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The Circular Economy Across Different Sectors: Plastics, Construction, Water, and Energy

Towards a Circular Plastic Economy – A Barrier Analysis of Closing Loops in Flexible Packaging

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Note: This is a first draft, some of the analyses are still ongoing.

1 Introduction

The circular economy (CE), either referred to as a concept or an industrial system, has gained momentum among practitioners, politicians and scholars alike. Many public debates in Europe are shaped by the conception that traditional linear patterns of production, consumption and disposal "take, make and dispose" are subject to limits and constraints (EMF, 2012). One of the main pillars of the concept is to decouple revenues and prosperity from resource consumption growth (Jackson, 2009). While the CE comprises many phenomena and has triggered new methodological positionings and approaches, plastics is a recurrent topic from a material point of view.

Plastic is one of the most pervasive materials of industrialized economies with a large array of applications and a steady rise in demand. Packaging, fully or partly based on polymers, accounts for its largest single market segment by consumption for the period 2002-14 (Geyer, Jambeck, & Law, 2017), food packaging alone representing 4 million metric tons per year. Conventional plastic manufacturing is resource-intensive and mainly depends on crude oil and natural gas. Manufacturing uses up to 6% of global oil production, a number expected to increase to 20% by 2050 (Barra & Leonard, 2018). The adverse impacts of plastic waste on the environment have long been shown and communicated by scholars and activists. Most plastic waste that is neither sent to physical nor thermal treatment accumulates in landfills or the natural environment (Barnes, Galgani, Thompson, & Barlaz, 2009). Even incineration of plastic waste with energy recovery still implies economic loss of material value, namely process energy.

Circular solutions, such as recycling, have the potential to mitigate negative effects of plastic waste. The European Union and its Member States have started to take responsibility for the threats associated with the linear plastic economy through a range of measures, most of them under the umbrella of the Circular Economy Package, published in December 2015. Part of the Package are ambitious recycling targets by 2030 and a review of the interface between chemical, product and waste legislation (European Commission, 2019). In its *European Strategy for Plastics in a Circular Economy,* the European Commission demonstrates how barriers can be transferred into opportunities by improving economics and quality of plastics recycling for example by fostering design for recyclability (European Commission, 2018; Hughes, 2017).

Industries along the packaging supply chain respond to the changed legislative situation in the EU by increasing their collaborative efforts to de-carbonize and close plastic packaging loops. Public pressure translates into ambitious industry commitments (e.g. UK Plastics Pact[1]) to improve the circularity of plastic packaging. Consortia (e.g. The Alliance to End Plastic Waste[2]) are forming to explore new solutions across value chains. Their mission is to further enhance the performance of plastics in the CE by designing and advancing better system solutions identified through the collaboration of companies representing an entire value chain.

Most academic contributions on CE barriers are conceptual by nature (Tura et al., 2019). While previous studies have clustered barriers and enablers identified by business and civil society stakeholders, scholars and policy makers (de Jesus & Mendonça, 2018; Kirchherr et al., 2018; Lawton et al., 2013; Preston, 2012; Ritzén & Sandström, 2017; Tura et al., 2019; Van Eijk, 2015), barrier analyses with industry focus are relatively scarce. CE barrier case studies more often apply a focus by geography (e.g. EU, USA or China) or business type (e.g. SMEs) than by industry sector. Kirchherr et al. (2018) argue that "future work may attempt to […] explore CE barriers in specific sectors" (p. 271) and Tura et al. (2019) likewise propose to "conduct additional empirical research illustrating how industry actors are affected by different drivers and barriers of CE" (p. 90). We therefore ask the question: "What does a collaborative industry prevent from closing loops?" and discuss it on the case of the (plastic/flexible) packaging value chain. To this end, our study systematically

[1] http://www.wrap.org.uk/content/the-uk-plastics-pact.
[2] https://endplasticwaste.org/.

investigates underlying barriers, hindering the transition towards closing loops in the flexible packaging value chain. Our study focusses on barriers associated with post-consumer packaging in mixed municipal solid waste, thus thermoplastic resins, exclusively.

The article is structured as follows. Section 2 reviews existing literature streams in three fields: Technical, economic and political. Section 3 refers to the methodological framework used as well as to the sample and a detailed case description. Section 4 presents the results regarding the identification of different barrier types to a circular plastic economy, with an emphasis on closed loop supply chains and coordination failure. Section 5 discusses the findings in relation to previous barrier analyses, highlights the limitations and eventually presents concluding remarks an outlook.

2 Literature review

A large amount of studies has focused on drivers and barriers, facilitating and hampering the transition towards sustainable ways of production. A specific literature on CE barriers has emerged since 2014. Previously, most barrier analyses referred to *resource efficiency*, rather than to CE. Despite rising academic awareness, the CE barrier literature combining both, value chain/ industry and policy focus is still fragmented.

Existing sector-specific CE barrier studies focus for example on textiles and clothing (Hu, Li, Chen, & Wang, 2014; Todeschini, Cortimiglia, Callegaro-de-Menezes, & Ghezzi, 2017), construction (Adams, Osmani, Thorpe, & Thornback, 2017), electronics (Kissling et al., 2013) or manufacturing (Ritzén & Sandström, 2017). A case study most similar to this article's phenomenon has been carried out by Mishra et al. (2018) on fast moving consumer goods, analyzing the integration of value creation and recovery activities into retail customer value propositions. Mishra et al. (2018) found that costs of collection, treatment, and segregation of products, components and materials are one of the biggest barriers to creating circular-inspired closed loops. While an established literature stream exists on plastic packaging in a CE context (Al-Salem, Lettieri, & Baeyens, 2009; Geueke, Groh, & Muncke, 2018;

Ragaert, Delva, & Van Geem, 2017; Tsiamis, Torres, & Castaldi, 2018), no systematic CE barrier study has been carried out in the plastic packaging industry.

