2021

A Review on European Union’s Strategy for Plastics in a Circular Economy and its Impact on Food Safety

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Recommended Citation

C. Matthews, F. Moran and A.K. Jaiswal (2021) A Review on European Union’s Strategy for Plastics in a Circular Economy and its Impact on Food Safety, *Journal of Cleaner Production,* 283 (2021) 125263. doi:10.1016/j.jclepro.2020.125263

Journal of Cleaner Production 283 (2021) 125263

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Review

A review on European Union's strategy for plastics in a circular economy and its impact on food safety

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A R T I C L E I N F O

Article history:
Received 8 June 2020
Received in revised form
25 October 2020
Accepted 22 November 2020
Available online 26 November 2020

Handling editor. Prof. Jiri Jaromir Klemeš

Keywords:
European strategy for plastics
Circular economy
Sustainability
Food safety
Food waste

A B S T R A C T

In 2018, European Union adopted a European strategy for plastics in a circular economy as a part of their action plan for a circular economy. Sustainability is the underlying motivation behind the plastics strategy with a goal of addressing how plastics are designed, used and recycled in the EU. One of the strategies outlined is that by 2030, all plastic packaging placed on the EU market is either reusable or can be recycled in a cost-effective manner. A large portion of food packaging is multi-layer plastic that is not recyclable in a cost-effective manner. Given the difficulties associated with recycling today's complex food packaging, what impacts will the European Union's strategies for plastics in a circular economy have on food safety? This article explores what is being done and what can be done to mitigate the risks to food safety while adhering to the EU's plastic strategy. It has been observed that the plastic plays a vital role in maintaining food safety, extending shelf-life and minimising food waste. However, it is currently not possible to recycle multi-layer plastic packaging which is widely used throughout the food industry, and there are currently no viable alternatives offering the same level of protection. Unless possible substitutes to multi-layer plastics offering the same level of food protection can be developed then there will be detrimental effects on food quality, safety and shelf-life, which will lead to increased food waste, additional food costs and a reduction in the variety and availability of certain foods.

Contents

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https://doi.org/10.1016/j.jclepro.2020.125263
0959-6526/

1. Introduction

Plastic plays a significant and growing role in modern day society, delivering many benefits particularly in food safety and preservation and can help reduce food waste. The Ellen MacArthur Foundation et al. (2016) point out that plastic packaging is lightweight which can have environmental benefits such as reduced transport costs, they are inexpensive delivering direct economic benefits and plastic packaging can deliver high performance such as extending product shelf-life. By minimising food waste, Yun et al. (2018) explain that plastic packaging could significantly reduce the overall environmental impact of producing the food itself. But plastic packaging also has its drawbacks specifically environmental concerns.

Geueke et al. (2018) highlight some of these concerns as high production volume, short usage time (mostly single use) and waste management and littering problems. Cordier and Uehara (2019) contend that plastic's non-biodegradable nature is leading to an increasing concern about the ever-growing accumulation of plastic in our oceans and natural environment. To help address the environmental issues surrounding plastics and move towards a more sustainable model for economic development, the EU launched "A European Strategy for Plastics in a Circular Economy" in 2018 (European Commission, 2018). One of the key requirements outlined in the plastics strategy is "by 2030, all plastics packaging placed on the EU market is either reusable or can be recycled in a cost-effective manner" (European Commission, 2018).

Today's food packaging often consists of multi-layers that are made from several different plastic polymer types. Packaging manufacturer Südpack's Johannes Remmele (BASF, 2019a,b9) reports that multi-layer packaging can consist of up to 11 ultra-thin layers offering different options such as oxygen barriers. These packaging solutions keep packaging volume to a minimum, reducing raw material use and lower CO_2 emissions while offering maximum protection to the food, extending shelf-life and reducing food waste. However, Dilkes-Hoffman et al. (2018) point out that these multi-layer plastics pose big challenges for recycling, with either high costs, technological difficulties with separating the different plastic polymers or the inability to recycle mixed polymers. Faraca and Astrup (2019) also explain that plastic is one of the most complex materials to recycle because plastics are made up of such a large group of polymers.

Given the difficulties associated with recycling today's complex food packaging what impacts will the European Union's strategies for plastics in a circular economy have on food safety? This article explores what is being done and what can be done to mitigate the risks to food safety while adhering to the EU's plastic strategy.

2. European circular economy

"In December 2015, the (European) Commission adopted a Circular Economy Action Plan with the aim to set the European Union on the course of the transition towards a more sustainable model for economic development" (Commission, 2019). Bocken et al. (2016) distinguish a circular economy from a traditional linear economy: The linear approach; take-make-use-dispose is a high user of resources and largely reliant on fossil fuels, whereas the circular approach focuses on continually reusing materials in an economically viable way and utilising renewable resources where possible. However, Moraga et al. (2019) contend that the concept of a circular economy is not so easily defined saying that the focus should not only be on material preservation through strategies such as recycling but should also take into account the life cycle approach including environmental, social, or economic effects. Murray et al. (2017) definition incorporates a much broader picture of what a true circular economy encompasses: The circular economy is "an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximise ecosystem functioning and human well-being" (Murray et al., 2017).

