) machinery to properly sort the plastic packaging into the target material. Even if NIR sorts plastic packaging with labels, problems may still occur at the reprocessing stage as the labels, adhesives and closures that remain attached to the bottles and/or PTTs can affect the overall recyclability of the plastic batch. Created contamination can occur due to food and other contents left over in the plastic packaging that may affect its sorting, whereas, non-target materials such as nappies and black plastic trays, may also find their way into the target stream contaminating the entire batch.

[4] In January 2018, Vietnam stopped issuing waste import licences. In July 2018, Thailand banned all imports of plastic and electronic waste. Poland also introduced restrictions on plastic packaging waste imports, due to stockpiles increasing beyond the capacity of its reprocessing sites which lead to waste being dumped or burnt. In May 2018, Malaysia has also placed restriction on the imports of plastic packaging waste from the UK.

4.2.3. Identification and quantification of monetary flows, and stakeholder identification

The plastic packaging mass flow provides only a partial understanding of the plastic packaging system. To gain a better insight into the plastic packaging system we also need to describe and analyse the monetary flows associated with the plastic packaging mass flow. Monetary flows are defined as the actual monetary transactions related directly and indirectly with the physical flows of plastic packaging and plastic packaging waste. This approach of tracing out the relevant transactions can aid the identification of relevant primary stakeholders in the system, which in turn expands our understanding of the system to include flows that are indirectly related to mass flows and hitherto identify secondary stakeholders, whose presence, role, incentives and nature of participation may well be causally relevant for the system under investigation.

Monetary flow analysis therefore complements traditional MFA, not necessarily because of the monetary figures *per se*, but rather because of the insights it provides into the type of stakeholders involved, their incentives, their respective (power) relationships to each other and the nature of those transactions.

It is important to note the addition of the raw plastic material flow in Figure 4-3. This flow was not included in the mass flow analysis because an estimate on the total amount of raw material used for the production of the total plastic packaging placed on the market and included in our analysis could not be derived due to the varying types and formats of plastic packaging flowing on the market.

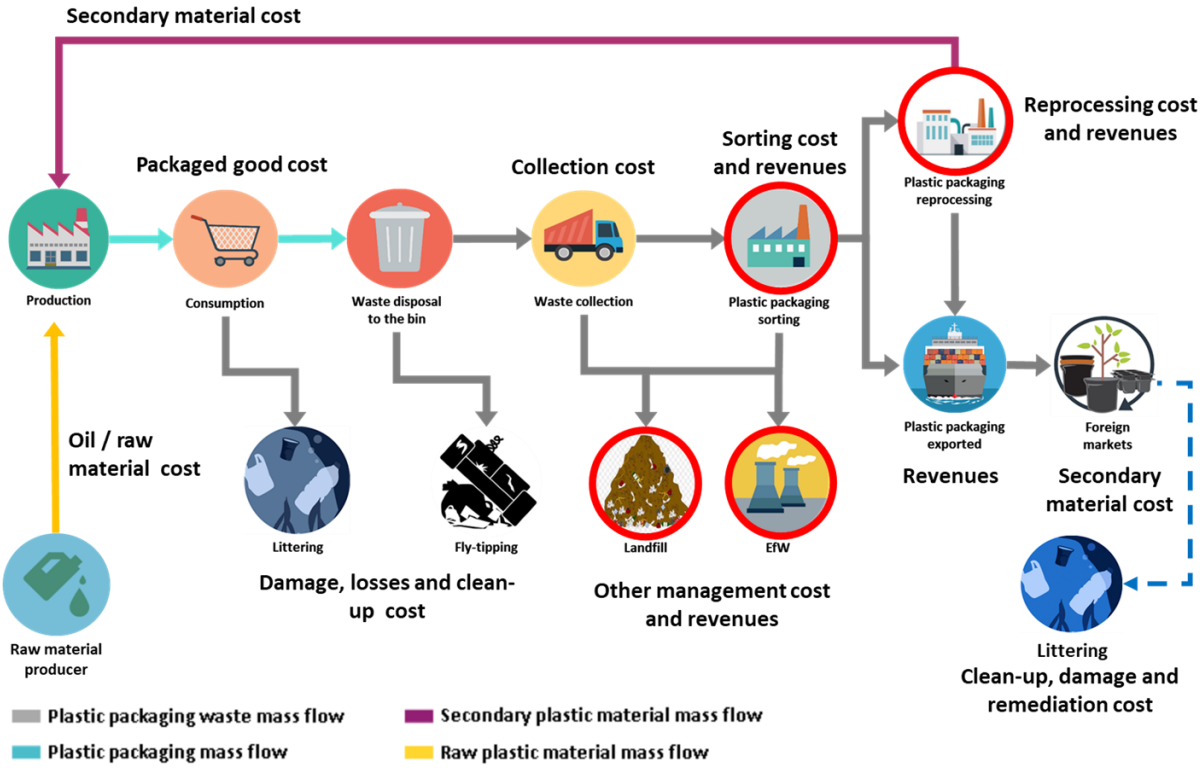

Figure 4-3 Description of key monetary flows. The red circles indicate a complexity associated with mass related monetary flows due to composition of waste received by waste management facilities.

The primary stakeholders are agents or institutions that have a direct influence on the plastic packaging cycle. One of the most important stakeholders in this system are the household consumers of plastic packaging. These consumers can make changes in their daily routines at a low cost that are key for encouraging the development of more sustainable products and responsible supply chains. Moreover, decisions in terms of purchases and consumption patterns are also very important; starting with avoiding plastic packaging, being conscious about the different types of plastic and whether they are recyclable or not, among others. However, the benefits of using plastic packaging in addition to the lack of information regarding financial and environmental costs of using this material leads to an overconsumption of plastic packaging.

Other primary stakeholders across the value chain (e.g. plastics industry, retailers, waste management industry), are in urgent need of improving their delivery of resource efficiency and technical performance to maximise the net benefits. They also need to improve their socio-economic sustainability, product prices, plastic types, market, etc. At the moment, the producers of plastic packaging are responsible for recycling part of their production, which is generally outsourced to another reprocessing company via compliance scheme companies.

Finally, the government and other institutions (e.g. NGOs) should encourage the development and adoption of well-targeted policies and guidelines to aid the transition to a sustainable society. One such policy, is the implementation of the Extended Producer Responsibility (EPR) Obligations Regulations, which extends the producer's responsibility for their components and products to the post-consumer stage of a product's life cycle. EPR is worldwide considered an efficient policy to improving the recycling of plastic packaging waste.

In the UK, the Producer Responsibility Regulations are fundamental as part of complying and implementing the EU Directive on packaging and packaging waste. A key part of the Producer Responsibility Obligations (Packaging Waste) Regulations 2007, is the use of a market-based EPR scheme for packaging, known as the Packaging Waste Recovery Note (PRN) system or Packaging Waste Export Recovery Note (PERN) system, where the packaging waste is recycled overseas. This evidence can only be acquired from UK accredited reprocessors and exporters, who are allowed to issue and sell packaging recovery notes (PRN) and packaging recovery export notes (PERNs), respectively (Environmental Audit Committee, 2017, National Audit Office, 2018). A PRN and a PERN provide equal evidence when presented to meet a producer's statutory obligations.

It is also a responsibility of the government to provide incentives for household consumers to sort their waste, such as penalties for failing to separate waste and to recycle. The implementation of taxation and financing measures by the government should aim at controlling the collection and sorting of plastic packaging waste. For instance, though some households and small business separate recycling waste, e.g. glass and plastic, others do not. In the latter case, recyclables are collected comingled and then are separated mechanically in dedicated facilities. When the collection and separation stages are outsourced to private companies that provide services to LAs, they make decisions in accordance to the markets and offtake qualities demanded and which delivers a profitable solution. This tactic may not always be the most overall beneficial for the society in terms of environmental, economic and social gains.

Table 4-2 outlines the main stakeholders involved in the plastics value chain and their influence in increasing the plastic packaging waste recycling rate.

Table 4-2 Stakeholders involved in the plastic packaging system, their actions, incentives, influence on the system, impact and point of intervention (POI) to initiate change, the latest trends and potential future interventions for increasing plastic packaging recycling rate

STAGE IN THE VALUE CHAIN	STAKEHOLDERS INVOLVED	ACTIONS, INCENTIVES, INFLUENCE, IMPACT, POI	LATEST TRENDS	POTENTIAL FUTURE INTERVENTIONS
PRODUCTION	Brand designers; Manufacturers; Importers; Retailers	**Actions*:*** produce and distribute the plastic packaging demanded by the consumers; constantly strive to improve the attractiveness, functionality and price-competitiveness of plastic packaging ***Incentives:*** short-term economic gains (e.g. profit); generally though, the 'Producers' are the chief (financial) beneficiaries of the primary plastics value-loop ***Influence:*** through lobbying activity and the economic resources they command (e.g., with respect to job creation); through their activities may generate plastic packaging waste that is hard to recycle and disturb efforts to promote circularity ***Impact:*** control the amount and type of plastic packaging introduced in the system and its designed characteristics, and influence purchasing decisions ***POI:*** policy reforms and taxation that will set stricter environmental targets which will require stakeholders at this stage to be engaged in reducing/better managing waste (Central/local government); social responsibility and awareness campaigns on the functionality of plastic packaging and avoidance of its use where not needed (NGOs/Academics)	• Light-weighting of plastic packaging • Proposal on reforming the current packaging producer responsibility system • Awareness campaigns	• Redesigning plastic bottles to increase their recyclability (standard-based regulations) • Taxes and levies on plastic packaging • Improved recycling information on products for consumers • Reform of the Packaging Recovery Notes (PRN) system
CONSUMPTION	Wholesalers; Retailers; Consumers	***Actions:*** demand, acquire, 'consume' in terms of handling, discard and dispose plastic packaging ***Incentives:*** for *wholesalers* and *retailers:* Cost-savings in the transport and storage of goods, point-of-sale advertising, and demand of plastic packaging by the consumer; for *End-Consumer*: Convenience ***Influence:*** stems primarily from the consumers purchasing power that is directed toward the acquisition of the plastic packaging contents and the perceived and actual advantages of the packaging material itself ***Impact***: reinforce the continuous plastic packaging production by their branding activities (retailers) and purchasing decisions (Consumers) ***POI:*** social responsibility impacting on the products they sell in plastic packages (Wholesalers/Retailers/NGOs/Academics); public engagement activities to raise awareness on the functionality of plastic packaging	• Proposal on reforming the current packaging producer responsibility system • Levy on plastic carrier bags, and potential increase in the future • Pledge on cutting black plastic packaging trays used in supermarkets • Plastic free aisles on supermarkets • Refill schemes in businesses	• Introducing a ban on black plastic packaging trays • Introducing a ban on plastic carrier bags • Leading supermarkets phasing out non-recyclable and single-use plastics from their own brand products

STAGE IN THE VALUE CHAIN	*STAKEHOLDERS INVOLVED*	*ACTIONS, INCENTIVES, INFLUENCE, IMPACT, POI*	*LATEST TRENDS*	*POTENTIAL FUTURE INTERVENTIONS*
		(Wholesalers/Retailers/LAs/ NGOs/Academics) and the true costs associated with its use (NGOs/Academics)		
WASTE GENERATION/ SEGREGATION	Consumers; LAs	***Actions:*** *consumers* discard and dispose plastic packaging shortly after it served its purpose, which can range from minutes to several days or weeks; the degree of segregation at the household level depends upon the perceived facility and cost of doing so *vs* failing to obey ***Incentives:*** for its *disposal*, the inconvenience of possessing plastic packaging after its useful life; for its correct *segregation*/*separation* at the household-level a civic conscience and fines ***Influence:*** LAs might be able to increase the degree of accurate segregation/ separation at the household level via awareness campaigns and fines ***Impact:*** insufficiently segregate/separate plastic packaging waste which results in higher waste management costs for LAs ***POI***: better product design to improve labelling that educates regarding recyclability (Brand designers/Manufacturers); better control of products imported in regards to their recyclability (Importers/Customs); penalties for failing to separate waste properly via PAYT (LAs)	• Confusion over what can be recycled and where to be disposed (in which bin) • Recycling participation rate in flats remains low • Awareness campaigns/information	• Preference of products with less/better plastic packaging • Introduce pay-as-you-throw (PAYT) scheme (need to reconsider)
COLLECTION	LAs; Waste collectors; Waste management companies; Recyclers; Brands	***Actions:*** LAs are responsible for the collection of household waste; under the privatised models, the physical collection is outsourced to private entities, which are paid for the service ***Incentives:*** for LAs, the management of household waste collection is part of their political mandate; private collectors are motivated by the profit motive ***Influence:*** LAs organize, coordinate and pay for the collection of the LACMW (which includes the plastic packaging waste under analysis); have the power to implement deposit return schemes (DRS) to increase collection rate ***Impact:*** incurs a financial burden with respect to the collection of household waste (LAs), decreases the amount of plastic waste to be collected results in lower gate fees impacting on investments (Waste collectors/Waste management companies/Recyclers); and affects quality impacting on recyclability and PRNs/PERNs production (Recyclers/Manufacturers/Wholesalers/Retailers)	• Introduction of mixed plastic recycling collections • Contamination in the recyclables lead to their rejection • Awareness campaigns/information to consumers	• Increase in separate collection of plastic packaging waste • Increase in bottles collected for recycling • Increase in PTTs collected for recycling • Increase in films collected for recycling • Deposit return scheme

STAGE IN THE VALUE CHAIN	*STAKEHOLDERS INVOLVED*	*ACTIONS, INCENTIVES, INFLUENCE, IMPACT, POI*	*LATEST TRENDS*	*POTENTIAL FUTURE INTERVENTIONS*
		POI: better segregation/separation at the disposal (Consumers) stage to improve quality; consistency in the collection system of the varying types of packaging (Central/local government); better allocation of costs involved (Producers)		
SORTING	LAs; Waste management industry; Recyclers	***Actions:*** plastic packaging waste gets sorted by waste management companies contracted by LAs, and through which they exercise control ***Incentives:*** for LAs the management of plastic packaging waste is part of their political mandate, and a means to generating income from the sale of clean plastic packaging waste or by discount on the management costs (gate fees); private sorting companies are motivated by the profit motive ***Influence:*** LAs organize, coordinate and pay for the management of plastic packaging waste; the oligopolistic structure of the waste management industry provides it with a certain degree of negotiating power ***Impact:*** incurs a financial burden associated with the collection and management of plastic packaging waste whether they in- or out-source the pertain services (LAs); affects amount of plastic that is to be recycled resulting in lower gate fees and downturn in profit impacting on infrastructure investments(Waste management companies/Recyclers) ***POI***: changes at the design of plastic packaging to improve sorting ability/recyclability (Brand designers/Manufacturers); better control of imported products in plastic packaging and plastic packaging to ensure that non-recyclable plastic packaging is introduced in the market (Importers/Customs); and better segregation at the disposal stage to improve quality (Consumers)	• Vulnerability to changes in the market • Lack of control over input quality, feedstock availability and cost • Infrastructure availability (capacity) to sort material can be limiting • Technologies used to sort materials can be aging/outdated • Black plastic is not sorted for recycling	• Increasing the capacity • Increasing the technological capacity of sorting all types of plastic packaging
REPROCESSING	Manufacturers; Retailers; Wholesalers; LAs; Recyclers	***Actions:*** reprocessing facilities transform the clean plastic packaging waste into secondary plastic material that is going to be turned into new products ***Incentives:*** profit motive ***Influence:*** reprocessors can generate reputational and financial gains over the quality of the material they sell, and secure control over the stream of clean plastic packaging waste; increases in the input and output material can influence secondary resource market ***Impact:*** market fluctuations can lead to a downturn in commodity prices and income generation (Recyclers); lower gate fees as a result of fluctuations in the flows of input material (Recyclers); inability to meet	• Availability of recycling end markets for the main polymers (PET; HD/LD-PE; PP) and applications • Polystyrene (PS) packaging from the household waste stream is not currently recycled because there is no end market • PRNs generation stage, purchasing and control	• Revisions to the Packaging and Packaging Waste Directive, set a 55% plastic packaging target by 2025 • Revisions to the Waste Framework Directive include a maximum level of landfilling of 10% by 2030 • Finding sustainable end markets for PTTs (to making the increase in the collection