1.1 Technical barriers

de Jesus and Mendonça (2018) systematically reviewed the academic CE and innovation literature between 1992 and 2015 (n=141) and found that the majority of mentioned CE barriers (35%) were in the realm of technology, including technological thresholds, technology gaps and the lack of educated staff. With a focus on plastics, Bartl (2014) states that each recycling step of a polymer implies an inherent loss of molecular mass, which limits the amount of life cycles. As an example: Bottle-to-bottle processes are a viable solution for PET, not yet for other plastic packaging applications. Several LCA studies have revealed that recycling only becomes ecologically viable if it replaces a minimum threshold of virgin material. Rajendran et al. (2013) calculate this threshold at 70–80% of virgin plastics. Below this value, thermal recovery would be favorable.

1.2 Economic/ supply chain barriers and coordination failure

The literature stream on closed-loop supply chains (CLSCs) provides additional insights into barriers to set up closed loops and reverse logistics with a focus on supply chain reconfiguration. In CLSCs the one-directional value creation of primary material flows (from manufacturers to converters to retailers to consumers) (Porter, 1985) is complemented with a reverse flow of post-consumer secondary material back to manufacturers (Souza, 2013). Barriers hindering value chain reconfiguration are associated for example with coordination failure, which occurs when a firm or a group of firms in the value chain could theoretically achieve a higher output but fails due to lacking coordination in decision making. Holimchayachotikul et al. (2014) emphasize the relevance of collaborative efforts, while proposing a new measurement of value added along the supply chain from a collaborative perspective. Trust (Doney & Cannon, 1997) and relationship duration (Ching, Holsapple, & Whinston, 1996) also appear to be relevant criteria for successfully establishing CLSCs. While the concept of CLSCs for creating and recovering value is widely acknowledged in supply chain management, no barrier analysis along an entire industry value chain has been carried out systematically and comprehensively.

1.3 Political-regulatory barriers

While some authors argue that institutional [and systemic] barriers have received less attention in the past compared to other barrier categories (Ghisellini, Cialani, & Ulgiati, 2016; Kirchherr et al., 2018), others point to the fact that regulation features regularly in CE debates as a key barrier or driving force in the transition processes (Milios, 2018; Pheifer, 2017; Rizos, Behrens, Kafyeke, Hirschnitz-Garbers, & Ioannou, 2015). With regulatory barriers mentioned in 23% of their analyzed sample, these barriers appear as the second most prominent family of barriers to CE, according to de Jesus and Mendonça (2018). Milios (Milios, 2018) found that policies affecting material efficiency in production and consumption are underrepresented at EU level. Specific challenges apply to three policy areas specifically: policies for reuse, repair and remanufacturing; green public procurement; and demand-side policies. Hughes (2017) adds lacking coherency of existing EU laws relating to life cycle thinking as an additional challenge. In this context, Murray et al. (2017) warn against "unintended consequences and over-simplistic goals" (p. 376).

3 Methodology

In order to empirically analyze barriers in the European flexible packaging industry, we chose a qualitative approach, including the analysis of archival data, expert interviews and a workshop. Expert interviews were chosen as we pursue in-depth information in the newly arising and still largely exploratory research field of CE barriers. To increase validity, workshops allowed us to subsequently triangulate ambiguous findings.

3.1 Sampling and case description

3.1.1 Sampling

With the aim to derive reoccurring patterns and identify systemic barriers, we collected data along the plastic packaging value chain by cooperating with a European industry consortium. It is composed of companies and associations representing the full value chain of flexible packaging with the objective to make all post-consumer flexible packaging recyclable by 2025. When our collaboration started in 2018 the consortium counted approximately 100 members and is growing until today. Sampled consortium stakeholders include midstream industries (raw material manufacturers), downstream industries (converters/ film producers, fillers, retailers), brand owners as well as collectors, sorters and recyclers on the post-consumer side. In order to generate a broad sample with a high level of variation, we incorporated both large multinationals (mainly represented by brand owners and raw material suppliers) and smaller players (mainly represented by recyclers). Industry structure, margins and market power differ considerably among sampled actors. The interviewees within each organization were in most cases the ones who represent the organization within the consortium as these people are assumed to be the most knowledgeable on the issue at hand. Consumers are not separately represented in the sample since barriers associated with consumer behavior are only related to in an indirect way.

3.1.2 Case description: The flexible packaging industry and its regulatory environment

Plastic packaging in general comprises rigid and flexible packaging. The latter refers to "easily yielding materials that, when filled and closed, can be readily changed in shape" (Glenroy, 2019). Our case focuses on flexible packaging in municipal solid waste. Fast moving consumer goods and packaging industries are closely intertwined. The growth of the former over the last decade has direct impacts on the rise in demand for plastic packaging especially for thin-film applications, progressively substituting aluminum foils and other resource-intensive materials. Flexible packages apply to consumer, institutional products and to industrial applications. Consumer product packages are predominantly used for food products (food containers, foils, trays, bags, pots, cups, pouches, etc.), followed by non-food products (hygiene or agricultural applications).

The (closed) flexible packaging value chain for plastics can be broken down into the following steps.

(i) *Raw material manufacturers*:
The petroleum industry transforms carbon-based material (crude oil and increasingly natural gas) into virgin monomers and polymers (via polymerization) in either granular or powder form. Further raw materials stem from the (bio)chemical industry such as plastic resins, adhesives, inks, coatings, additives/fillers (Nonclercq, 2016). Most raw material manufacturers are large corporates with relatively high market power.

(ii) *Converters/ film producers*:
Flexible packaging converters manufacture finalized and semi-finalized packaging products such as films and foils. They receive virgin feedstock from raw material suppliers as well as secondary feedstock from recyclers (closed-loop scenario). Value-adding finishing operations, namely assembly work or printing are equally part of their portfolio (New InnoNet, 2016). Converters show a large diversity in terms of size. Some increase their market power by collaborating with raw material manufacturers.

(iii) *Brand owners and retailers:*
In the third step the product (e.g. food) is wrapped into the flexible package by brand owners/fillers, retailers or by their third party suppliers, and sent to the point of sale (Nonclercq, 2016), where it is purchased by consumers, transported, stored, consumed and the package discarded. Brand owners are mostly large corporates with high market power due to proximity to the consumer and high profitability.

(iv) *Collectors:*
Post-consumer plastic packaging waste falls under municipal solid waste and is in many countries associated with extended producer responsibility (EPR) schemes. Waste collection systems divide into door-to-door separate collection or bring points/ drop-off containers. Both, collectors and sorters can be private or public service providers, in some countries organized as monopoly or oligopoly, under the responsibility of cities or municipalities. They are mostly small players with relatively low profit margins.

(v) *Sorters:*
Sorters separate collected plastic waste into mono-material fractions as far as possible based on a large range of sorting technologies. Selectivity and accuracy determine the purity of the resin, a key aspect for recycling efficiency and recyclate value. Plastic waste of minor quality is sent to incineration or landfill.

(vi) *(Mechanical) recyclers:*
Recyclers recover and reprocess sorting output into pellets of secondary plastic material. Usually, common steps include shredding, sorting, grinding, washing, drying and pelletizing. Pellets are sent to converters in

a closed loop scenario. The European recycling sector is fragmented with a large number of small players, some of them currently benefitting from government subsidies and rising virgin material prices.

The regulatory environment is shaped by the 2018's Circular Economy Action Plan's legislative proposal. Therein, the EU adopted a recycling target of plastic packaging of 55% by 2030, meaning a dramatically increased share of (mechanically) recycled content also for packaging. The EU recycling target will require significantly increased use of recycled content, estimated at almost 50% for PET and ~30% for PE and PP (Deloitte Sustainability, 2017). To reach the 55% target, sorting capacity will need to increase by a factor of 2.6, recycling by a factor of almost five, making it the Achilles heel of plastic packaging. Although the EU appears to be furthest when it comes to plastic packaging recycling rates, ranging around 42.4% in 2016 (Eurostat, 2018), at a global scale, countries' progress varies considerably. Countries show a big spread as national waste management systems face different stages of development and as methods of measurement and calculation are only now being harmonized. Measuring output sorting is replaced my measuring input into a final recycling process. Recycling targets are very ambitious for some Member States, less so for others. For flexible packaging in particular, non-thermal recycling is not yet taking place at large scale. The ongoing banning and decommissioning of landfills further increases the demand for solutions to utilize waste (Tura et al., 2019).

3.2 Data collection and analysis

We conducted 25 semi-structured interviews between October 2018 and March 2019 - 17 interviews with stakeholders of the consortium, validated by 8 interviews with external interview partners, partly recommended by consortium stakeholders. The geographical limit of the sample was Europe for the consortium being European. Interviews were conducted in person or via phone, lasting between 45 and 100 minutes. As part of each interview, we began with an identical open-ended question regarding the interviewee's vision for closing material loops in the flexible packaging industry, followed by customized interview guides on the different barriers that we designed based on a detailed background analysis of archival data. All interviews were recorded and most relevant interviews were transcribed.

The data analysis was two-fold: In order to investigate how barriers hinder recycling in flexible packaging, in a first step all sampled barriers were mapped along the three for this context most relevant areas for barrier mapping as suggested by Tura et al. (2019)[i]: technological [and informational], economic-financial, as well as political-regulatory [and institutional]. Among these three categories, institutional barriers have received least attention in the past (Ghisellini, Cialani, & Ulgiati, 2016; Kirchherr et al., 2018), we therefore emphasize them here. Second, we identified equivocal barriers around the same three categories. Making the different underlying assumptions explicit in a two-hour workshop allowed us to understand where more factual information was required. Participatory workshops have been applied in the past to identify and help to overcome CE barriers (Heyes, Sharmina, Mendoza, Gallego-Schmid, & Azapagic, 2018; Mendoza, Gallego-Schmid, & Azapagic, 2019). For consistency, the workshop participants were selected from the pool of consortium interviewees exclusively. All interviewees were invited and eight agreed to participate. They were confronted with the equivocal barriers, aiming at collecting further arguments for both sides (see Section 4.5). Table 1 lists participants of expert interviews and the workshop.

Table 1 – Overview of Interviewees and workshop participants

Affiliation to consortium	**#**	**Workshop participation**	**Organization**	**Position**	**Type**
Stakeholders	1		Raw material producer	Head of Market Development Biopolymers	Business
	2	X		Marketing and Value Chain Manager	Business
	3	X		R&D Fellow	Business
	4	X	Film producer/ Converter	Director Sustainability	Business
	5	X		Director Corporate R&D	Business
	6	X	Brand owner	Director Sustainability	Business
	7		Collector, sorter, recycler	Director Business Development	Business
	8			Director Business Innovation	Business
	9	X		Managing Director	Business
	10	X		Managing Director	Business
	11			Managing Director	Business
	12			Director Communication-Public Affairs	Business
	13		Technical consulting	Managing Director	Business

	14	X		Managing Director	Business
	15		Industry organization	Managing Director	Interest Group
	16			Managing Director	Interest Group
	17			Managing Director	Interest Group
Externals	18		Raw material producer	Head of Innovation Management	Business
	19		Brand owner	Project Manager Sustainability	Business
	20		Collector, sorter, recycler	Managing Director	Interest Group
	21		Technical consulting	Managing Director	Interest Group
	22		legislator/ regulator	Policy Analyst	Government
	23		legislator/ regulator	Member of National Parliament	Government
	24		NGO	Director Sustainability	Interest Group
	25		Academia	Senior Researcher	Academia

4 Results

The findings of the barrier analysis are represented in Table 2. Not all mentioned barriers have been emphasized by all actors alike. They depend on the relative market power of the actor and in how far their business model is put at risk by closed loop supply chains or the integration of external actors. In this context the table represents a basic consensus neglecting strongly contrasting opinions. We do not exclude the possibility that some barriers have not yet been perceived and reported by some actors although being already affected by them. As part of the barrier analysis, we differentiate between unequivocal and equivocal barriers. The dividing lines between the two categories are elaborated on further below.

4.1 Unequivocal barriers

Table 2 shows the most relevant barriers that we collected from various actors along the flexible packaging supply chain. Barriers often are highly intertwined and interdependent. The organization in three categories (technical, economic-financial, and political-regulatory) is an attempt to highlight the dominant feature of each barrier.