STAGE IN THE VALUE CHAIN	*STAKEHOLDERS INVOLVED*	*ACTIONS, INCENTIVES, INFLUENCE, IMPACT, POI*	*LATEST TRENDS*	*POTENTIAL FUTURE INTERVENTIONS*
		targets related to the current packaging producer responsibility system (Manufacturers/Retailers/Wholesalers) ***POI***: changes at the design of plastic packaging to improve sorting ability/recyclability (Brand designers/Manufacturers); better control of imported products in plastic packaging and plastic packaging to ensure that non-recyclable plastic packaging is introduced in the market (Importers/Customs); better segregation at the disposal stage to improve quality (Consumers); consistency in the collection system of the varying types of packaging (Central/local government); better allocation of costs involved (Producers)		and sorting feasible and viable) • Increase infrastructure capacity and technological development to increase material reprocessing rate
EXPORTS	Central government; Policymakers; Regulators; LAs; Recyclers; Exporters; Importers (or countries of destination)	***Actions:*** for *policymakers* - assent to and provide the legal framework for the physical export of plastic packaging waste, or effect payments to *countries of destination*, where necessary; for *Recyclers/Exporters* - effect the physical shipment of plastic packaging waste to countries of destination in exchange for a consideration ***Incentives:*** for *policymakers* - elimination of the *domestic* plastic packaging waste disposal problem; for LAs - elimination of plastic packaging waste from the sight of their constituents; for *Recyclers/Exporters* - the net revenue to be earned and/or the costs to be saved; for *Importers* – short-term economic benefits ***Influence:*** for *policymakers* - primary influence as they set the legal framework for the management of plastic packaging waste; for *Recyclers/Exporters* - influence through lobbying activities and the economic resources they command (e.g., with respect to job creation); for *Importers* – bring financial gains to a small group of beneficiaries, while the socio-environmental costs have to be borne by the wider population, particularly the poor ***Impact:*** unsustainable practice of managing the exported plastic packaging waste can result in high clean-up costs and/or management of low quality/contaminated plastic packaging waste; LAs/Exporters/*Importers* – negatively affected (reputational and financially) in mid- to long-run due to socio-environmental and economic impacts caused by the large amounts of imported plastic packaging waste ***POI***: at every single stage of the value chain as described above (Brand designers/Manufacturers/Importers/Wholesalers/Retailers/Consumers/LAs/Waste collectors/Waste management companies/Recyclers/Exporters)	• Chinese ban on plastic waste has shifted plastic packaging to other destinations some of which have lesser known infrastructure capacity (e.g. Indonesia, Vietnam, Poland) • Rise of illegal exports of plastic packaging (e.g. Poland) which leads to landfilling or open burning of material considered to be 'recycled' • PRNs generation stage, purchasing and control	• Increase control in plastic packaging waste exported • Restriction on the amount of plastic packaging waste exported

STAGE IN THE VALUE CHAIN	*STAKEHOLDERS INVOLVED*	*ACTIONS, INCENTIVES, INFLUENCE, IMPACT, POI*	*LATEST TRENDS*	*POTENTIAL FUTURE INTERVENTIONS*
		and via reforms and changes at international politics and trade regulations(International bodies/Central governments)		

The relationship between the different stakeholders in the value chain is depicted in *Figure 4-4*. The purple arrows represent monetary flows directly related to mass, whereas the green arrows represent monetary flows indirectly related to mass.

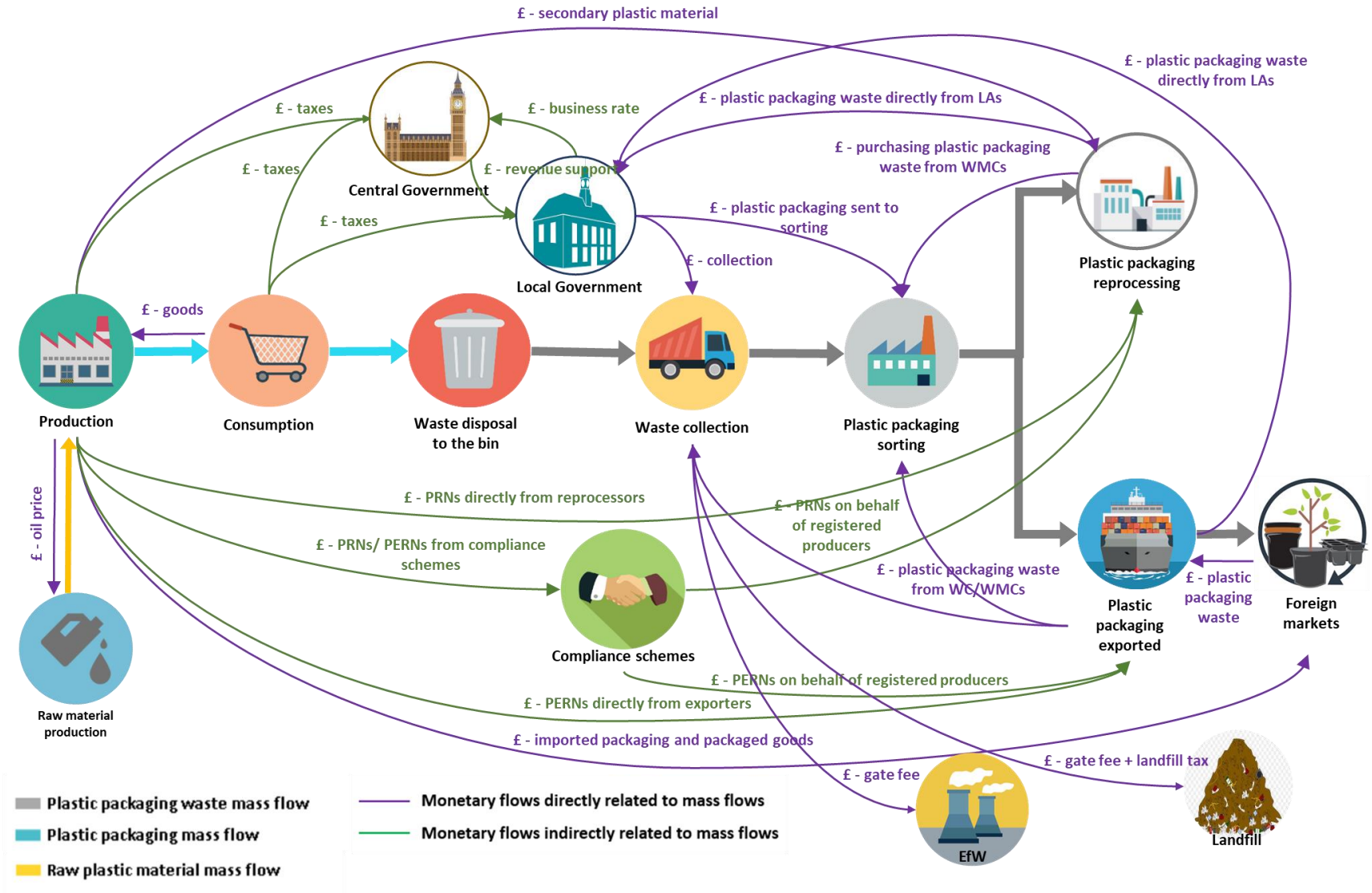

Figure 4-4 Plastic packaging system monetary flows description and stakeholder mapping

An important aspect to consider in the development and assessment of future interventions in plastic packaging waste management is the issue of its ownership. This is a factor which plays a central role in the power-relations between stakeholders and hence in the effectiveness of new policy measures and the equity of the projected outcome.

The ownership structure in the current plastic packaging life cycle can be sketched as follows: The consumer owns the plastic package the instant they acquire the product enclosed in it at the production stage and whilst on their property. After the consumption of the good, the plastic packaging has mostly lost all of its utility to the consumer, such as its lightweight nature and ability of preserving and transporting the product safely to the consumer at a low cost. As a result the consumer may discard the plastic package and dispose it in the bin, transferring the ownership of the plastic package - that may had cost them on average £1,900 per tonne to acquire in the first instance – to the LA or their contracted company responsible for the collection. The contract will often define the placement of that material to a destination and therefore the next transfer of ownership is to the waste management facility owner. At that point the LA losses control of the material and its ownership becomes the value chain. After the sorting process the ownership of the plastic packages is transferred to the recyclers and exporters of plastic packaging. Via the EPR implementation the ownership of the packaging is virtually transferred back to the producer. The potential introduction of the Deposit Return Scheme (DRS) will change the ownership structure of the plastic package, as it will transfer the ownership of the plastic packaging from the consumer directly to the producers.

In the current situation, the producers extract the £1,900 per tonne of plastic packaging from the uninformed consumers, and the waste-management companies, recyclers, reprocessors, compliance schemes and traders share the remainder of the majority of the value produced in the secondary cycle, in addition to their revenue streams for the service fees and PRN-sales (£45 per tonne). Hence, the consumers and LA end up being the major net payers in both the primary and the secondary cycles, while industry remains the major net-recipient of the value streams.

If the value of the unsorted plastic waste is increased via the processes of sorting and reprocessing into secondary plastic, the LA could be the beneficiary of a significant share of this value creation. This could leave to the respective servicing companies (i.e. the collecting, sorting, reprocessing) only the service revenues (and the revenues from the PRNs in the case of the reprocessing entities). In a similar way, one can take, for instance, the example of an oil company, who owns the crude oil that lies underground. It lacks, however, the expertise and the capacity to extract, transport and refine it. Hence, it outsources those aspects to specialised sub-contractors that are paid for these services. The resource, from its crude state underground (i.e., the plastic packaging waste) to its refined form (i.e., secondary plastic material) remains in the oil company's ownership throughout the process and all the majority of the value enhancement (minus the sub-contracted service costs) accumulates to the

earnings of the oil company, not the sub-contractors. Such a scenario would lead to a more equitable distribution of value-sharing throughout the plastic packaging's lifecycle.

This is a focus of refocus in the Extended Producer Responsibility (EPR) proposal that intends to change the contribution to the costs by the producers from around 10% to near 100%. In the future the government could opt for a private sector solution and turn 'plastic waste' into a new alternative 'asset class' to attract private investment in the sector. These investors will want to know who owns what, why and under which conditions, so that they can estimate the expected returns more precisely. In fact, due to the novelty of such a scheme, it would in any case require a major government involvement in the first case as the private sector might be reluctant to invest in a novel 'asset class'.

- ***Quantification of monetary flows***

Driven by the demand[5] for plastic packaging products by various industries that cater for the consumer sector, the raw material 'plastic' (i.e., the various polymers) is transformed by the means of various processes involving labour and technology. Virgin plastic resin is worth on average £1,200 per tonne, and is turned into plastic components and products worth on average £1,900 per tonne, as shown in Figure 4-5.

As these new plastic components and products flow through the 'primary' consumption cycle and eventually reach the end of their useful life (i.e., disposed in a bin, or as litter), their value is significantly impaired. This is owing to the loss of their primary purpose which results in a subsequent loss of value. This downgrade to 'waste' can reduce the plastic packaging's monetary value to approximately £90 per tonne. In the absence of a 'secondary' consumption cycle, i.e. via recycling, even this little value might be compromised (i.e., drop to £0), especially as the plastic packaging waste may end up being landfilled.

When the plastic packaging waste is littered, or is fly-tipped together with other wastes[6], its value becomes negative due to the costs involved for its clearance. These costs were difficult to derive due to data availability on accurate cost of clean-up activities, and the mixed nature of wastes reported under clearance and associated costs. For example, in England the cost of clearance of large fly-tipping incidents reported in 2017/18, which accounted for 4% of the 1 million fly tipping incidents, was more than £12 million (Defra, 2018c).

[5] The high demand for packaging material made of plastic arises from the various conjoint economic and functional benefits that not only make it stand out from all the available alternatives but, arguably make plastic the packaging material of the (early) 21st century economy and of the fast-paced, consumerism driven lifestyle (one made possibly, perhaps, only because of the former's existence in the first place).

[6] Fly-tipping incidents reported in England involve in their majority (66%) household waste.

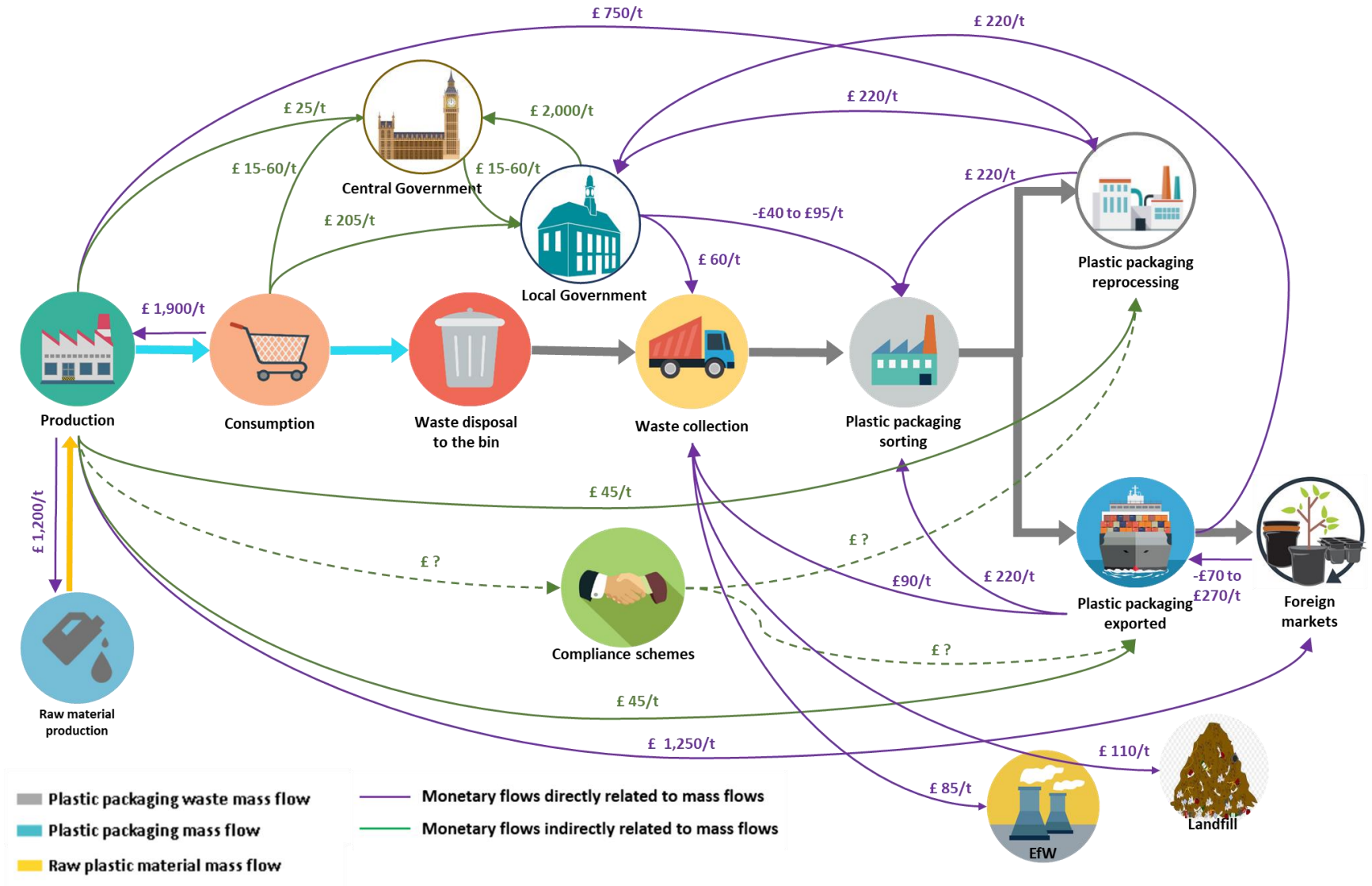

Figure 4-5 Quantification of monetary flows per tonne of plastic packaging flowing into the UK value chain, using monetary values from years 2017/18

Plastic packaging waste that has the potential to be recycled is often exported to developing countries for recycling; yet the absence of sophisticated facilities for handling plastic packaging waste that cannot be recycled might result in the plastic packaging waste being mismanaged. This mismanagement can imply disposal of plastic packaging waste to landfills, or even dumpsites and other illegal dumping sites, where amounts of plastic packaging waste can be leaked into the aquatic environments.[7] This can impose clean-up costs ranging from £3,300 to £33,000 per tonne. Moreover, if the exported plastic packaging is of an insufficient quality, which is the most likely scenario in the absence of appropriate domestic sorting and reprocessing capabilities, the price is negative, i.e. the exporter pays the importer to accept their waste.