As part of the analysis, a number of general observations or meta-barriers can be identified. These meta-barriers focus on the dynamics in the value chain that prevent actors from moving decisively toward strategy and investments, thus create inertia. An example would be uncertainty beyond corporate business risk, i.e. risk aversion associated with value creation in a closed-loop scenario. Circular value creation will entail substantial changes for the entire value chain. The speed of change, mostly driven by public debate and (planned) policy interventions, is not anticipated by all players alike. To address the current obstacles to a circular model, most industry representatives have realized that collaboration is key, with raw material producers and recyclers representing the two diverging ends of the still mostly linear value chain.

4.1.1 Technical barriers

Technical barriers include material diversity/lack of purity, contamination, low quality of recyclate and new materials. While recyclers argue that many virgin applications are theoretically substitutable by recycled material, brand owners tend to point out that proven and optimized packaging performance leading to product safety cannot be compromised. Hence, the dominant technical challenge is to enhance recyclability of flexible packaging with the required speed without compromising on high standards of functionality and product safety. This trade-off marks one of the major debates around closing loops in the flexible packaging industry. A number of respondents emphasized the key role of packaging, which lies in its protection of a specific product over a predefined amount of time. In this regard, packaging innovation that leads towards increased shelf lives in the food sector can even reduce food waste.

4.1.2 Economic-financial barriers

Economics face temporary hurdles, as well as structural disadvantages. Most relevant economic-financial barriers are associated with comparatively high cost of recyclate production while production of virgin material is comparatively inexpensive. This results in a lack of incentives to use recyclate in production as competition with virgin material is structurally skewed. Recyclers in particular are still largely dependent on virgin material price development, especially on crude oil prices, deciding upon the profitability of their business model. The high fluctuation of raw material prices poses an additional threat as the ability of recyclers to absorb market shocks is poor. Further barriers are associated with low funding, lack of demand and/ or supply, economic lock-ins and missing alternatives to mechanical recycling.

4.1.3 Political-regulatory barriers

Identified political-regulatory barriers refer to food contact legislation, lack of financial support, missing information on material composition, disincentivized cooperation, ineffectiveness and lacking system transparency. The majority of respondents agree that regulation has to play an important role to set up markets and to spur innovation. Simultaneously, regulation should be partially revised towards “enforced adaptation” (*Converter*) to make circular approaches viable. From a regulatory point of view, hygiene and food contact packaging law represent a major barrier, as they exclude flexible food package production from the use of recyclate. Sometimes however, regulatory leeway is not taken advantage of by the industry, such as in one reported case of interpretation of European feed legislation (e.g. for pet food packaging), which is less strict than food legislation: *“We do not see why we should use substances for packaging products for pets that are restricted for human food contact packaging. How shall we explain to our customers that we put their pets at risk?” (Brand owner)*

Table 2 – Overview of unequivocal barriers

		Detailed description
Technical	Material diversity/ lack of purity	Versatility, material savings and technical performance such as durability are the major reasons for the widespread use of plastics in packaging applications. Plastic materials can, compared to other materials, reduce the product’s weight, decreasing the economic and environmental costs from production and transport. Performance-enhancing characteristics yet come at the expense of recyclability. While glass, paper and cardboard are rather homogeneous in their respective material characteristics, aluminum (alloys) and plastics in particular show a higher spectrum of materials. Lacking material purity leads to challenges in terms of identification and separation as mechanical recycling processes can only treat mono-materials. Polymer composites such as multi-layer laminated packaging pose a problem. Composite films, combining e.g. polyolefins and polyamides, are necessary for certain barrier properties (oxygen, water vapor, UV) guaranteeing low material use, at the cost of eco-design and recyclability.

	Contamination	Contamination barriers can be associated with packaging design (additives) and exposition (mixed waste streams) on one hand as well as with the point of contamination on the other, i.e. use phase, collection or sorting. Contamination of recycled material can stem from residues from previous use, from incidental misuse or from non-authorized substances (European Union, 2008). ▪ Design: Some additives (flame retardants, antioxidants, …) used in the design of primary plastics products can have a detrimental effect on the physical characteristics of recycled plastics (OECD, 2018). Lack of transparency and missing information on the potential presence and nature of additives can be a barrier for recyclers. Hence, specific material streams are excluded from recycling as feedstocks cannot be ensured to be additive-free. ▪ Exposition: During production, consumption and collection, plastic packages are exposed to a variety of potentially contaminating sources. Three component categories are inorganic components, organic components and other plastics (mineral oil hydrocarbons (MOSH. MOAH), bisphenols, phthalates, photoinitiators as well as toluene, benzene, toxic heavy metals, such as cadmium). Migration can occur in both directions, submitting and absorbing components (Geueke et al., 2018). Another source of contamination can be bio-degradables in mixed waste streams.
	Low quality of recyclate	Although recyclate quality has increased over past years, it is on average still lower than virgin material. Many virgin applications are theoretically substitutable by recycled material (e.g., ‘film-to-film’ applications such as stretch around pellets or even ‘film-to-rigid’). For high-end applications, especially in the hygiene and food industries, regulators and producers are not willing to compromise on product safety. The use of functional barriers combining primary and secondary feedstock currently is the only option that allows using recycled post-consumer plastics in food-contact applications.
	Consumer convenience	Consumers have rising expectations on performance criteria of flexible packages. The most important criterion is increased shelf life, often implying multilayer solutions or new materials. From a conventional mechanical recycling point of view, material mixes as well as new materials (e.g., bio-degradables, carbon fibers) pose a higher risk than common materials.
Economic-financial	Low production cost of virgin material	Plastic packaging is mainly fabricated of petrochemical feedstocks, especially crude oil and natural gas. In Europe, there is a trend away from mineral oil towards natural gas [source: Low and volatile global resource prices (source: IMF commodity price index/ Total). Raw material prices, especially of crude oil, are low compared to secondary raw materials which results in low operating costs for primary plastics production. Main reasons are low marginal cost due to economies of scale and process technology maturity. External costs are not priced in. Virgin plastics further benefit from indirect fossil fuel subsidies and externalities that are not priced in. Low virgin material prices have repeatedly been stated as the major barrier for market integration of secondary raw materials.
	High production cost of recycled materials	The low operating costs of primary plastics production are contrasted with high processing costs for the production of recyclate. The market for secondary feedstock, is smaller, more fragmented and therefore lacks both, scale and waste stream access. Recycling technology is at times still immature as industry structure in key steps of the value chain is not well placed to take risks. Above all food packaging is an unsolved issue as quality of re-granulates is still lower than virgin materials (due to e.g., material mixes, contamination with additives and inks, multi-layer laminated mixed materials). High price sensitivity especially in food retailing implies an additional competitive disadvantage for recycled plastics compared to virgin materials. (add decoupling markets?)
	Lack of funding	It is undecided among industries who bears which share of the investment cost of system changes. Very limited public funding has been spent on innovation in sorting and recycling. Along the value chain, it is also unclear how costs shall be shared in the future.
	Lack of demand/ immature markets	The Market for low quality materials is small and secondary markets are only slowly building up, especially food grade packaging requires virgin material, except for PET and few examples of HDPE. Recycled packaging products cannot always meet esthetic product criteria for example full transparency.

	Lack of supply	Amount of existing high-end recyclate is not available (most of current plastic recyclate is of minor quality) on the market to reach the industry objective of using 20% in 2025. Currently less than 10% of recyclate is kept in the loop.
	Economic Lock-ins	Packaging has been cost-optimized over past decades. Economics lock-ins stem from previous investments, both large scale (collection and sorting infrastructure) and small scale (e.g., limited machine runability for new materials) that prevent disruptive innovation. Producing, processing and using recyclate entails modifying and adapting production processes. Investment cycles for packaging machines are rather long and amount to approximately eight years.
	Lack of alternatives to mechanical recycling	Alternatives to mechanical recycling are available (many piloting facilities) but not commercially viable yet and/or come at higher environmental cost. Chemical recycling is still at an early stage, alternatives to plastics like paper may have a higher environmental impact and biodegradable materials lack scale and face technical hurdles.
Political-regulatory	Recyclate excluded from re-use for food grade material	In the EU, Regulation No 10/2011 on plastic materials and articles sets out a list of substances that are permitted and restricted for use in the manufacture of plastic food contact materials. Recyclate does not comply with the plastic regulation, mainly due to the risk of contamination, with the exception of PET and HDPE in the United Kingdom, both for beverage bottles. This puts pressure on sales markets for recyclate as food contact grade plastics account for a high market share for which recyclate is excluded. Most interviewees agreed that the high standards of food safety should not be comprised.
	Packaging for animal food	Some legislative demands are interpreted in a stricter way than compulsory by law. This is the case for animal food ("feed"/"feedingstuff") packaging legislation which differs from human food packaging legislation to the extent that the use of recyclate in new products is sometimes permitted. Not taking advantage of this possibility results in lower demand or re-granulate. In the United States of America in contrast to European law, pet food is governed by the same standards as human food.
	Lack of financial support	Existing loans, tax reductions and incentives are either not targeted or not effective. The lack of financial R&D support has been raised as a recurrent issue in interviews. This can be due to lacking awareness by companies of existing subsidies, cumbersome application processes for existing grants and/ or exclusion of certain industry sectors. Many companies along the disposal industry, especially sorters, are classified as service providers and not as manufacturers which excludes them from grants they would actually need.
	No standards and labelling	The amount of information which products contain which types of materials is insufficient for recyclers due to missing labelling and declarations on plastic packaging. The idea of product passports has been proposed in the past and was taken up and referenced to in interviews. Consumers can be confused by inappropriate or misleading information on packaging. A common example is information provided on biodegradability. There is no uniform standard on compostability and biodegradability.
	Disincentivized cooperation	Current regulation prevents companies from sharing data and knowledge among each other which would be beneficial for addressing most pressing technical and economic hurdles. Antitrust law in particular impedes cooperation, especially when a competitor intends to approach a mutual problem in a mutual way. As a consequence, industries act with considerable caution when communicating to each other in order to avert violating antitrust law.
	Ineffective policies	Many policy instruments are considered ineffective to meet high quality outputs. The landscape of measurements and standards is considered insufficient. Target setting is not expedient without monitoring and control of implementation.

Lack of system transparency	Waste management and recycling systems tend to be perceived as non-transparent and "out of control" (interview). EPR fee flows and their spending have been mentioned as examples.
Lack of end consumer awareness	Waste sorting by consumers is essential to increase material purity in the recycling step. Purity of collected municipal waste varies significantly between countries and systems. Many consumers are either not sufficiently aware or not willing to sort at home caused by habits or convenience.
Misguided public opinion/ Perception bias	An important driver of innovation is public opinion. It can influence brand owners and manufacturers. There is a risk of supporting and disseminating wrong facts through media and interest groups, which can entail non–priority policy making and industry reaction.

4.2 Equivocal barriers

The barriers described so far have either been reported as consensual or been pointed out by some players with consent by others. Another group of barriers that are described in the following are barriers that have been contested to varying degrees by players along the value chain or even within one value chain step. We identified three equivocal barriers on which industry's perspective is heterogeneous arising from different assumptions about trends and drivers (e.g., how quickly technology will become available and at which cost). As underlying root cause we identified the amount to which the business model of each value chain player is threatened. This cause however has different origins and characteristics, depending on where the organization is located in the value chain. The major three origins are associated with technology and material; market and competition; and the political environment. The three equivocal issues are derived from these fields and address the potential of chemical recycling; vertical and horizontal value chain integration; as well as the degree of regulatory interventionism. We defined an issue as equivocal as soon as one respondent clearly disagrees or contradicts the opinion of another. As this occurred several times, we included only the most debated topic from each of the three fields.

4.3.1 Potential of chemical recycling

While there is a strong consensus on technical barriers in general, the potential of chemical recycling has been identified as an equivocal issue. In contrast to mechanical recycling, melting, shredding and grinding plastic waste without significantly changing the chemical structure, chemical recycling is defined as a conversion to monomer or production of new raw materials by changing the chemical structure of the material (International Organization for Standardization, 2008).