The introduction of a 'secondary' cycle instigates a value-creation loop. In this loop the original value of £90 per tonne can be recovered, or can be further enhanced. The sorting of the plastic packaging waste will lead to an increase of the secondary plastic value to around £220 per tonne, although this figure is subject to market fluctuations.[8] Further gains in value can be realized if the sorted plastic waste is successfully reprocessed into secondary plastic material, i.e. £760 per tonne, which can subsequently either be reintroduced into the 'primary' domestic cycle or, alternatively, be exported.

The plastic packaging waste that ends up in the residual waste stream, and which cannot be sorted or reprocessed, can be fed into a value-creation loop, where the material might be used for fuel or domestic energy production through the processes of pyrolysis and incineration. The former management option (pyrolysis) entails the processing of plastic packaging waste into a fuel, which can extract a value of about £160 per tonne. Incineration of plastic packaging waste results in the production of electricity in dedicated power plants, yielding a value up to £83 per tonne. These prices can be understood as 'opportunity costs' caused by the absence of a secondary in the plastic packaging waste cycle, and are defined by the value lost when plastic packaging is disposed of in landfills, where no value creation is presently assumed. The opportunity costs can be estimated through alternative activities that create and enhance its value if the plastic packaging was not left in the landfill, e.g. EfW or exporting waste.

The figures of these alternative treatments are, however, much lower than those that could be realized through reprocessing. It thus appears economically sensible to increase the capacities in this superior value-enhancing recycling loop, which will require significant

[7] A recent study suggest that 80% of all marine plastic waste originates from land-based sources. For further details look at: Lebreton, L. C. M., J. van der Zwet, J.-W. Damsteeg, B. Slat, A. Andrady and J. Reisser (2017). "River plastic emissions to the world's oceans." Nature Communications 8: 15611.

[8] Subject to market fluctuations. As the sorting of waste can be a tedious and expensive process, though, it is advisable to ensure that the process is implemented at the point of the lowest cost of execution, i.e. the household, which incurs virtually zero additional costs when sorting the plastic packaging material correctly at the point of collection – all that is requires, is the right set of (economic) incentives.

improvements on the sorting and reprocessing stages. The investments might be worthwhile, however, as unsorted plastic waste worth £90 is turned into £760 (figure 4-6).

The sorting stage is pivotal for maximising the amount of plastic packaging waste that is suited for reprocessing (either domestically or abroad) and arguably poses one of the greatest bottlenecks in this particular value-enhancing loop. It is thus important to identify the juncture in the value chain, where the sorting process can be implemented most efficiently and at its lowest costs; the most likely candidate being the household level, where virtually zero additional costs are incurred in the accurate sorting of plastic packaging waste, thereby maximising the quality of the waste at the collection point. Such cost reductions and value enhancements are particularly important in an environment of austerity, where financially constrained local governments are in dire need of reducing costs and finding alternative income streams.

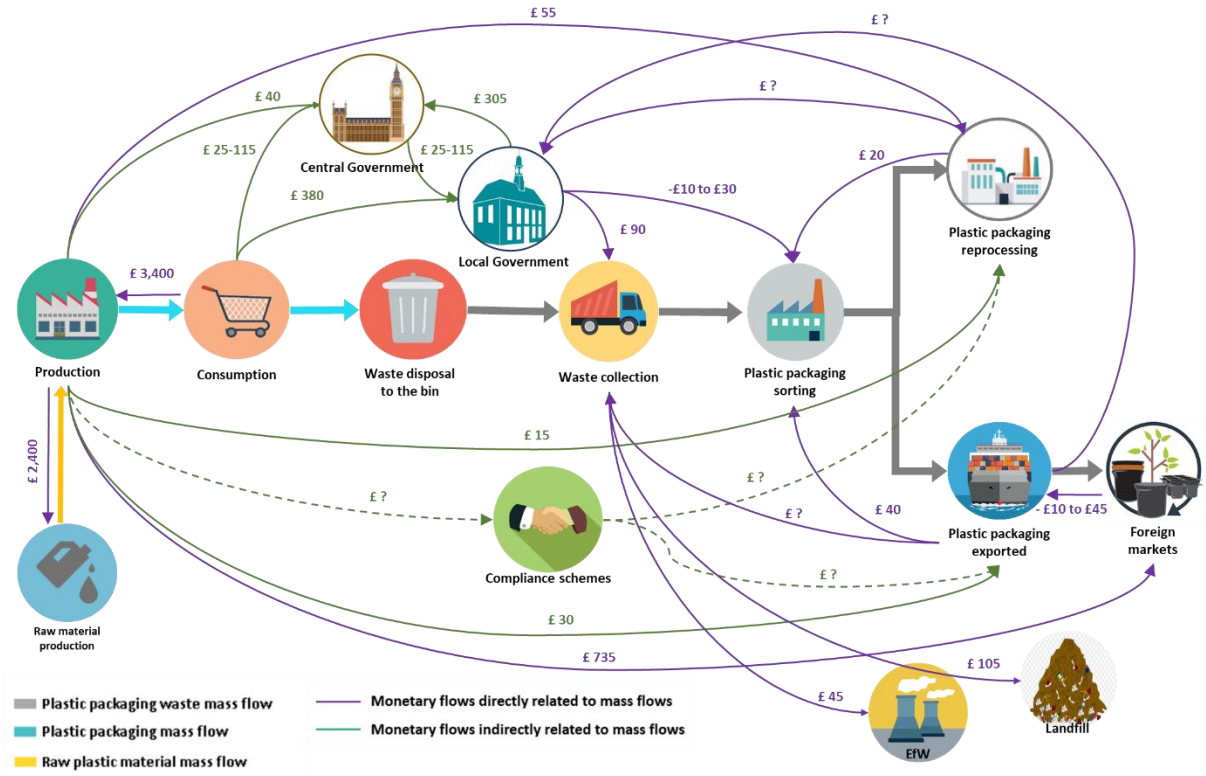

Figure 4-6 Quantification of revenue cost of plastic packaging flowing into the UK value chain, using monetary values from years 2017/18

Local authorities are facing further funding restrictions in the near future – the average revenue support dropping from £60 per tonne in 2015/16 to only £15 in 2019/2020 and eventually to £0 in 2020/2021. Additionally, further increases in the already relatively high council taxes (£200 per tonne of plastic packaging waste) and business rates (£2,000 per

tonne of plastic packaging waste) would be very difficult to politically implement besides the drawback of putting a further financial burden upon the working- and middle-classes. For improving the local governments' financial situation, it will be necessary to redesign the system in such a way that the former is cut-in with respect to the value created. The government's proposal of improving the EPR that places the responsibility for the full net cost recovery[9] for the collection and treatment of consumer plastic packaging POM to the producer, will be a role changer. Producers would no longer be burdened with compliance costs of the existing Packaging Waste Recovery Notes (PRN) system (Defra, 2019c).

Currently, the price of PRNs in the spot market is around £40 per tonne of plastic packaging waste in 2017.[10] These notes are issued by reprocessing companies, which use some of the generated income to invest in recycling projects that helps the UK government to meet its recycling goals. Although the central government indirectly benefits from this financial support given by the plastic packaging producers to reprocessors, the LAs, which are responsible for managing and collecting waste, do not benefit from this financialization of the waste industry. LAs must rely on the income from council tax and revenue support to finance their activities.

4.2.5. Analysis of system structure, dynamics and drivers

The case of plastic packaging waste is particularly complex and complicated. A systemic analysis can unveil many important aspects that have to be taken into account. There are two pertaining aspects that govern the functioning of that system: 1) the policy initiatives and political dimensions of banning and redesigning plastic packaging; and 2) the politics of plastic packaging waste management and the need to meet regulatory targets at the cost of 'out of sight, out of mind' environmental problem-shifting solutions.

Conceptualising the system is extremely important for a holistic assessment. In CVORR, understanding system dynamics and drivers is a complex process that takes into account the interconnectedness of systems using the co-evolutionary framework developed by Foxon (2011). This framework enables us to analyse the socio-technical and techno-economic changes for making the transition towards sustainable practices. According to this framework, information based on five coevolving and interacting systems, i.e., *ecosystems*, *technologies*, *institutions business strategies* and *user practices,* needs to be integrated. In CVORR, we have adopted this framework for the development of a step-wise approach for collecting relevant information, within 5 realms called *'levels of information'*, presented in Figure 4-7.

[9] That is 100% of the net economic cost of dealing with packaging waste.
[10] The price of the PRN in the spot market is highly volatile reaching £550 in June 2019.

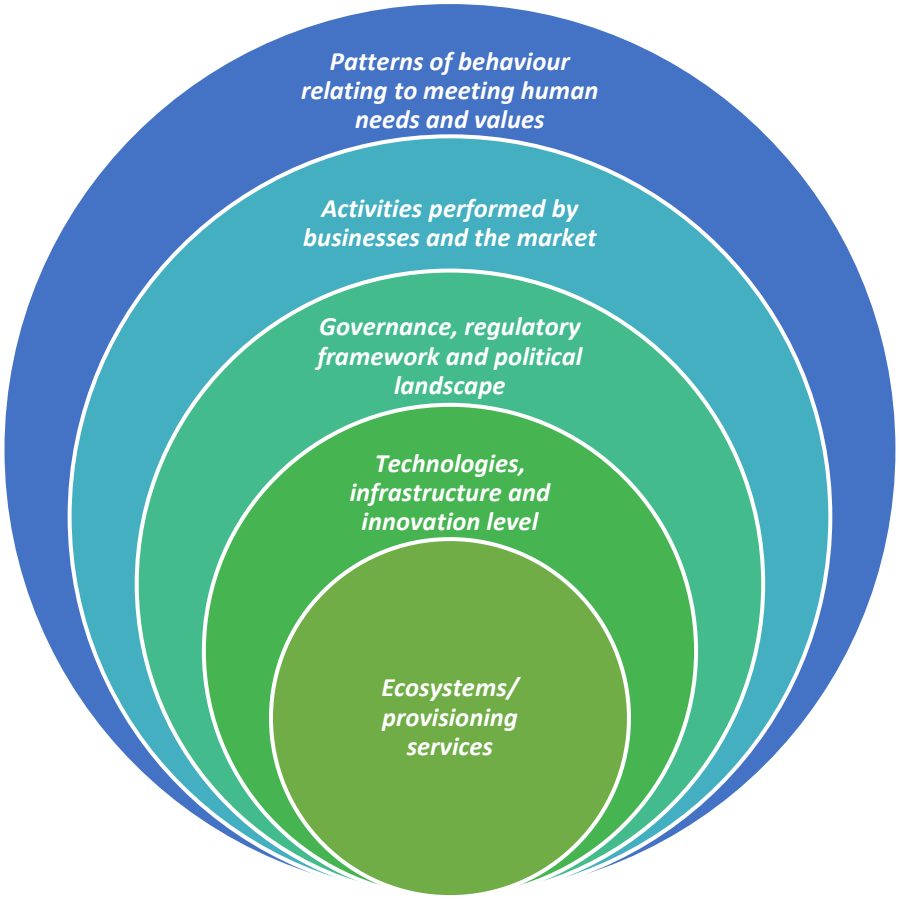

Figure 4-7 CVORR's '5 levels of information' – a narrative approach to conceptualising multi-dimensional value

In CVORR the *5-levels of information* are as follows:

1. *Ecosystems/ provisioning services – refer to the natural flows and provisioning services ability to maintain and enhance living systems;*
2. *Technologies/ Infrastructure – refer to infrastructure and innovation level of transforming waste into secondary resource;*
3. *Institutions – refer to governance, regulatory framework and political landscape;*
4. *Business practices/ market – refer to the activities performed by businesses*
5. *User practices – refer to patterns of behaviour related to meeting human needs and values*

The following sub-sections describe the key information gathered to get an insight into system dynamics and drivers of current practices governing the plastic packaging system.

- ***1st level of information: Ecosystems and provisioning services***

Plastic packaging, and specifically plastic bottles, makes up a large proportion of a household's recyclable waste stream, which is required by local authorities to collect and manage. A small amount of packaging is littered (e.g. crisp packets or plastic bottles). If littered plastic packaging waste is not collected, it can be transferred via different sources and pathways from the terrestrial and riverine to the marine environment. It takes years to degrade and as a result it causes serious harm to ecosystems.

Currently there is a lack of consensus as to what constitutes a source (i.e. origin of plastic debris to the environment) and pathway (i.e. the route of plastic debris from land and riverine to the marine environment) of plastic marine debris to the environment. This is accruing for different perceptions on how human behavior, socio-economic aspects, and socio-technical regimes in different areas may impact the way plastics enter the environment. Sometimes a source can also be considered as a pathway. In any case, plastic debris can pose risks to the marine biota and fauna, and may also impact on human health. The plastic packaging (also called macroplastics) can be broken down into smaller fragments (called secondary microplastics) which may lead to greater impacts on the ecosystems and may also enter the food chain.

Fly-tipping, i.e., the illegal deposit of waste on land, is another way by which plastic packaging waste can enter the environment and lead to pollution. Tackling illegal waste disposal is an important issue and LAs are responsible to deal with this waste and the cost of its clearance. In England, two thirds of the 1 million (998,000) fly-tipping incidents that occurred in 2017/18 involved household waste. As a response to these incidents LAs have started to improve the way they capture and report fly-tips over the past few years, and carried out enforcement actions and issued penalty notices; yet the definitions used to describe fly-tipping incidents can be broadly interpreted by the LAs which is problematic in ensuring proper enforcement and mitigation of this problem.