Many debates on how to reach ambitious recycling targets refer to a combination of mechanical and chemical recycling processes, yet the assumption that chemical recycling will be a game changer in recycling of flexible packaging is contested by some respondents.

Supporters argue that new recycling technology allows for a significant increase in recyclate application. The hope for chemical recycling to solve this is prominent with material producers as well as retailers and brand owners alike. Currently, many hygiene packaging and most food packaging products are restricted for the use of mechanically treated recyclate, as highlighted in Table 2. De-polymerization outputs (i.e. monomers) go further back in the production chain, are not considered secondary raw material by law and can therefore be used even in hygiene and food packaging. Chemical recycling holds the potential to address further barriers of mechanical recycling such as difficulties to handle multilayer products, de-inking and discolorating, desodorisation of recycled plastics and the removal of forbidden substances (cf. REACH, POP, RoHS).

Skeptics, represented mainly by collectors and sorters, question the anticipated impact of chemical recycling, feasibility, implied risks and time horizons. They argue that a lack of clean material streams significantly decreases yields from chemical recycling. Although chemical recycling is not a new phenomenon, most technologies can be considered early-stage with insufficient commercial scale-up: *"Economies of scale are an issue today. Investment in chemical plants against established processes must be carefully weighed. Investment risk is high as costs are largely unknown" (Film producer/Converter)*. Already in the 1990s, waste management systems and chemical companies invested heavily in chemical recycling technologies without coming up with economically viable solutions. A lack of demand for recycalte causes, due to respondents, the slow uptake of technological progress.

4.3.2 Potential of vertical integration

Value chain integration has been identified as the second equivocal issue. Integration takes places when business segments are assimilated following an acquisition. The packing industry undergoes organizational changes as actors along and beyond the value chain integrate vertically and consolidate horizontally. Vertical integration can occur in the form of backward and forward integration. The underlying business strategy determines the balance of power over material streams and the transparency of markets. Respondents disagree which type of business integration is most effective in fostering innovation.

Horizontal consolidation refers to specialization and economies of scale as well as agglomeration. In the view of supporters, this leads to more innovation in process optimization. Horizontal consolidation is common practice in most industries. A number of examples has shown that recyclers in particular have been a target of acquisition, integration and consolidation. A potential risk is that individual players might feel incentivized to subvert established and well-functioning system-level schemes. For example, retailers that set up their own collection systems can cannibalize public collection through a lack of critical mass.

Supporters argue that vertical integration allows for a strategic coordination of innovation across the entire value chain, e.g., from packaging design to production of secondary raw material. While horizontal consolidation bears the risk of slowing down system-level innovation, vertical integration theoretically fosters innovation through competition. Along the flexible packaging value chain, upstream players tend to be more capital-intensive than recyclers. Theoretically, forward integration is more likely than backward integration. Yet, even forward integration of raw material/polymer producers up to recyclers, as existing in the paper, glass, aluminum and steel industry, is not very common for plastics. We noted a considerable interest in the case of external players integrating vertically in the waste management value chain. An example of external vertical integration in Europe is the Schwarz group, a German retail group, with the purchase of Tönsmeier, a German recycler in 2018. The relevant question is whether other actors will follow this model.

During the workshops, collaboration was mentioned as a new approach or *"third way" (Consultant)*. Companies along the flexible packaging value chain tend to implement cooperative approaches beyond traditional vertical and horizontal models to foster innovation: *"I think we are moving away from traditional models. We are not talking vertical or horizontal integration [anymore]. I think we are moving to collaborative models that encompass characteristics of both integration models" (Consultant)*

4.3.3 Degree of market intervention

The degree of market intervention by the regulator has been identified as the third equivocal issue. It was uncontested among respondents that regulation has to play an important role to set up markets and to spur innovation. Purely voluntary commitments will not be sufficient. Contested were the different types of policy mix design and their directions of action. Different degrees of market intervention are thought to be most efficient for a circular transformation of the plastic packaging industry. High market intervention would be represented by a high quantity of demand-side policies and material/product bans, less intervention by more indirect supply-side policies and EPR schemes.

Supporters of high policy intervention via demand-pull instruments stress that quality cannot be easily brought to virgin levels, hence markets need to be forced to adapt. High-quality recylate on the other hand is financially not competitive; financial support is needed for deployment: *“The next wave of legislation is needed. For Copper, there is no legislation needed, but plastics is simply too cheap.” (Collector, sorter, recycler).*

Critics of high market intervention refer to the relevance of supply-side instruments. They consider lacking materials and process innovation as the main barrier to a circular plastic packaging value chain. Public funding for example via research and development grants or tax exemptions can foster innovation in sorting and recycling and increase economies of scale. They strongly oppose product/ material bans, such as the EU Single Use Plastics Directive Proposal from 2018: *“Bans are a short-cut solutions. Most policy makers do not have the necessary information to impose a ban. Communication of targets offers more leeway.” (Consultant)*

5 Discussion and conclusion

What does a collaborative industry prevent from closing loops? To answer this question, 25 European firms, associations and regulatory agencies were interviewed, 17 from an industry consortium for flexible packaging, and 8 others, resulting in the formulation of 20 barriers. All interviewees and workshop participant are sustainable development professionals in their respective sector. While all of them have been familiar with the concept of CE, it is still far from being considered as mainstream.

We show that barriers are not always consistent, nor uncontested. Their formulation and weight varies between different players in the value chain, depending on assumptions an organization or individual adopts, their place in the value chain, economic outlook, risk aversion and other factors. This led toward the identification of two major types of barriers, unequivocal and equivocal, which combine the existing barrier literature and the empirical evidence from the industry consortium. The proposed sub-classification at a system level includes technical, economic-financial and political-regulatory barriers. Boundaries between barriers are somewhat blurred as they are intensely interlinked and often are the direct consequence of each other. While previous studies pointed out that technical and economic barriers were the most prominent in CE debates (de Jesus & Mendonça, 2018; Ghisellini et al., 2016; Kirchherr et al., 2018), we did not derive any hierarchy between barrier categories in our sample. The implications for policy and the value chain, limitations and suggestion for future research are discussed next.