Another illegal activity that can contribute to plastic waste pollution is the operation of illegal waste sites[11]. In these sites management activities are not being undertaken in a proper manner, presenting a significant risk to the environment and human health (EA, 2017). Another issue that adds to this problem is also the misdescription of waste. According to EA the misdescription of waste occurs when an operator fails to assess, characterise and classify a waste correctly, and/or fails to apply the correct waste classification code or provide an adequate written description of the waste (EA, 2017). It is believed that this may often be done deliberately in order to reduce disposal costs and evade paying the correct rate of landfill tax. While this activity can save money to waste operators, they may impose negative

[11] According to EA an illegal waste site is *"a site operating without the appropriate permit for the activity being carried out where multiple loads of waste are deposited, treated, stored or disposed of, and where activity is, or appears to us to be taking place in an organised manner. The activities at the site will generally (but not always) be known to the landowner or the legal occupier of the site and will often be run as a business.",* EA, 2017, pg. 3.

impacts on the environment and human health due to failure to dispose of the waste in a safe and proper manner, which may lead to leakages to other environmental compartments (e.g. marine environment) (EA, 2017).

A considerable amount of plastic packaging waste is collected to be recycled. Some plastic components, such as films, some pots, tubs and trays (PTTs) and black plastics, are not widely recycled in some local authorities in England, neither are the multi-layered and laminated plastic packaging. They are considered to be problematic types of waste with limited recycling options; thus are often seen as impurities in the high value streams such as PET and HDPE bottles. Most plastics that are not recycled are collected and used for energy production or sent to landfill.

It is at local government level that waste is collected and managed and the planning is approved. Local government operates under either a one tier system, i.e. unitary authorities, or a two tier system, i.e. county and district councils. Unitary authorities are responsible for both the collection and treatment of their waste and the planning approval for the waste management facilities, whereas in the 2-tier system district councils are responsible for the waste collection and the county in which they belong is responsible for the treatment and strategic planning. The collection and management of the waste is largely funded by a combination of public money and revenue made by selling collected recyclable materials, such as plastic packaging waste.

LA's decision on how to deal with their municipal waste, including plastic packaging, impacts their financial situation. As a result, LAs can often be in-house service providers (known as Direct Service Operators (DSOs)), or they may decide to outsource these services by means of particular contracts with waste management companies through compulsory competitive tendering (WRAP, 2014a). LAs can opt to outsource the collection service only or they may enter into a long-term contract (typically 25-30 years) with a private contractor selected, who will build the facility and treat the waste for the duration of the contract (OFT, 2006).

The number of waste management companies competing in the market is around 300, offering a diverse range of services such as treatment or disposal services, a collection only service, or integrated services including the collection, management and trading of materials. Veolia is leader in this field followed by Biffa, Suez, Viridor and FCC, the so called "Big Five" of the waste management services industry. In 2018, these companies, dominated the market in terms of revenue, with a combined 4.8 billion British pounds generated (statista, 2019).

The contracts between the LAs and waste management contractors can be partly funded by the LAs Private Finance Initiative (PFI) scheme for large waste infrastructure projects as part of the Waste Infrastructure Delivery Programme (Uyarra and Gee, 2013), stimulating the development of a number of large-scale recycling facilities. In any case the LAs are those with the responsibility to make land use provision for the management of waste, and provide the

planning permit for waste management facilities in order to ensure that waste is handled in a way that poses no risk to the environment and human health (GOV.UK, 2014).

LAs are also responsible for the type of facilities that are going to be built to suit the respective local circumstances (ODPM, 2004). This means that in a LA more than one waste management facility could be provided, generally procured through multiple contracts. The type of facilities procured often reflect the type of collections implemented by LAs, as existing infrastructure may not be able to support a separate collection of plastic packaging, or the collection of a variety of plastic packaging materials (Hahladakis et al., 2018). And whilst there is demand for improved recycling rates, this may not always be feasible in some LAs due to infrastructural constraints (Purnell, 2019).

Over the last years, reductions in government funding (NAO, 2018), have encouraged LAs to move waste services in-house to make savings (Fulford, 2013). However, the Environmental Services Association (ESA), which represents private firms in the waste sector, claims that the projected savings to LAs for insourcing their waste services do not properly account for the risks that can be availed under an outsourced solution, whilst competition can bring down cost and boost innovation (Williams, 2018). For example, risks associated with trading recyclables, such as plastic packaging, directly with reprocessors can be avoided when the reprocessors become unavailable. The waste management companies may use contracts with other reprocessors, or they often have established relationships with brokers crucial in availing such risks. Operational issues such as lack of storage space for material at the depot are also avoided when LAs outsource their waste management. Waste management companies can also capture more dry recyclates because they receive the revenue from their trading, they safeguard material quality because it is worth more; and they actively seek to maximise the onward sale value of the material at all times in the market cycle (WRAP, 2014a).

Nevertheless, WRAP, suggests that a well organised authority could carry out waste management service and materials trading in-house generating some revenue, even if the collection service is outsourced (WRAP, 2014a). Pushing up recycling rates can reduce the loss of potential value through additional supply chain interactions; in this case, the profit margin, perhaps a risk premium and sometimes additional operational cost being applied by the waste management contractor, and also decrease the amount of residual waste and associated cost of collection and management (WRAP, 2014a). Operationally, however, this situation is difficult to achieve when the waste collected remains in the ownership of the LA, but the waste management company is responsible for the sorting and bulking of recyclables. This is due to liability issues and material quality risks which would need to be clearly allocated between the LA and the waste management company.

The decision of LAs to insource their waste services comes as a response to further cuts on government funding as a result of phasing out the Revenue Support Grant (2015/20),

whereby councils will get to keep 100% of the money raised locally through the business rates retention (LARAC, 2018). Revenue Support Grant will leave almost half of LAs scheduled to no longer receive any core central government funding by 2019/20 (LARAC, 2018), who will be raising their money predominantly through council tax and business rates.

As a result of this change, the lack of legislation and penalties on meeting the targets, and the need for LAs to streamline their services more effectively in order to achieve more with less, has seen recycling rates reaching a plateau (LARAC, 2018). Providing separate collection for different materials, including plastic packaging, can be costly and LAs are often introducing additional charges, as in the case of garden waste, which affects the stability of the system as some residents may opt to pay for it and others not with the externality of having garden waste disposed onto the residual waste stream. Other LAs are often unable to offer separate collections of different waste streams including plastic packaging, due to associated costs of collection and recycling of these streams. Instead, they regard this as an opportunity for loosening target-based controls and shifting money from waste to other policy areas. This results to waste been sent to landfill or to EfW incineration facilities as they are cheaper options rather than investing in changes to the collection services provided to increase their recycling rates (Davoudi, 2009, Davoudi and Evans, 2005, Read, 1999).

- ***2nd level of information: Infrastructure and innovation level of transforming waste into secondary resource***

The long-term waste collection or disposal contracts that LAs make with waste management contractors makes it difficult for them to implement changes in infrastructure. For example, for LAs to implement separate collections, they will need to consider carefully how to take account of any constraints, costs of change or termination costs associated with the contract. Termination or variation costs might be looked at separately from the basic economic case for the choice between separate and co-mingled collections (WRAP, 2014b). Austerity has brought divergent implications for waste collection and management at the LA level, and Brexit is likely to bring more instability in the way waste management services are provided and potentially lead to a technological lock-in.

Separate collection will be economically practicable so long as the cost is not excessive, or disproportionate to the benefits. In deciding what the cost of different options might be, it will be important to take account of all of the relevant financial impacts – not just the collection costs such as vehicles, crew, fuel, containers, but the likely income from materials, processing costs and haulage costs. Except where any extra costs of separate collection are very small or very large, assessing 'proportionality' is not straightforward. It may not be sufficient to show, for example, that the extra costs would marginally exceed the current waste budget. It may even be proportionate to consider cuts to other discretionary expenditure in order to meet the legal obligations regarding separate waste collection (WRAP, 2014b).

In the UK, MRF and PRFs are primarily operated by the waste management industry. The majority of these facilities are owned by the so called “Big Five” of the waste management services industry (i.e., Veolia, Biffa, Suez, Viridor and FCC) which dominate the market in terms of revenue. In the case of PFI contracts the assets themselves or often owned or part owned by the LAs and many of those revert to the LA at the end of the contract. As a result, the expansion of the respective capacities as well as the development and introduction of innovative solutions is highly dependent upon the profitability of the entire process, which, in turn, depends upon various other factors within the wider system. For instance, a lack of sorting by consumers on the household level will increase the costs of the sorting process and further squeeze the margins. Similarly, low commodity prices will make it financially less profitable to recycle plastic waste. Sorting efficiencies are an additional problem, with the majority of MRFs resulting in a rejection of target plastic waste materials of approximately 13% to 18% (Hahladakis et al., 2018a). This is in addition to other losses due to non-target plastic waste materials that are discarded, which account for another 12% to 5%. Rejections at PRFs can be up to 30%.

This may lead to a consequential technological lock-in where the most established technologies (e.g. EfW or MBT with RDF/SRF, landfill) may prevail over others, due to increasing returns and greater experience with them. Due to these benefits, they offer competitive advantages over competing technologies that can be locked-out. In regards to their role in the plastic packaging system:

EfW – the use of this waste management option for the treatment of plastic packaging waste as a way to recover the calorific value of plastic waste for power generation is restricted due to its calorific content. The high capital cost of incineration facilities that comply with the EU Waste Incineration Directive makes it economically unattractive to burn a waste feed with a relatively high calorific value (20-23MJ/Kg). This is because such facilities derive a large proportion of their revenue from the gate fees they charge for the feed waste material. When the calorific value of the feed is high this means that the gate fee revenue per unit power production is low. Capital cost is largely related to power output so the facility would be unable to generate sufficient revenue to repay its investors. Another factor is the maximum amount of energy that the EfW contractor can produce/send to the grid. Plastic packaging waste generates a large amount of energy, so there is a cap for these companies with regards to the amount of plastic packaging they can incinerate. EfW plants are designed with a fuel quality range and a target energy production. When the fuel mix changes this can lead to a restriction on how much fuel can be processed, leading to a loss of revenue from gate fees as the energy output is capped by the facility design and the equipment and export capacities. If the energy value is too low then the facility will not achieve its maximum energy output.

Landfill – value untapped: The plastic packaging waste that is sent to the landfill carries a high opportunity costs for society. This type of waste, which has a high calorific value, could be used for energy generation and create monetary value in the system through the incineration

process. Alternatively, the plastic packaging waste that is left in the landfill could be reprocessed and transformed into secondary plastic material that could be fed back into the plastic packaging flow. The greatest challenge of extracting monetary value from the plastic packaging that is sent to the landfill is waste contamination. The high costs of sorting plastic packaging material from other types of waste hinder its use for the production of energy or secondary plastic material. Thus, it is once again evident that sorting waste at the consumer stage is crucial to maximise the monetary value of plastic packaging waste and to minimise its environmental damage.

Exports of plastic packaging waste represent a grey area. It is very difficult, and almost impossible at present to verify what is happening to the 100% of all of the plastic waste flows. This is owing to the fact that some importing countries have generally less reliable or weaker institutions and are often less committed to environmental issues; they may lack the infrastructure for the proper management of waste; and political barriers may force countries of destination to alter their 'code of practice'. Moreover, the problem may sometimes arise from within with EA reporting that there are numerous illegal waste exports that take place (not only of plastic packaging waste though). EA reported that an estimated 191 illegal exports were prevented across a 2-year period (2014/15) (EA, 2017).

- ***3rd level of information: Governance, regulatory framework and political landscape***

Plastic packaging waste has been recently attracting criticism for poor recycling performance and pollution of the marine and terrestrial environments. This has resulted in increased pressure for a response from both commerce and government to improve resource efficiency of plastics, reduce marine pollution, and other environmental impacts. The responses have been many and varied.

For example, the UK Government has responded via the publication of the 25-year Environment Plan (HM Government 2018), which has committed the UK to eliminating avoidable plastic waste by the end of 2042. This commitment has also been strengthened in the Resources and Waste Strategy for England (Defra, 2018d), following by the proposals to reforms to the UK packaging producer responsibility system, consistency in the materials collected for recycling, the introduction of DRS and the plastic packaging tax on plastic packaging with less than 30% recycled plastic. Industry has also responded to the scourge of plastic packaging waste via the UK Plastics Pact (WRAP, 2018c). The UK Plastics Pact is a voluntary commitment by the UK business initiated by the Ellen MacArthur Foundation (2017) as part of its New Plastics Economy initiative. As a result, more than 40 UK businesses have committed to a deadline of 2025, by which plastic packaging must be:

- 100% reusable, recyclable or compostable
- 70% effectively recycled
- 30% average recycled content across all plastic packaging

Meeting these targets may result in considerable changes to the way that plastic packaging is produced and used, as well as how it is treated and disposed of when it becomes waste. Initiatives such as plastic bag bans, 'plastic free aisles' in supermarkets and proposed deposit return schemes may help to improve prevention of plastic packaging production but meeting the above targets require interventions elsewhere in the plastic packaging system.

While banning materials is considered to be a direct solution to the pollution problem, it also leads to misguided legislative pressures and perceptions. The ban on specific plastic items, may be used as a rationale for industry to refuse to adopt more stringent environmental practices in the future (Maxwell et al., 2000). Moreover, the use of bioplastics must demonstrate that these are compatible with the existing recycling system, and that collection of this type of plastic packaging is at sufficient quantities to justify investment in new recycling processes (Hahladakis et al., 2018).

In regards to collection, Regulation 13[12] (of the Waste England and Wales Regulations 2011), mandates that LAs in England must decide whether they must collect glass, metal, paper and plastic materials ('the four materials') separately from one another, or whether they can collect some or all of them commingled by 1st January 2015 (WRAP, 2014b). However, there are circumstances under which it may be permissible to collect materials comingled. This must be justified based on the particular circumstances in each area, e.g., if a separate collection will not ensure that the separately collected wastes are recycled, and/or shows that are technically difficult or economically or environmentally challenging to recycle. This test of economically, environmentally and technically practicable (abbr. TEEP) solutions is a defined test and can be used to justify those cases where separate collection is not required (WRAP, 2014b).

Pricing instruments such as the landfill tax, which raised the cost of sending waste to landfill up to £89 per tonne in 2018 (HMRC, 2018), represent a significant financial incentive for LAs to recycle material instead of disposing it to the landfill. These instruments have also increased efforts in stimulating plastic packaging recycling. However, the landfill tax does not reflect the externalities associated with promoting alternative management options (Defra, 2011). While landfilling has been made more expensive, EfW incineration has become the next favourable option for residual waste due to less costs involved. Therefore the impetus to using EfW incineration was not only regarded as favourable alternatives to avoid landfill disposal charges and taxes, but also to meet the recycling targets required by the Waste Framework Directive (WFD) through '*recovery*' (Cook et al., 2015).

Imposing a tax on EfW incineration could stimulate changes on the way wastes are managed, but this change in waste management could represent just an additional cost to LAs and have not material impact on the recycling outcomes. Diverting waste away from energy recovery

[12] Aims to ensure that waste undergoes recovery operations in accordance with Articles 4 and 13 of the Waste Framework Directive and to facilitate or improve recovery.

plants could also have implications on PFI contracts (LARAC, 2018), which creates a lock-in to demand for material to be incinerated, preventing innovation. Other market failures impeding the transition towards an optimised waste management system comprise, *inter alia*, the lack of information and imperfect competition between waste management companies, with only a few being on the lead by providing integrated services, and the long payback periods (Defra, 2011).

The PRN/PERN system currently implemented in the UK does not impose any formal obligation on LAs; it covers companies that make or sell packaged goods (such as supermarkets), and plastic packaging manufacturers and handlers. This system introduced a *de minimis* threshold; companies that handle less than 50 tonnes of packaging a year and have a turnover of less than £2 million are not held responsible for their packaging. All the rest, need to demonstrate that a certain amount of packaging has been recycled on their behalf (National Audit Office, 2018).

As an alternative to companies taking responsibility for acquiring their own evidence of recovery, producers can decide to join an approved compliance scheme. The largest of these schemes, Valpak, represents 38% of registered companies and handles 48% of the obligated tonnage (National Audit Office, 2018). One of the main benefits of joining a compliance scheme is that the producer is no longer responsible for dealing with legal and regulatory issues, which is a service provided by the compliance scheme. In the case of mistakes, the plastic packaging production company is not punished, but the compliance scheme, which are companies specialised in dealing with and following any updates regarding the regulation.

One of the biggest drawbacks of the regulations is that they do not place a direct requirement on obligated companies to collect and recycle their own packaging. Instead, they shift the physical and financial burden of municipal packaging waste collection to the consumer through council tax and *a posteriori* to LAs which have the obligation to collect, sort and sell this packaging for recycling, or manage it via landfilling and incineration. For example, in 2017, £73[13] million were generated from PRNs/PERNs (National Audit Office, 2018). From this amount, very little was used to compensate LAs for the £700 million cost associated with the collection and sorting of packaging, incl. plastic packaging. Some LAs that collect, sort and reprocess/export the plastic packaging themselves can get some cost compensation via the PRNs/PERNs directly (Environmental Audit Committee, 2017, LARAC, 2018, National Audit Office, 2018). For the rest of the LAs there is no evidence to support that they get any cost compensation. As a result, it is reasonable to assume that this system is the least effective for LAs.

In addition, price volatility in PRNs, has impeded infrastructure investment due to uncertainty over returns and has led to a growing dependence on export markets. This is owing to the

[13] This also includes revenue made from commercial and industrial packaging recycled which is not collected by local authorities.

fact that the financial value/cost of evidence notes is determined by the market. They fluctuate in price in response to a range of factors, such as the supply of recyclables; the price of raw materials; the price of secondary materials; the availability of evidence; and the level at which the targets have been set. The following SWOT statement provides an insight into the potential opportunities and constraints of EPR implementation in the UK.

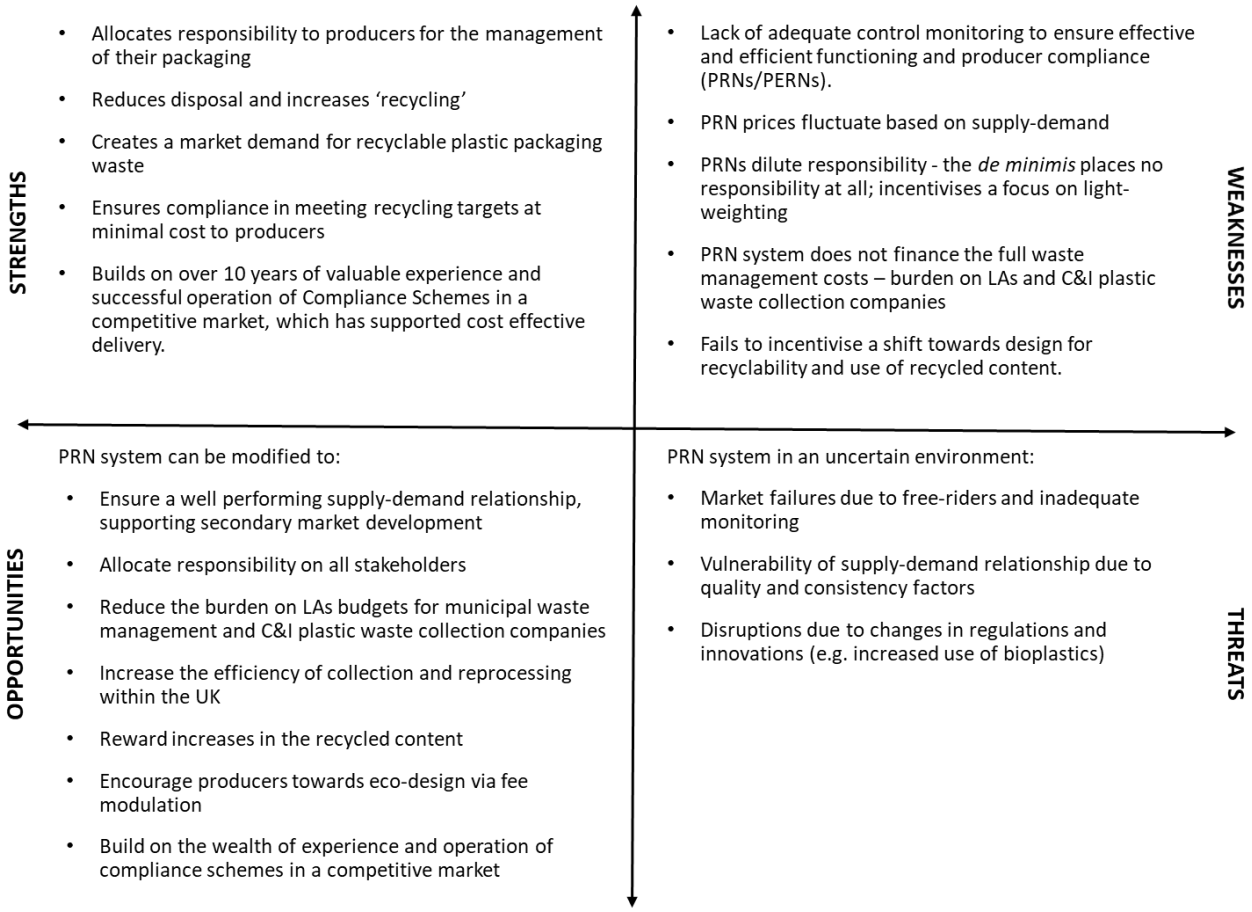

Figure 4-8 SWOT statement of the EPR implementation in England in regards to plastic packaging

It must be noted that the public sector is paying for most of the materials and products to be collected for recycling, making the producer only marginally responsible and LAs are left with a disproportionate share of the cost burden for collecting this packaging. The new EPR proposal for reforming the UK Packaging Producer Responsibility System, is being designed to correct this.

- ***4th level of information: Business practices and the market***

Volatile markets for waste products can reduce the expected revenues associated with operating a waste treatment facility. This reduces the expected returns and can deter

companies from bidding for municipal contracts (OFT, 2006). In turn, this could lead to a shortage in PRNs. Shortages in PRNs leads to higher cost PRNs, and drive more investment in recycling. This leads to a surplus of PRNS, which reduces the PRNs cost and leads to a decline in recycling investments. When the demand for PRNs goes up, reprocessors and exporters may fraudulently claim they have recycled more plastic packaging; with the supply-demand dynamics creating a vicious circle that halts any progress in recycling (National Audit Office, 2018).

Reprocessors are not only profiting from their economic activity, but also from the change in material prices that can lead to some speculation, e.g. selling more or less PRNs according to the expectation for the price in the future, not based on the situation of the company. Any sorting that takes place within that facility prior to entry into the final recycling process is not taken into account. This is justified by the Packaging Directive where the amount of packaging recycled is measured as the input to an 'effective' recovery or recycling process, given that losses are 'negligible'. In reality losses can often be significant for some materials, e.g. mixed plastic bottles and PTTs, which means that there is an over-reporting of the amount of plastic packaging recycled.

Obligated companies may not always comply with the regulations, either deliberately or due to ignorance, leading to potential fraud and error (National Audit Office, 2018). This may impact on the legitimate waste industry and the overall economy, often undercutting gate fees and tax. In addition, there is a financial incentive for companies to over-claim, especially for plastic packaging, with recovery notes representing around 60% of the price of waste plastic bottles over the first six months of 2018 (National Audit Office, 2018). Another significant risk is that the plastic packaging exported for recycling can be of poor quality, which means that some of it is not recycled under the equivalent standards to the UK, and is instead sent to landfill or contributes to pollution. Whilst, it is illegal to ship waste with significant levels of contamination, the EA's low visibility and control over the exported plastic packaging (National Audit Office, 2018), may mean that small quantities of unsuitable materials might be exported.

Outputs from MRFs must meet some quality specifications. These specifications provide reference to the acceptable level of contamination for the plastic packaging waste that is to be reprocessed. For example, a 2 – 5% by weight of general contamination can generally be tolerated in baled bottles reprocessed domestically, whereas for exported plastic packaging waste contamination can be significantly higher (WRAP, 2009). In the UK most plastics reprocessors use financial penalties to deal with loads that are not compliant to the specifications. Plastic waste that does not meet the quality specifications instead of being rejected, it is accepted by reprocessors at a lower price depending on the contamination level. The price reduction might fluctuate depending on whether the contamination was with non-target plastics, or non-plastic materials, or both (WRAP, 2009). Similarly, plastic waste that

exceeds the quality specified by the standard can fetch a higher price incentivising improvement in the sorting processes.

Returning back to the risk of fraudulence and error, this might be a result of the way the system is designed, which relies on reprocessors and exporters self-reporting the amount of packaging material they have recycled or exported for recycling abroad. It also relies on obligated companies to identify for themselves whether they need to register, creating inefficiencies in the way the system performs (National Audit Office, 2018). The problem is relatively pronounced with potentially around 1,889 companies that are obliged to pay into the system not registered, either deliberately or in error. These companies are being flagged by the EA, who is responsible to identify potential non-compliance and to perform compliance visits to reprocessors, exporters and obligated companies, but no follow-ups have been recorded (National Audit Office, 2018).

Additional measures are required to improve plastic packaging recycling rates, as the PRN system provides insufficient incentives for producers to take a greater responsibility for the design of their products and contribute to increasing packaging recycling rates. The true costs for collecting and reprocessing of packaging waste should be reflected through the compliance scheme, which transparently transfers adequate funds to help LAs to meet the cost of collecting the packaging. The government's proposal for reforms to the current packaging producer responsibility system makes a similar proposal in its change of definition of full net cost recovery and approaches to recovering full net costs from producers (Defra, 2019b). But in the long-term, investment in reprocessing infrastructure and policy interventions that can help create a demand for recycled materials and increase the design for recyclability are considered to be more effective in improving recycling rates and increasing productivity.

- ***5th level of information: Patterns of human behaviour relating to meeting needs and values***

A critical aspect to consider in the plastic packaging system, is the perception of consumers - as prospective co-producers of plastic packaging waste and contributors to its management outcomes (e.g. sorting recycling, returning packaging) - on the value of the plastic package. The consumer buys a product contained in plastic as it preserves and protects the product, or they choose to use plastic packaging even when the product is not contained in them in order of convenience (e.g. loose fruits and vegetables) and/or for safely carrying the product from the retailer to their household (e.g. plastic bags). In both cases consumers consider plastic packaging to be a valued product due to the functionality it serves, and is where most of the packages' value is created. When the consumer removes the product from the packaging, the packaging immediately loses its primary function and becomes waste with a zero perceived value.

Nonetheless, the true value loss occurs at the stage where the consumers makes the decision of how to dispose the plastic packaging waste. Consumers' behaviour at this stage is pivotal in determining the plastic packaging waste fate. A number of factors such as cultural, economic, educational, come into the mix affecting the fate of the plastic packaging waste. For example, some consumers may choose to recycle plastic packaging waste due to personal values and/or the moral obligation of doing so, while others may decide to dispose it to the residual bin due to lack of information or confusion as to how they should dispose of it.

Product information and recycling symbols on packaging can sometimes be confusing and misinterpreted leading to materials not being appropriately recycled. On-pack labelling is also essential for assisting residents with the knowledge of how to recycle. Consumers are increasingly confused over what they can recycle and what not, also due to the different rules about what can and cannot be recycled applied in different areas. As a result they may affect the quantity of recyclables collected, or unintentionally compromise the quality of recyclables collected. This is due to inconsistencies in the collection system and the types of materials collected for recycling, at different LAs that are considered to be an important constraint to improving recycling rates (WRAP, 2018a). To tackle confusion tackle confusion and make recycling easier the government has committed to make improvement in the collection systems. A proposal to accelerate consistency in the materials collected for recycling as a way to improve the quantity and quality of what is recycled both at home and at work in England is currently under development (Defra, 2019a).

Then there is also the issue of the asymmetric information involved:

- Plastic packaging is often used to preserve and protect the product, but it is also used for marketing purposes and to make a product attractive to the consumer, often with the intention of influencing consumers purchasing decisions. At the time of the transaction (i.e., the purchase of the primary item), the consumers are generally unaware of the high price that they (directly) implicitly incur for plastic packaging as it is contained in the overall purchase price of the primary product. Hence, they become blind to the £1,900 per tonne of plastic packaging wealth they transfer to the manufacturing industry. At the same time, the consumers are also generally unaware of the true cost involved in the management of this waste that they finance via the tax they pay to the local government. The consumer comes to perceive of plastic packaging as being a low cost and high-value packaging material due to the functionality it serves (e.g. portability of drinks, means to carry loose vegetables and fruits), and thus over-consumes it on the basis that they are paying for the recycling of the packaging waste they generate.
- Consumers think that they pay for the collection of plastic packaging waste via the council tax. While it is true that a fraction of the council tax is allocated to waste management, it makes little difference to the consumer if they produce, 5 kg, 10 kg of plastic packaging waste a year or 20 kg as they always pay the same amount of council tax. For this reason, they never perceive the marginal cost arising from each additional unit of plastic packaging that they produce. Hence, we have a moral hazard situation.

- Consumers are also likely to be unaware of the true costs involved in the plastic packaging waste management process that indirectly have to pay for. As a result they tend to overconsume products contained in plastic packaging, and generate and discard a large amount of plastic packaging waste, often disposing it improperly, ignoring the real costs involved.
- Consumers are likely to be similarly ignorant with regard to the true environmental costs that arise from plastic packaging waste; a social cost that might, in fact, never be accurately reflected in any current price figures. However Blue Planet 2 and other media spotlights have raised the wider impacts of plastics to consumers more recently.

Consumers have a critical role to play in achieving the ambitious targets set by the government. Their role can be spread into different levels of action: during purchasing decisions – opt out for no plastic where not needed; at the consumption stage – perhaps reuse the package (e.g. plastic bottle reuse, punnet reuse) a couple of time before discard; at the disposal stage - separating the plastic packaging waste properly at source (i.e., household level and appropriate bins while on the go). And this is just a simplified representation of some key issues; the role of the consumer in the plastic packaging system is far more complex and beyond the scope of the analysis carried out in this report.

For the UK to achieve its recycling targets as outlined in the UK Plastics Pact far-reaching behavioural change is likely to be needed in relation to plastic, e.g. reducing consumption of single-use plastic items (such as food packaging and water bottles) and recycling them.

5. VALUE RATIONALISATION AND METRICS SELECTION AND DEVELOPMENT

In CVORR, we introduced the concept of multidimensional value; the positive and negative impacts in the environmental, economic, social and technical domains as influenced by the respective political and institutional structures. Values can be conceptual, quantitative and qualitative.

To identify values and the representative metrics for their measurement we must first make explicit what is it that needs to be optimised in the resource recovery process from waste system. The use of the CVORR *baseline analysis* (Steps 1-5, *Figure 3-1*), i.e. mapping the mass and monetary flows, identifying relevant stakeholders and their power relationships, and analysing the system structure, dynamics and drivers, helps us to understand the challenges in governing the plastic packaging system, and rationalise the values selected for its assessment.

To aid values rationalisation and enable the selection and/or development of metrics for their measurement, we need to clearly understand the problem and state the objective of the analysis. Specifically, we need to gain a detailed insight into the system structure, dynamics and drivers (i.e. cause and effect relationships). Values are informed by aspects that describe the intensity of the problem, factors that cause the problem in the first place, and lock-in situations that demonstrate the importance of monitoring progress over time.