5.1 Implications for policy

A central finding is that consistent and coherent policy intervention will be key to overcome a multitude of these barriers, which is in line with previous barrier analyses (de Jesus & Mendonça, 2018). Some studies have shown that some types of CE policies are underrepresented at EU level (Milios, 2018). CE regulatory agencies have set ambitious targets, mostly accepted by industry, although not all of them being truly circular. Building functioning markets that can fulfil those targets in an economically efficient way will be challenging. Inconsistent and geographically fragmented policies could become an even greater barrier – increasing system cost and putting the targets at risk. Eventually, consumer behavior bears the risk of strongly affecting any circular transition – in both directions. Awareness rising and public education can address to reduce system cost, e.g. around willingness to sort, but also convenience of separating waste. Food packaging, being the main application of flexible packaging, seems an unsolved issue today when it comes to recycling. The precise direction, policy mix design and distribution of responsibility as well as costs remains to be decided upon. Economic risk specifically could be faced by distribution of investment costs along the value chain, as already applied in some EPR systems: *"This is where EPR and the whole value chain can provide some level of risk management by undertaking and committing to use and provide markets for recycled materials and by financing* *the economics via putting a true cost of plastics into the market. […] The consortium can provide the checks and balances for the people who make these investments. […]“ (Consultant).*

5.2 Implications for industry

This study further demonstrates that change has to come to the entire value chain; incremental and unconnected change on separate value chain steps will not be sufficient to reach the overarching goals. This is in line with the European Commission's Strategy for Plastics that incentivizes actors to adopt circular solutions but not yet specifies which and how: "[it] will require action from all players in the plastic value chain, from plastic producers and designers, through brands and retailers, to recyclers" (European Commission, 2018, p. 8). In addition, the required change is very fast – technology will need to be developed and deployed in a still uncertain policy environment. The identification of opposed opinions on chemical recycling exemplifies how hard it is to push or pull the entire value chain in a certain direction to overcome the coordination failure. Although the will and recognition that the value chain has to transform as one is prominent, the alignment of interest remains a challenge. The insights that are provided in this study aim to facilitate the development of policy guidelines and organizational strategies in the plastic packaging industry.

5.3 Limitations and suggestions for future research

While concentrating on identifying different types of barriers of CE in the plastic packaging industry, this study did not specifically address the role of consumer behavior in the transition process, although respondents with high customer proximity (i.e. retailers and brand owners) emphasized "mental barriers" of customers (see also Kirchherr et al., 2018). We also limited our core sample (most interviews, workshop) to one industry value chain and did not validate our results by comparison with similar value chains within the plastic industry, such as rigid packaging, building and construction, textiles, industrial machinery, consumer and institutional products, etc. (OECD, 2018). Furthermore, barriers are not subordinate to any hierarchical structure. The research gaps of this paper point to potential avenues for further research.

References

Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017). Circular economy in construction: current awareness, challenges and enablers. *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, *170*(1), 15–24. https://doi.org/10.1680/jwarm.16.00011

Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management*, *29*(10), 2625–2643. https://doi.org/10.1016/J.WASMAN.2009.06.004

Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *364*(1526), 1985–1998. https://doi.org/10.1098/rstb.2008.0205

Barra, R., & Leonard, S. A. (2018). *Plastics and the Circular economy*. Washington. Retrieved from https://www.thegef.org/sites/default/files/council-meeting-documents/EN_GEF.STAP_.C.54.Inf_.05_Plastics.pdf

Bartl, A. (2014). Moving from recycling to waste prevention: A review of barriers and enables. *Waste Management & Research*, *32*(9_suppl), 3–18. https://doi.org/10.1177/0734242X14541986

Ching, C., Holsapple, C. W., & Whinston, A. B. (1996). Toward IT support for coordination in network organizations. *Information & Management*, *30*(4), 179–199. https://doi.org/10.1016/0378-7206(95)00054-2

de Jesus, A., & Mendonça, S. (2018). Lost in Transition? Drivers and Barriers in the Eco-innovation Road to the Circular Economy. *Ecological Economics*, *145*, 75–89. https://doi.org/10.1016/j.ecolecon.2017.08.001

Deloitte Sustainability. (2017). *Bluepring for plastics packaging waste: Quality sorting and recycling - final report*. Retrieved from https://www.plasticsrecyclers.eu/sites/default/files/PRE_blueprint packaging waste_Final report 2017.pdf

Doney, P. M., & Cannon, J. P. (1997). An Examination of the Nature of Trust in Buyer-Seller Relationships. *Journal of Marketing*, *61*(2), 35. https://doi.org/10.2307/1251829

European Commission. (2018). A European Strategy for Plastics in a Circular Economy. Brussels.

European Commission. (2019). *A Circular Economy for Plastics - Insights from research and innovation to inform policy and funding decisions*. https://doi.org/10.2777/269031

European Union. Commission Regulation No 282/2008 of 27 March 2008 on recycled plastic materials and articles intended to come into contact with foods (2008). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0282&from=EN

Geueke, B., Groh, K., & Muncke, J. (2018). Food packaging in the circular economy: Overview of chemical safety aspects for commonly used materials. *Journal of Cleaner Production*, *193*, 491–505. https://doi.org/10.1016/j.jclepro.2018.05.005

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, *3*(7), e1700782. https://doi.org/10.1126/sciadv.1700782

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Glenroy. (2019). Flexible Packaging Definitions. Retrieved June 10, 2019, from https://glenroy.com/tools/flexible-packaging#fp_f

Heyes, G., Sharmina, M., Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2018). Developing and implementing circular economy business models in service-oriented technology companies. *Journal of Cleaner Production*, *177*, 621–632. https://doi.org/10.1016/J.JCLEPRO.2017.12.168

Holimchayachotikul, P., Derrouiche, R., Damand, D., & Leksakul, K. (2014). Value creation through collaborative supply chain: Holistic performance enhancement road map. *Production Planning and Control*, *25*(11), 912–922. https://doi.org/10.1080/09537287.2013.780313