In our analysis, the problem is that plastic packaging recycling rates in England are too low. Therefore, the objective of the analysis was to help the government devise new metrics to monitor and assess progress towards increasing the plastic packaging recycling rate up to 70% by 2025, minimise plastic packaging POM and improve the recycling of plastic packaging POM domestically. Some of the values that emerged from the CVORR *baseline analysis*, are:

- Plastic packaging waste is not properly sorted at source.
- Plastic packaging is littered.
- Some types of plastic packaging (multi-layered, black) are not recycled.
- Sorting facilities have a high rejection/losses rate.
- PRNs not distributed equally.
- Design changes on plastic packaging cannot be easily implemented.
- Exported plastic packaging waste is considered to be recycled and is taken into account in meeting the recycling targets.
- Plastic packaging tax is important in improving recycling rates.

Embedded values (e.g., raw material consumption, energy use, embodied carbon, water use, additives, etc.) associated with the lifecycle fate of plastic packaging were not considered in

this analysis. It must be emphasised that such values need to be taken into account when assessing the sustainability of any resource recovery system.

According to Mitchell et al. (1995) metrics can help us interpret values (issues of concern) in 'complex systems' and enable us to measure and assess progress towards specific goals and objectives. To succeed on that, metrics must be used as a means to assess current situations in relation to a desirable state, and communicate this effective to stakeholders so that effective management decisions can be taken towards achieving a particular goal (Mitchell et al., 1995). In other words, our selection of metrics must support us in the following key considerations:

- gain insights into the business-as-usual;
- measure the performance of current and future policies (assessment); and
- track the progress of new initiatives (monitoring).

Metrics selected to measure short-term improvements within the current system, must align with existing policies and inform changes needed to support UK's transition to a circular economy. An important aspect to think about is the longevity of the waste policy changes in the UK, and support issues that are not considered now, but may be important in the future. This will ensure support in the monitoring process, helping to capture responses to policy and processes changes in England in the long-term.

A top-down and a bottom-up approach is used for metrics selection and development. In the bottom-up approach, metrics selection occurs heuristically from existing pools of metrics. CVORR research has identified more than 100 metrics that can be used to assess the economic, social, environmental and technical aspects of resource recovery systems (Iacovidou et al., 2017b). Other pools might be directly related to the particular system analysed in relevant works. Relevant documents (academic and technical) must be reviewed across the environmental, economic, social and technical aspects related to a specific assessment to identify potentially useful metrics.

For example, in the Resources and Waste Strategy for England, published on December 2018, the Government has generated its own list of metrics for measuring progress against the Strategy's objectives. The metrics developed correspond to six strategic indicators[14] (in CVORR this is 'values') that have been developed to monitor progress towards meeting three of the goals of the 25 Year Environment Plan, namely *using resources from nature more sustainably and efficiently* (goal number 5), *mitigating and adapting to climate change* (goal

[14] Strategic indicators are: Resource productivity; Greenhouse gas emissions; Waste production; Recycling; Landfilling; Waste crime.

number 7) and *minimising waste* (goal number 8). Each Key Strategic Indicator has one or more metrics associated with it. The full list of metrics is presented in Table 3-2.

Table 5-1 List of metrics developed by the UK government to measure progress in meeting the targets set in the Resources and Waste Strategy for England

METRIC	STRATEGIC INDICATOR CORRESPONDS TO	MEASURED USING
RAW MATERIAL CONSUMPTION	Resource productivity	Tonnes per capita, -£ GVA per tonne
CARBON FOOTPRINT OF WASTE (IN LINE WITH CARBON BUDGET DEFIN.)	Greenhouse gas emissions	Unit of footprint per capita, £ GVA per unit of footprint
CARBON FOOTPRINT OF CONSUMPTION	Greenhouse gas emissions	Unit of footprint per capita, £ GVA per unit of footprint
CARBON FOOTPRINT OF SHOPPING BASKET OF CONSUMER PRODUCTS	Greenhouse gas emissions	Index
TOTAL WASTE GENERATED	Waste production	Tonnes per capita
TOTAL RESIDUAL WASTE GENERATED PER CAPITA	Waste production	Tonnes per capita
HOUSEHOLD WASTE RECYCLING	Recycling	Recycling rate (tonnes recycled as a proportion of total household waste)
MUNICIPAL WASTE RECYCLING	Recycling	Recycling rate (tonnes recycled as a proportion of total municipal waste)
COMMERCIAL AND INDUSTRIAL WASTE RECYCLING	Recycling	Recycling rate (tonnes recycled as a proportion of all waste)
LANDFILLING	Landfilling	Tonnes
LANDFILLING OF BIODEGRADABLE WASTE	Landfilling	Tonnes
ILLEGAL WASTE SITES	Waste crime	Number of sites
FLY-TIPPING	Waste crime	Number of incidents
LITTER	Waste crime	Use of dashboard set out in the litter strategy

In the top-down value-focused approach, metrics selection and/or development follows a two-stage method. In the first stage, metrics selection and development is informed by the values evolving from our analysis (inductively), and in the second stage it involves an expert

workshop for discussing and aiding key metrics selection (deductively). This two-stage approach was adopted to increase the robustness of the metrics selection process.

5.1. ANALYSIS FOR METRICS SELECTION AND DEVELOPMENT

CVORR *baseline analysis* provides the necessary background for effective and useful metrics to be developed. It helps us to understand the context in which institutions, processes and structures interact in the plastic packaging system in England. This context helps us to rationalise the core values embedded in the system. Therefore, selection and development of metrics for measuring the identified values evolves naturally from our analysis, and is a sensible approach to use. It builds on the core strength of the CVORR *baseline analysis* (i.e., the mass and monetary flows quantification and analysis of system dynamics and drivers), and allows us to deliver a coherent story to the rationalisation of metrics selected for their measurement.

As the values derived from a systems analysis can be many and varied, so can be the metrics used to measure them. To address this ambiguity, we supported the process of metrics selection by setting a number of criteria. To develop the criteria we agreed that our proposed metrics should be: a) meaningful and applicable to the context they will be used; b) complementary to the metrics selected from the bottom-up approach (e.g. complement Defra's metrics); c) capture system and stakeholder specific aspects (i.e. reflecting the unique contribution of CVORR analysis); d) sufficiently general, but also scalable to aid system assessment at 'current state' and over time (i.e. dynamic); and e) sufficiently generic to cover 'macro-aspects', yet provide a suitable minimum level of detail (across all domains of value) required in assessing the specific system, and its overarching 'problem'. Therefore, the proposed criteria developed mandated that metrics selected must:

- be easy to understand;
- be simple to use;
- represent the issue under consideration (i.e., 'fit for purpose');
- can be measured and tracked over time (scalable); and
- be appropriate for the specific system and governance context (contextual).

Based on the above criteria the following metrics have been proposed under each domain of value: environmental, economic, social and technical (Tables 1-4).

Table 5-2 Environmental metrics proposed for the plastic packaging system assessment

PRIORITY ORDER (TOP DOWN)	WHY?	UNIT
REPROCESSING EFFICIENCY	To measure the proportion of plastic material that is reprocessed into secondary material within the UK.	% wt. (tonnes of plastic packaging waste reprocessed into secondary material as a proportion of overall waste generated*)
POST-CONSUMER RECYCLED CONTENT IN PACKAGING	To capture the proportion, by mass, of post-consumer plastic packaging waste that is used in new packaging produced and used domestically.	% wt. in a new plastic packaging produced
% PLASTIC PACKAGING WASTE EXPORTED	To measure the amount of plastic packaging waste exported, and the degree of allocated responsibility elsewhere in the system due to the likelihood of exported plastic packaging waste to escape into the environment.	% wt. (tonnes as a proportion of overall waste generated*)
ENERGY RECOVERY EFFICIENCY	To measure the net-gain of the energy content of plastic packaging waste (calorific value) using the energy output that is recovered in the form of electricity and heat.	% (kWh/t)

Table 5-3 Economic metrics proposed for the plastic packaging system assessment

PRIORITY ORDER (TOP DOWN)	WHY?	UNIT
PLASTIC LAND, RIVERINE AND MARINE LITTER DAMAGES, LOSSES AND CLEAN-UP COSTS	To capture the total spent on clean-ups, damages and losses in to fisheries, shipping, tourism, wellbeing and remediation activities.	£
COST EFFICIENCY / REVENUE LOST (E.G. FROM LANDFILLING; EFW; EXPORTS; LITTER; FLY-TIPPING)	To capture the cost that can be avoided and/or the revenue that can be captured if recycling is increased.	£

Table 5-4 Social metrics proposed for the plastic packaging system assessment

PRIORITY ORDER (TOP DOWN)	WHY?	UNIT
ACCEPTABILITY / CONVENIENCE	**TO UNDERSTAND POTENTIAL IMPLICATIONS OF HOUSEHOLDERS RESPONDING TO BANS, DESIGN INTERVENTIONS AND ON THE DEPOSIT RETURN SCHEMES.**	**QUALITATIVELY**
PARTICIPATION RATE IN RECYCLING SCHEMES	**TO MEASURE PROGRESS IN PEOPLE PLACING RECYCLABLE MATERIALS IN RECYCLABLE COLLECTION STREAMS WITH CONSISTENT COLLECTIONS.**	**% WT. (TONNES OF PLASTIC PACKAGING WASTE THAT ENDS UP IN THE RECYCLING WASTE STREAM PER OVERALL WASTE GENERATED*)**
INEQUALITY	**TO MEASURE THE ALLOCATION OF THE COSTS (AND INCOMES) PRODUCED BY THE RECYCLING PROCESS IN THE OVERALL SYSTEM, IN ORDER TO IDENTIFY THE MISALIGNMENT BETWEEN THE COST-BEARING (E.G. GOVERNMENT) AND REVENUE EXTRACTION ACTIVITIES.**	**% (ON £)**

Table 5-5 Technical metrics proposed for the plastic packaging system assessment

PRIORITY ORDER (TOP DOWN)	WHY?	UNIT
% SORTING FACILITIES EFFICIENCY	To capture losses/rejections of plastic packaging waste sent to sorting facilities (i.e. MRFs and PRFs); reflects changes in design and collection	% wt. (tonnes output per tonnes input of plastic packaging waste received at sorting facilities, i.e., MRFs and PRFs)
% COLOURED PLASTIC PACKAGING SORTED	To measure the proportion of coloured plastic packaging in total plastic packaging sorted for recycling, in order to reflect on amount of packaging that will go into lower quality applications (colour is restrictive)	% wt. (tonnes of coloured plastic packaging as a proportion of overall waste sorted for reprocessing)
% MULTILAYER PLASTIC PACKAGING	To measure the proportion of plastic packaging that cannot be recycled due to designed attributes	% wt. (tonnes as a proportion of overall waste generated*)

5.2. EXPERT WORKSHOP

The workshop was divided into two parts. The first part of the workshop aimed at communicating the usefulness of the CVORR *baseline analysis* in describing the system holistically, and gauging the opinion of participants. The aim of the second part of the workshop was the presentation of the selected metrics. Participants were asked to discuss the potential usefulness of proposed metrics in assessing and monitoring changes in the plastic packaging waste system in England in the short- and long-term, and select one key metric from each domain of value.

The workshop involved 12 experts that were split into 3 groups. The experts' respective backgrounds encompassed the fields of waste management, policy (incl. regulation) and the social sciences, particularly economics. There was a fair mix of technical experts, practitioners, academics, and policy-makers with experience in waste management and planning, particularly plastics.

In the first part of the workshop the groups were asked to discuss the strengths and weaknesses of our analysis in unpacking the specificities and underlying aspects of the plastic packaging waste in England. We used Sli.do to record their responses.

We received 30 responses in total. Some of these responses were recommendations for future work, which formed part of the next task. For clarity, these recommendations have been allocated to the appropriate table (Table 5-7).

Table 5-6 Strengths and weaknesses of the plastic packaging waste system analysis

STRENGTHS	***WEAKNESSES***
- Holistic analysis, including future developments, including systematic analysis of unintended negative and positive side-effects. - Good exercise to see the status quo. - Useful insight into entire system - Accept that environmental standards are often lower where the recycling occurs, but regulatory costs do tend to lead to displacement (e.g. EU emissions trading). - Captures wider social impacts and issues - consumers' awareness. - Streamlines the entire system - greater transparency	- Not useful without having insight into alternative material flows. - Need to distinguish open and closed loop recycling; lifecycle impacts are very different. - Different types of plastics present different challenges. - Better insight needed on the way different collection methods impact reprocessing/ follow-on steps. - Assumption that export is negative (lost value) when evidence suggests overseas losses may be similar to those in UK. Most manufacture is overseas. - Greater detail about revenue flows needed

STRENGTHS	*WEAKNESSES*
- Flow of material - economic and financial incentives of consumers for recycling - Clear focus on materials (with value) avoids getting bogged down in legal waste definitions - Picture to better understand what we are talking about and a good overview. Valuable for future conversations, development ideas, help in discussion	- Difficulties at different collecting places need to be accounted - Indicate other additional costs at each stage in reprocessing as the given not the only cost factor - Down to supply chain impacts when increasing the recycling - Relating the other aspects to financial aspects important but more clarity required, what they mean - Cash flow capture one aspect, but other financial flows as the former do not exist in isolation

After discussing the strengths and weaknesses of the analysis, the groups were asked to offer recommendations for improvements and future work. The following Table presents their responses.

Table 5-7 Recommendations for future improvements in the analysis

RECOMMENDATIONS FOR FUTURE ANALSYSIS
- There should be two different stories for different types of plastic rather than a general story as different types of plastic. - Who impacts who? - The value that is delivered- in landfill long term safe disposal that is controlled - Keep questioning every little aspect - other aspects opex and capex and the other value that is created in the process - Integrate a differentiated view on plastic packaging, e.g. length of life time. - Integrate potential for more (financial) producer responsibility. - What would the alternatives look like? Alternative use of resources, material, alternative. - Analysis of profitability of investments (or other changes) for various stakeholders, under various regulatory and tax/incentive regimes. - More information about profit margins, job creation and value that creates. - Important to understand what happens within the boxes on the diagram, e.g. reprocessors. - Also consider other outputs from the processes. - Strengthen EPR - potential re-integration of some waste management in business operation - or cooperation of businesses. - Add granularity on reprocessed plastic. - Internationally accepted buying and selling standards also for plastic, like for paper and metal; industry standard process.

RECOMMENDATIONS FOR FUTURE ANALSYSIS

- Where is the revenue from EPR going?

In the second part of the workshop the groups were asked to rank the proposed metrics in terms of their priority order, and explain which one they would select as their top metric. They were also asked to comment on whether the metrics proposed fit the criteria we used for their selection. For recapping, the criteria are as follows:

- Easy to understand
- Simple to use
- Fit for purpose (i.e. representative of a problem)
- Useful in monitoring progress (measured and tracked over time)
- Appropriate for the specific system and governance context (contextual)

<u>Views and suggestions on the environmental metrics</u>

- ***Reprocessing Efficiency****:* suggested to be a streamlined and refined version of 'recycling efficiency'; useful; selected amongst the top metrics. This is already used to capture losses in plastic packaging waste sent for recycling.
- ***Post-consumer recycled content in packaging***: useful and insightful in terms of meeting future policies. Second top metric. Difficulties in measuring *recycled content*, were expressed as plastic comes from all over the world, making it very difficult, or even impossible to determine in a globalised market, particularly as producers are unlikely to provide the required information.
- ***% Plastic packaging waste exported*****:** Would ideally require a list of countries of destination (current), as well as a 'blacklist', i.e. countries to which plastic packaging waste ought not to be exported (might be politically difficult?). Environmental protection standards across countries - for *exporting* metric - to discourage export to countries with lack of capabilities. It is important that the chosen metrics can be relevant in 5, 10, 15, 25 years, and in various scenarios. There was no mention in our selected metrics on the circular economy indicators. How can these be integrated into the assessment process?
- ***Energy recovery efficiency***: This metric might be an economic rather than an environmental one, because is the production of more energy (and associated CO2 emissions) really environmentally desirable – some might prefer having plastic packaging waste being landfilled (a safe option in the UK) rather than it being burnt for environmental reasons.

Additional comments: The first two metrics (the proportion of plastic packaging that is reprocessed into secondary material, and that that is reprocessed into packaging) seemed to come out top. It was strongly suggested that C and I plastic packaging should be included in the analysis, even if it's only the household-like material (e.g., plastic PET and HDPE bottles used in restaurants, hospitality etc). Also disaggregating to polymer types, and into primary and secondary plastic, would make metrics related to domestically produced/ imported/ exported rates more useful. It was also suggested that the data for these metrics could sensibly be collected facility by facility because different MRF's and PRF's tend to specialise in certain types of plastic. Adding granularity to the plastic packaging system is important for understanding its fate (within national boundaries). In globalised chains it is impossible to follow the fate of plastic packaging; complexity increases as different types of plastic have different stories to tell. An important question raised was "What is it that captures the environmental performance of plastic waste?"; 'environmental' metrics, e.g. LCA impacts categories, carbon emissions, toxicity, hazardous content/contamination, energy, litter/marine litter could be added to the mix. We need to take into account other externalities, not just carbon. Litter was agreed unanimously that it fits into the environmental domain, and must be included. It was suggested that *Energy efficiency* could fit into the economic metrics; it can be a bit dubious for environmental metrics; it is often presented to be positive for the environment.

Views and suggestions on the technical metrics

- ***% sorting facilities efficiency****:* losses at this stage might be a useful metric; adding granularity on recycling, downcycling and upcycling percentages was suggested to be useful, as well as the need to rename this metrics '*percent-losses for sorting facilities'*.
- ***% coloured plastic packaging sorted:*** useful; might be difficult to associate with value in the long-term due to changes in design and technology.
- ***% multilayer plastic packaging:*** useful; this packaging is a good metric, but concerns raised regarding the functionality of this packaging and that is a heavily invested area for industry.

Additional comments: Technical metrics should be able to capture the material innovation and the designer choices. All three suggested metrics are recognised as important, but might be best to just record tonnes of material rejected, ditto coloured and multi layered material. The percentages can always be calculated separately to put them into context. We must be careful not to prejudge what would be the desired movement of an indicator here. For example, in a few years' time, a fall in the proportion of black packaging rejection might be because of developments in technology that allows black packaging to be recycled. Similarly, new technology might come along that can deal with 'multi layered' plastic packaging.

Views and suggestions on the economic metrics

- ***Plastic land, riverine and marine litter damages, losses and clean-up costs:*** useful and important; but it's very difficult to quantify the cost of amenity of litter, and fly-tipping on tourism and well-being, and even more difficult to narrow that down to plastic packaging, unless it is done on a compositional basis of litter items found and allocate costs accordingly. Perhaps easier to focus more on measurable impacts, i.e. *plastic litter generated; % packaging in plastic litter collected; costs of plastic clean-up* rather than getting into the factors causally responsible for littering because these are many and not well understood at present, e.g. psychological causes of littering. In regards to *plastic clean-up costs*, this incurs a cost only if the waste is actually cleaned up, and it should not be excluded to marine or beach waste only. There are externalities associated with plastic litter and monetarizing externalities can be difficult and often misleading.
- ***Cost efficiency:*** this was the most popular metric in terms of capturing costs that can be avoided and/or the revenue generated if recycling is increased. Recognition that 1 tonne of packaging that is reprocessed means 1 less tonne in residual waste. What are the associated cost savings, e.g. transport, energy, carbon?

Additional comments: The purpose of the economic metrics should be to capture a generalizable aspect related to plastic packaging management. Some basic economic data on the plastic production, distribution, management industry and the related local and central governments (e.g. turnover, employment) can be useful to demonstrate who bears the actual cost. There is currently a lot of uncertainty in this domain and lack of knowledge.

Views and suggestions on the social metrics

- ***Acceptability****:* rejected, because the adequate policies and leadership are required to create the appropriate type of acceptability. It needs leadership to create acceptability.
- ***Convenience****:* important and useful; interesting, but not easy to measure. Measure of convenience or degree of content? This might be tricky to clarify substantially to allow its use.
- ***Participation rate in recycling schemes:*** (i.e. the % people who recycle) is important to understand households' understanding, perception and habits of recycling; the extent to which people consider recycling useful and trust that the government does what it takes to manage the plastic waste properly influences their participation rate. But, an increased *participation rate* doesn't necessarily translate into consumers doing the right thing – they might still be putting things in the wrong bins. People are often unaware of the differences between different types of plastic packaging, which hinders their ability to sort them properly. Therefore, there is a trade-off between

quantity (placing all plastics in the recycling bin) and quality (contaminating recyclable plastics with other types) of the material. New technological developments might lead to less sorting at household eventually. But currently, sorting is needed and emphasis needs to be placed on improving the impact of '*participation'* in the system, now and in the medium- and (potentially) long-term. Therefore, this metric can be important to use in assessing participation to the recycling process in general, and the usefulness of information and tools provided to support them. Another question, for the future: if automatization continues and technological advances at the sorting stage improve, might it be possible to lift the burden of sorting from the households and move it back to the sorting facilities?

- ***Inequality****:* this metrics was the most popular; solidly expressed that there is a need to rename it because 'inequality' has emotive connotations. The idea behind this metric was suggested to be extremely important, although issues were raised that link back to monetary flows – what does the diagram really tell us? Important to have a detailed understanding of the economic processes involved and the flows. EPR systems are trying to do this. Hundreds of data points to measure the inequality. Share of producers in paying for collection and recycling (that is not profitable at this point in time).

Additional comments: Suggestions for identifying/developing a metric that could reflect the success of local initiatives to increase packaging recycling, particularly if this could be related to, for example, a reduction in council tax because of less contamination, more recycling and higher sales of recyclates. This metric would also help measure people engagement. Another suggestion for a social metric was the measurement of jobs created and jobs lost. Difficult to create jobs in the sector due to technological advances, e.g. robotics in sorting. Focus on the outcome of littering rather than moving to people's actions and incentives to litter. Littering relates to peer pressure, ownership of the space, as in private space not acceptable but perhaps in public itis, generally the relationship to space. Share of plastic packaging clearly readable labelled by polymer type (triangles with numbers).

5.3. GENERAL OVERVIEW OF WORKSHOP FINDINGS

The expert workshop has acknowledged the importance of a systemic analysis for understanding the challenges related to closing the plastic packaging loop. It also exposed further challenges associated with the plastic packaging system that future studies might need to take into account. For example, the sustainability of closed- vs open-recycling is important to be analysed for different plastic types for promoting future solutions. Granularity per plastic type is need to understand aspects that govern their current recycling rates.

A zooming in on different aspects (e.g. collection and sorting, and related financial aspects) adds an important layer of information to the analysis. It might reveal lock-in situations due

to the technical interrelatedness (complementarity/modularity) among different parts of the system (i.e., collection, sorting, reprocessing, and exports), system scale economies and quasi irreversibility of the investments because of high switching costs. The extent to which these lock-ins create inefficiencies in the plastic packaging system needs to be explored further.

As Cecere et al. (2014) suggest, core competences can turn into core rigidities. When technology and innovation introduces alternatives into the system, LAs and waste management industry's knowledge (i.e. the knowledge about the way in which the components of a technical system interact) must also adapt. However, this is not a straightforward process. Regulatory reforms, budget cuts, existing infrastructure, financial contracts, etc. may pose formidable barriers, and LAs and industry may struggle to reconfigure their respective capabilities in order to maintain a successful process operation and market leadership.

The current EPR implementation and the way the PRNs system currently operates creates another 'lock-in' situation. PRNs/PERNs ensure compliance in the recycling of plastic packaging and create demand for plastic packaging waste as a secondary resource. But this scheme, also creates a particular set of routines and competences that bound industries' behaviour and limit their adaptive intelligence, making it possible for them to search, explore and learn only at a 'local' level (Cecere et al., 2014). Routines developed over time and a long specific technological and institutional trajectory can be constraining forces (Cecere et al., 2014). These aspects must be addressed in the analysis to show that change and innovation can cause disruption in the way organisations operate and the system as a whole, and adaptation activities and processes to the new context will be needed to help companies overcome such issues.

Besides the technological and organizational sides of lock-in, there are also constraints in increasing the plastic packaging recycling rates associated with consumers. The purchase of plastic packaging, the participation in the recycling collection schemes, littering, etc. are affected by consumers' characteristics, attitudes and behaviours. More clarity and a better understanding of the impact of these on plastic recycling system is required.

A number of recommendations were made for addressing some of these issues. A better understanding of the financial viability and risk of investing in improving plastic packaging recycling rates and of the organisational aspects associated with it, was flagged as most desirable. The need for granularity in the system in terms of types of plastic and lifecycle fate was also suggested as a future research topic, although the challenges related to such a detailed view of the system were discussed. Comparisons with other materials was suggested to be useful to understand other underlying environmental, economic, social, technical, and organisational issues associated with this material type.

The decision of which metrics could be most suitable, appropriate and beneficial for the government to use for assessing and monitoring progress in the short-, medium- and long-term reinforced the challenges raised in first part of the discussion. Context appropriate metrics were decided to be the best ones in measuring progress in the plastic packaging system, as well as those that can continue to be used to monitor change in 5, 10, 15 years.

Experts also pointed to the need for more than one metric in some domains and specifically on the environmental and technical in order to make future assessments more meaningful and useful.

The metrics that were selected from each domain are as follows:

- **Environmental:** *Reprocessing efficiency*
- **Technical:** *Percent losses for sorting facilities*
- **Economic:** *Cost efficiency*
- **Social:** *Inequality*

6. DISCUSSION AND CONCLUSIONS

The selection of appropriate metrics that can be used for monitoring and assessing progress in meeting the targets set by the Government is important, but it must be put into systemic context. There are some major challenges associated with the plastic packaging system that this report has analysed, associated not only with the need for achieving higher recycling rates, but with the aspiration to bring about change and to monitor that change. Addressing these institutional, economic, environmental, technological and cultural challenges requires a holistic understanding of the key processes, stakeholders and values and of the ways that these intertwine in the plastic packaging system, from extraction and production to disposal and waste management. The CVORR approach employed in this report provides a structured method to address the multidimensional nature of systems, and guards against the dangers of looking closely at only one part of the chain, or looking at the system through only one lens (e.g. environmental or economic).

Confronting and breaking the lock-ins to current regulations and infrastructures is key to achieving more sustainable transformations in the plastic packaging system and in resource recovery systems more generally. Infrastructure investments in the waste and resource sector designed and implemented alongside policy interventions can help create demand for recycled materials and stimulate design for recyclability in the plastic packaging system. To build demand for recycled materials requires government and businesses to reinvent their relationship and make it economically viable. Essentially, understanding stakeholders' values, interests and behaviour, through the analysis of the system as a whole, is important in finding ways to better connect the downstream with the upstream part of the plastic packaging value chain, overcoming barriers and socio-technical prejudices against recycled or alternative materials, components and products.

To achieve the recycling rates set by the UK Government there needs to be a system change. It cannot be done by siloed-thinking and interventions that focus only on one or a few parts of the plastic packaging system. Regulators, local, regional and national government need to work together with brand designers, manufacturers, importers, wholesalers, retailers, waste management companies, recyclers, consumers and other organisations (e.g. trade-unions, associations) to coordinate their actions across the system and make it economically feasible to maintain secondary materials markets; to promote technological innovation and investment; to consistently implement transparent environmental policies; and to use information-based instruments to raise consumer awareness and create a sense of ownership of environmental goals to improve waste separation at households and minimise litter and illegal disposal.

The current EPR implementation creates a particular set of routines and competences that are bound to lead to failure. For example, it overburdens LAs with the cost of collection and management of plastic packaging waste, offering very little (if any) cost compensation. It also

hampers infrastructure investment due to uncertainty over cost returns leading to a growing dependence on export markets, and encourages a lack of transparency regarding the sale of evidence notes and the way income therefrom supports recycling of packaging waste. The new EPR proposal for reforming the UK Packaging Producer Responsibility System is being designed to correct these failures and support improvements in the system (Defra, 2019b). The government also aims to tackle confusion and make recycling easier by making improvement in the collection systems. A proposal to accelerate consistency in the materials collected for recycling as a way to improve the quantity and quality of what is recycled both at home and at work in England is currently under development (Defra, 2019a).

As the UK addresses the issue of Brexit, there will be uncertainty in the way waste and resources are governed. The European policy on waste has over the past forty years helped the UK to make significant progress in improving waste management, via deep changes in the infrastructural and organisational system that enabled and regulated the efficient collection and management of waste, including plastic packaging waste.

The future policy direction set by the UK Government looks promising in securing the positive impact made over the past years. However, proper assessment and monitoring of the progress made to minimise plastic packaging POM and to recycle more of what is placed on the market is needed to make UK the beacon of change. The use of the CVORR approach, tracking all kinds of value across interlinked systems, is expected to play a key role in ensuring the alignment of policies with tangible impacts over time, helping the UK move toward sustainability.

With CVORR, new interventions and policy measures can be examined via the lens of multi-dimensional value to ensure that any interventions can unlock more positive than negative impacts through orchestrating the whole value chain. This requires forward-thinking and time-investment in understanding how waste and resource systems evolve, culturally, temporally and spatially, and what are the positive and negative environmental, economic, social and technical impacts associated with their production, use and management. There is no one perfect solution. Many well-targeted and informed ways of addressing the multidimensional impacts revealed by a systems approach, such as CVORR, is the only way to achieving the desired sustainability goals.

7. REFERENCES

BPF. 2018. *Recycling Plastic Packaging. Available at: http://www.bpf.co.uk/packaging/recycling.aspx* [Online]. London, UK: © Copyright British Plastics Federation 2018. [Accessed 2018].

CECERE, G., CORROCHER, N., GOSSART, C. & OZMAN, M. 2014. Lock-in and path dependence: an evolutionary approach to eco-innovations. *Journal of Evolutionary Economics,* 24**,** 1037-1065.

COOK, E., WAGLAND, S. & COULON, F. 2015. Investigation into the non-biological outputs of mechanical–biological treatment facilities. *Waste Management,* 46**,** 212-226.

DAVOUDI, S. 2009. Scalar tensions in the governance of waste: the resilience of state spatial Keynesianism. *Journal of Environmental Planning and Management,* 52**,** 137-156.

DAVOUDI, S. & EVANS, N. 2005. The Challenge of Governance in Regional Waste Planning. *Environment and Planning C: Government and Policy,* 23**,** 493-517.

DEFRA 2011. The Economics of Waste and Waste Policy. *Environment and Growth Economics, Defra* London: Department for Environment, Food and Rural Affairs.

DEFRA 2012. Updated compositional estimates for local authority collected waste and recycling in England, 2010/11 - EV0801. A report prepared by resourcefutures for Defra. *Science and Research projects.* London, UK: Department for Environment, Food and Rural Affairs.