Hu, Z. H., Li, Q., Chen, X. J., & Wang, Y. F. (2014). Sustainable rent-based closed-loop supply chain for fashion products. *Sustainability (Switzerland)*, *6*(10), 7063–7088. https://doi.org/10.3390/su6107063

Hughes, R. (2017). The EU Circular Economy Package – Life Cycle Thinking to Life Cycle Law? *Procedia CIRP*, *61*, 10–16. https://doi.org/10.1016/J.PROCIR.2016.12.006

International Organization for Standardization. ISO 15270:2008 - Plastics - Guidelines for the recovery and recycling of plastics waste (2008). Retrieved from https://www.iso.org/standard/45089.html

Jackson, T. (2009). *Prosperity without Growth - Economics for a Finite Planet* (1st Editio). London. https://doi.org/https://doi.org/10.4324/9781849774338

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the Circular Economy: Evidence From the European Union (EU). *Ecological Economics*, *150*(December 2017), 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028

Kissling, R., Coughlan, D., Fitzpatrick, C., Boeni, H., Luepschen, C., Andrew, S., & Dickenson, J. (2013). Success factors and barriers in re-use of electrical and electronic equipment. *Resources, Conservation and Recycling*, *80*, 21–31. https://doi.org/10.1016/J.RESCONREC.2013.07.009

Lawton, K., Carter, C., Lee, J., Tan, A., de Prado, A., Luscombe, D., & Briscoe, S. (2013). The opportunities to business of improving resource efficiency - Publications Office of the EU. Retrieved January 30, 2019, from https://publications.europa.eu/en/publication-detail/-/publication/f95279c2-1635-460d-9c56-a3534aefd629/language-en

Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2019). Building a business case for implementation of a circular economy in higher education institutions. *Journal of Cleaner Production*, *220*, 553–567. https://doi.org/10.1016/J.JCLEPRO.2019.02.045

Milios, L. (2018). Advancing to a Circular Economy: three essential ingredients for a comprehensive policy mix. *Sustainability Science*, *13*(3), 861–878. https://doi.org/10.1007/s11625-017-0502-9

Mishra, J. L., Hopkinson, P. G., & Tidridge, G. (2018). Value creation from circular economy-led closed loop supply chains: a case study of fast-moving consumer goods. *Production Planning and Control*, *29*(6), 509–521. https://doi.org/10.1080/09537287.2018.1449245

Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, *140*(3), 369–380. https://doi.org/10.1007/s10551-015-2693-2

New InnoNet. (2016). *Analysis of the plastic packaging value chain*.

Nonclercq, A. (2016). *Mapping flexible packaging in a Circular Economy*. Delft, Netherlands. Retrieved from https://ceflex.eu/public_downloads/FIACE-Final-report-version-24-4-2017-non-confidential-version-Final.pdf

OECD. (2018). *Improving Markets for Recycled Plastics - Trends, prospects and policy responses*. https://doi.org/10.1787/9789264301016-en

Pheifer, A. G. (2017). *Barriers & Enablers to Circular Business Models*. Retrieved from https://www.circulairondernemen.nl/uploads/4f4995c266e00bee8fdb8fb34fbc5c15.pdf

Porter, M. E. (1985). *Competitive Advanatage - Creating and Sustaining Superior Performance*. New York: The Free Press.

Preston, F. (2012). A Global Redesign? Shaping the Circular Economy. *Energy, Environment and Resource Governance*. Chatham House. https://doi.org/10.1080/0034676042000253936

Ragaert, K., Delva, L., & Van Geem, K. (2017). Mechanical and chemical recycling of solid plastic waste. *Waste Management*, *69*, 24–58. https://doi.org/10.1016/J.WASMAN.2017.07.044

Rajendran, S., Hodzic, A., Scelsi, L., Hayes, S., Soutis, C., AlMa'adeed, M., & Kahraman, R. (2013). Plastics recycling: insights into life cycle impact assessment methods. *Plastics, Rubber and Composites*, *42*(1), 1–10. https://doi.org/10.1179/1743289812Y.0000000002

Ritzén, S., & Sandström, G. Ö. (2017). Barriers to the Circular Economy - Integration of Perspectives and Domains. *Procedia CIRP*, *64*, 7–12. https://doi.org/10.1016/j.procir.2017.03.005

Rizos, V., Behrens, A., Kafyeke, T., Hirschnitz-Garbers, M., & Ioannou, A. (2015). The Circular Economy: Barriers and Opportunities for SMEs. Centre for European Policy Studies (CEPS).

Souza, G. C. (2013). Closed-Loop Supply Chains: A Critical Review, and Future Research*. *Decision Sciences*, *44*(1), 7–38. https://doi.org/10.1111/j.1540-5915.2012.00394.x

Todeschini, B. V., Cortimiglia, M. N., Callegaro-de-Menezes, D., & Ghezzi, A. (2017). Innovative and sustainable business models in the fashion industry: Entrepreneurial drivers, opportunities, and challenges. *Business Horizons*, *60*(6), 759–770. https://doi.org/10.1016/J.BUSHOR.2017.07.003

Tsiamis, D. A., Torres, M., & Castaldi, M. J. (2018). Role of plastics in decoupling municipal solid waste and economic growth in the U.S. *Waste Management*, *77*, 147–155. https://doi.org/10.1016/J.WASMAN.2018.05.003

Tura, N., Hanski, J., Ahola, T., Ståhle, M., Piiparinen, S., & Valkokari, P. (2019). Unlocking circular business: A framework of barriers and drivers. *Journal of Cleaner Production*, *212*, 90–98. https://doi.org/10.1016/J.JCLEPRO.2018.11.202

Van Eijk, F. (2015). Barriers & Drivers towards a Circular Economy - Literature Review. Naarden: Acceleratio. Retrieved from http://www.circulairondernemen.nl/uploads/e00e8643951aef8adde612123e824493.pdf

[i] Four areas were left out due to their lower relevance for the purpose of our study, namely environmental, supply chain, social and organizational.