DEFRA 2018a. Digest of Waste and Resource Statistics - 2018 Edition. *Official Statistics, Open Government Licence v3.0.* Department for Environment, Food and Rural Affairs.

DEFRA 2018b. Digest of waste and resource statistics, 2018 edition. London, UK: Department for Environment, Food and Rural Affairs.

DEFRA 2018c. Fly-tipping statistics for England, 2017/18. London, : Department for Environment, Food and Rural Affairs (Defra).

DEFRA 2018d. Our Waste, Our Resources: A Strategy for England. London: Defra, Resources & Waste Strategy Team.

DEFRA 2019a. Consultation on consistency in household and business recycling collections in England. London: Department for Environment, Food and Rural Affairs (Defra).

DEFRA 2019b. Consultation on reforming the UK packaging producer responsibility system - Summary of consultation responses and next steps. Open Government Licence v3.0. www.nationalarchives.gov.uk/doc/open-government-licence/ Crown Copyright.

DEFRA 2019c. Reforming the packaging producer responsibility system in the United Kingdom. Impact Assessment (IA). London: Department for Environment, Food and Rural Affairs (Defra).

EA 2017. Evidence - Waste crime interventions and evaluation project. Bristol, BS1 5AH, http://www.gov.uk/government/organisations/environment-agency: Environment Agency.

EEA. 2019. *Recycling of municipal waste* [Online]. Brussels: European Environment Agency. Available: https://www.eea.europa.eu/airs/2018/resource-efficiency-and-low-carbon-economy/recycling-of-municipal-waste [Accessed].

ELLIOTT, T. & ELLIOTT, L. 2018. A Plastic Future: Plastics consumption and waste management in the UK. A report for WWF: Prepared by Eunomia Research and Consulting Ltd. Bristol, UK: World Wildlife Fund (WWF).

ENVIRONMENTAL AUDIT COMMITTEE 2017. Plastic bottles: Turning Back the Plastic Tide. *First Report of Session 2017–19; HC 339.* Published by authority of the House of Commons.

EU 2011. Commission Decision 2011/753/EU of 18 November 2011 establishing rules and calculation methods for verifying compliance with the targets set in Article 11(2) of Directive 2008/98/EC of the European Parliament and of the Council notified under document C(2011) 8165. Brussels: European Union.

FULFORD, J. 2013. *Local authority waste contracts: who's the daddy?* [Online]. isonomia. Available at: http://www.isonomia.co.uk/?p=2157. [Accessed].

GOV.UK. 2014. *Guidance: Waste. Provides further information in support of the implementation of waste planning policy.* [Online]. UK Government. Available: https://www.gov.uk/guidance/waste [Accessed].

HAHLADAKIS, J. N., PURNELL, P., IACOVIDOU, E., VELIS, C. A. & ATSEYINKU, M. 2018. Post-consumer plastic packaging waste in England: Assessing the yield of multiple collection-recycling schemes. *Waste Management,* 75**,** 149-159.

HM GOVERNMENT 2018. A Green Future: Our 25 Year Plan to Improve the Environment. London: Department for Environmnet Food and Rural Affairs.

HMRC. 2018. *Landfill Tax: increase in rates. Available at: https://www.gov.uk/government/publications/landfill-tax-increase-in-rates/landfill-tax-increase-in-rates* [Online]. London: HM Revenue and Customs (HMRC) for Landfill Tax. [Accessed].

IACOVIDOU, E., MILLWARD-HOPKINS, J., BUSCH, J., PURNELL, P., VELIS, C. A., HAHLADAKIS, J. N., ZWIRNER, O. & BROWN, A. 2017a. A pathway to circular economy: Developing a conceptual framework for complex value assessment of resources recovered from waste. *Journal of Cleaner Production,* 168**,** 1279-1288.

IACOVIDOU, E., VELIS, C. A., PURNELL, P., ZWIRNER, O., BROWN, A., HAHLADAKIS, J., MILLWARD-HOPKINS, J. & WILLIAMS, P. T. 2017b. Metrics for optimising the multi-dimensional value of resources recovered from waste in a circular economy: A critical review. *Journal of Cleaner Production,* 166**,** 910-938.

LARAC 2018. The future of local authority waste funding. A LARAC policy paper. Local Authority Recycling Advisory Committee.

MAXWELL, J. W., LYON, T. P. & HACKETT, S. C. 2000. Self-regulation and social welfare: The political economy of corporate environmentalism. *The Journal of Law and Economics,* 43**,** 583-618.

MITCHELL, G., MAY, A. & MCDONALD, A. 1995. PICABUE: a methodological framework for the development of indicators of sustainable development. *International Journal of Sustainable Development & World Ecology,* 2**,** 104-123.

NAO 2018. Ministry of Housing, Communities & Local Government, Financial sustainability of local authorities 2018. *HC 834 SESSION 2017–2019.* National Audit Office.

NATIONAL AUDIT OFFICE 2018. The packaging recycling obligations. *HC 1386 SESSION 2017–2019 23 JULY 2018.* London, UK: Department for Environment, Food & Rural Affairs and Environment Agency.

ODPM 2004. Planning for Waste Management Facilities: A Research Study. London: Produce by: Enviros Consulting for the Office of the Deputy Prime Minister.

OFT 2006. More competition, less waste. *Public procurement and competition in the municipal waste management sector* Office of Fair Trading.

PURNELL, P. 2019. On a voyage of recovery: a review of the UK's resource recovery from waste infrastructure. *Sustainable and Resilient Infrastructure,* 4**,** 1-20.

READ, A. D. 1999. Making waste work: making UK national solid waste strategy work at the local scale. *Resources, Conservation and Recycling,* 26**,** 259-285.

STATISTA 2019. Revenues from leading waste management services working in the United Kingdom (UK) in 2017/2018 (in million GBP). https://www.statista.com/statistics/298437/revenues-of-leading-uk-waste-management-services/: statista.

UKELA. 2018. *Law & Your Environment - The plain guide to environmental law* [Online]. UK Environmental Law Association. Available: http://www.environmentlaw.org.uk/rte.asp?id=85 [Accessed].

UYARRA, E. & GEE, S. 2013. Transforming urban waste into sustainable material and energy usage: the case of Greater Manchester (UK). *Journal of Cleaner Production,* 50**,** 101-110.

VALPAK 2011. PackFlow 2017. UK: A report jointly funded by Valpak Ltd and the Waste and Resources Action Programme (WRAP).

WILLIAMS, C. 2018. *ESA backs outsourcing as half of council waste contracts up for grabs* [Online]. Material Recycling World (MRW). Available at: https://www.mrw.co.uk/latest/esa-backs-outsourcing-as-half-of-council-waste-contracts-up-for-grabs/10029896.article. [Accessed].

WRAP 2009. MRF Output Material Quality Thresholds Banbury: Waste and Resources Action Programme (WRAP).

WRAP 2013. PlasFlow 2017 Banbury, UK: Waste and Resources Action Programme.

WRAP 2014a. Approaches to materials sales: A guide for local authorities, . *Section 7.0 Allocation of risk in collection contracts.* Banbury, UK: Waste and Resources Action Programme.

WRAP 2014b. Waste Regulations Route Map. Banbury, UK: Waste and Resources Action Programme.

WRAP 2018a. A framework for greater consistency in household recycling in England. Banbury, UK: Waste and Resources Action Programme.

WRAP. 2018b. *Plastic Packaging. Available at: http://www.wrap.org.uk/content/plastic-packaging* [Online]. Banbury, UK: Waste and Resources Action Programme (WRAP). [Accessed].

WRAP. 2018c. *The UK Plastics Pact* [Online]. Banbury, UK: Waset and Resources Action Programme Available: http://www.wrap.org.uk/content/the-uk-plastics-pact [Accessed 22 February 2019 2019].

WRAP 2018 PlasticFlow 2025: Plastic Packaging Flow Data Report. Banbury: Prepared by Valpak, Verde and Recoupx.

APPENDIX A

A.1. DATA COLLECTION AND PROCESSING

Table A-1 Mass flows data on plastic packaging flow in England on year 2010/11 (Tonnes)

			YEAR 2010/11 ENGLAND
UK Production			**BAU (Low)**
Consumption		**Assumption**	**2,027,600**
	based on source	**Consumer**	**1,677,551**
		Non-consumer	**151,001**
		TOTAL PLASTIC PACKAGING	**1,828,552**
Waste generation			
	Consumer (household):	**Plastic bags**	195,252
		Film packaging	456,058
		Drink bottles	264,255
		Non-drink bottles	161,562
		PTTs	600,423
	Non-consumer (C&I - LA collected):	**Plastic bags**	18,574
		Film packaging	43,495
		Drink bottles	17,510
		Non-drink bottles	8,239
		PTTs	63,183
		TOTAL	**1,828,552**
	Plastic packaging waste littered / fly-tipped rate in the UK	1%	**18,286**
	Plastic packaging littered (only)	0.4%	**7,204**
	Assumed to be collected	80%	
	Assumed to remain on restricted land	50%	
	Adjusted litter/ fly-tipping	**Estimated**	**10,971.31**
	Adjusted litter rate	**Estimated**	**0.60**
		TOTAL	**1,817,581**
Consumer (household) plastic packaging waste collected for recycling			
		Bags	
	at kerbside	**0.056**	10,889
	at HWRCs	**0.007**	1,395
	at Bring Sites	**0.000**	0
	at street	**0.000**	0
		Total (bags)	**12,284**
		Films	
	at kerbside	**0.041**	18,779
	at HWRCs	**0.005**	2,198
	at Bring Sites	**0.000**	0
	at street	**0.000**	0

	Total (films)	**20,977**
	ALL BOTTLES	
Collected at kerbside	**0.486**	**206,942**
Commingled	82%	169,693
Separate	18%	37,250
Brought to HWRCs	**0.029**	12,541
Brought at Bring sites	**0.026**	**10,968**
Commingled	4%	439
Separate	96%	10,529
Collected at street recycling	**0.003**	1,327
	TOTAL (all bottles)	**231,779**
	PTTs	
Collected at kerbside	**0.125**	**75,021**
Commingled	84%	**63,018**
Separate	16%	**12,003**
Brought to HWRCs	**0.003**	1,770
Brought at Bring sites	**0.007**	**3,976**
Commingled	4%	**159**
Separate	96%	**3,817**
Collected at street recycling	**0.001**	481
	Total (PTTs)	**81,249**
non-consumer:		
Bags	**0.000**	**0**
Film packaging	**0.000**	**0**
Drink bottles	**0.081**	**1,410**
Non-drink bottles	**0.145**	**1,198**
PTTs	**0.015**	**945**
Total non-consumer commingled	6%	**213**
Total non-consumer separate	94%	**3,541**
Collection for recycling (total)	**Consumer**	**346,289**
Collection for recycling (total)	**Non-consumer**	**3,553**
Collection for recycling	**TOTAL**	**349,842**
ERROR CHECK (diff.)		
Plastic packaging sorting at MRFs		
MRFs input	***Assumption***	282,902
UK MRFs capacity	**3,600,000**	
UK MRFs plastic capacity	**360,000**	
	% MRFs capacity used	**0.786**
MRFs efficiency:		
Rejects of non-targetted material	**25%**	70,726
Output	***(total)***	212,177
Proportion sent to:		
PRFs	**50%**	106,088
UK reprocessors	**23%**	48,801

Exports	27%	57,288
Plastic packaging sorting at PRFs		
From separate collection:		
Consumer bottles going to PRF	75%	35,834
Consumer PTTs going to PRF	75%	11,865
Non-consumer separate going to PRF	50%	1,770
PRFs input from separate collection	Assumption	49,470
PRFs input from MRFs	Estimated	106,088
TOTAL PRFs input		**155,558**
UK PRFs capacity	350,000	
	% PRFs capacity used	**0.44**
PRFs efficiency:		
Losses	30%	46,667
Output	Estimated	**108,891**
Proportion sent to:		
UK reprocessors	24%	26,134
Exports	76%	82,757
UK Plastics Reprocessing Input		
from collections (non-consumer separate)	25%	885
from MRFs	Estimated	48,801
from PRFs	Estimated	26,134
UK reprocessing capacity	260,000	
UK reprocessing (total)	Assumption	75,820
	% repr. capacity used	**0.29**
	% reprocessing rate	**4.15**
Losses (2%-11%, I used the average)	6.5%	**4928.27**
NPWD - reported amount reporcessed	183,372	
Non-LA collected that was reprocessed		107,552
Exports		
from collections,		
Consumer bottles	25%	11,945
Consumer PTTs	25%	3,955
Non-consumer separate	25%	885
from MRFs		57,288
from PRFs		82,757
from reprocessing		4,928
Exports (total)		**161,758**
	% exported for recycling	**8.85**
NPWD - reported amount exported	426,537	
Non-LA collected that was exported	264,779	
Collection with residual		
of which ***consumer***		
Bags	0.937	182,968
Film packaging	0.954	435,081

All bottles	**0.456**	194,039
PTTs	**0.865**	519,174
Non-consumer:		
Bags	**1.000**	18,574
Film packaging	**1.000**	43,495
Drink bottles	**0.919**	16,100
Non-drink bottles	**0.855**	7,041
PTTs	**0.985**	62,238
TOTAL residual		**1,478,710**
TOTAL residual minus litter/fly tipped		**1,467,739**
Residual to landfill	**65%**	**955,894**
Residual to incineration or other treatment	**35%**	**511,844**
Incineration of MRFs/PRFs losses		**117,393**
% 'recovered'		**34.62**

Data used on monetary flows calculations are as follows:

Table A-2 Monetary flows directly related to mass

SECTOR	*DATA*	*SOURCE*
RAW MATERIAL	£ 1,200	Office for National Statistics (ONS)
PRODUCTION	£ 1,900	Office for National Statistics (ONS)
UNSORTED PLASTIC	£ 90	Plastics Recyclers Europe
SECONDARY PLASTIC	£ 760	Plastics Recyclers Europe
VIRGIN PLASTIC	£ 1,260	Plastics Recyclers Europe
IMPORTS	- £70 to £270	Office for National Statistics (ONS)
EXPORTS	£ 220	PRODCOM
COLLECTION	£ 60	Statistics Government UK
EFW	£ 85	RECOUP-2018
LANDFILL	£ 110	Let's Recycle

Table A-3 Monetary flows indirectly related to mass

SECTOR	*DATA*	*SOURCE*
TAX (PRODUCER)	£ 25	HM Revenue & Costumes
TAX (CONSUMER)	£ 205	Office for Budget Responsibility
REVENUE SUPPORT	£15 to £70	Financial Times
BUSINESS RATE	£ 2,000	Office for National Statistics (ONS)

A.2. EXPERT WORKSHOP

Some of the content of this work has been produced via an expert workshop that took place on April 2nd 2019.

The workshop participants are listed in Table A-4.

Table A-4 Expert workshop attendees

Participant's Name	**Organisation**
Peter Calliafas	Petros EcoSolutions Ltd
Diana Bradford	Environment Agency
Billy Harris	WRAP
Robert Vaughan	Defra
Dawn Woodward	Defra
Melanie Foster	Defra
Peter Noyce	Defra
John Walsh	Defra
Callum Clarke	Defra
Jonathan Hickie	Defra
David Wilson	DcW
Francesca Medda	UCL
Stephen Chapman	Aberystwyth University
Costas Velis	University of Leeds
Andy Brown	University of Leeds
Oliver Zwirner	University of Leeds
Norman Ebner	University of Leeds
Bianca Orsi	University of Leeds
Eleni Iacovidou	Brunel University
Andrew Woodend	Defra