The goal of the EU's action plan (Commission, 2015) is to maximise the usefulness of resources and materials keeping them in the economy for as long as possible while minimising waste. The EU (Commission, 2015) proposes that the move to a more circular economy will provide Europe with a sustainable competitive advantage achieved by ensuring that businesses are not reliant on scarce resources and volatile prices. The Ellen MacArthur Foundation and the McKinsey Center for Business and Environment (2015) predict that a circular economy could grow Europe's resource productivity by up to 3 percent annually by 2030, generate benefits to the value of €1.8 trillion, and offer resource independence, innovation, employment, and growth. However, the technical revolution necessary to capture the circular opportunity has only started and is not yet enough to economically utilise the opportunities. The Ellen MacArthur Foundation and the McKinsey Center for Business and Environment (2015) further report that opponents to a circular economy argue that European companies already recycle, remanufacture and reuse the most economically viable materials and point out that the costs involved in switching to a more circular economy are unaffordable. But the Intergovernmental Panel on Climate Change (IPCC, 2018) warns that urgent action is required to limit the rise in global warming and expresses that we only have until 2030 to radically reduce our greenhouse gas emissions before the damage is irreversible. It could be argued that the impending environmental crisis requires governments, manufacturers and users of resources to take a more holistic approach, which accounts for the environmental impact of products and not just the current economic situation.

Two of the five priority sectors identified in the EU's action plan (Commission, 2015) are plastics and food waste. The action plan expresses that plastic recycling is an essential part of a circular economy and that less than 25 percent of collected plastic waste is currently recycled and about 50 percent goes to landfill. The action plan proposes that "smarter separate collection and certification schemes for collectors and sorters are critical to divert recyclable plastics away from landfills and incineration into recycling" (Commission, 2015). At the same time there is an increasing concern about the amount of food wasted in Europe and the impact it has on the use of natural resources and the environment. This is echoed by the United Nations (2016) who as part of their sustainable development goals for 2030 (goal 12.3) set a target of halving global food waste per capita at retail and consumer levels and reducing food losses throughout the food chain.

Given the EU's restrictions on using recycled plastics (European Commission, 2008) as food contact material, there appears to be a contradiction between the EU's plans to recycle more plastics and at the same time reduce food waste. However, in their action plan (Commission, 2015) the EU also acknowledges that plastics play a role in better food preservation which can contribute to the circular economy.

A considerable development in the EU's action plan was realised in 2018 when the European Commission adopted their plastics strategy "A European Strategy for Plastics in a Circular Economy" (European Commission, 2018). Misko (2019) explains that the goal of the plastics strategy is to address how plastics are designed, used and recycled in the EU. One of the key components of the plastics strategy is highlighted by REPAK & RPS Group (2018): "By 2030, all plastics packaging placed on the EU market is either reusable or can be recycled in a cost-effective manner." This component will potentially have the greatest impact on food safety, shelf-life and food waste. The European Committee of the Regions (van de Nadort, 2018) also expressed their concern about its impending impact and called for "further research on the relation between packaging and food preservation on a life-cycle basis and possible alternative approaches to prevent food waste without the use of (complex) plastic packaging."

3. EU food contact material (FCM) regulations

EU regulation 1935/2004 (European Commission, 2004) food contact material Recital 24 states that "the use of recycled materials and articles should be favoured in the community for environmental reasons, provided that strict requirements are established to ensure food safety and consumer protection." Under the requirements in Article 3 materials or articles must not transfer their constituents to food in quantities which could, endanger human health or change the composition or organoleptic characteristics of the food.

Article 5 of Regulation 1935/2004 (European Commission, 2004) covers specific measures for groups of materials and articles; for plastics this is covered under EU Regulation 10/2011 (European Commission, 2011) on plastic materials and articles intended to come into contact with food. The regulation stipulates that plastics used as FCM can only be manufactured from approved materials and additives and must comply with the relevant requirements set out in Article 3 of Regulation 1935/2004.

Recital 27 of Regulation 10/2011 (European Commission, 2011) relates to multi-layers of plastic. FCM can consist of several layers of different plastic to maximise the protection offered to the food with a functional barrier separating the layers from the food. Non-authorised substances may be used behind the barrier providing that their migration levels remain within detection limits and they are not mutagenic, carcinogenic or toxic. The migration limits are set out in Articles 11–12 of the regulation. Similar requirements apply to multi-layers consisting of a combination of several materials, which is covered in Recital 28.

To ensure that food packaging made from recycled plastic is safe, in March 2008 the EU adopted Regulation 282/2008 (European Commission, 2008) on recycled plastic materials and articles intended to come into contact with food. According to the European Commission (2008b) the regulation determines how recycled plastics can be used for FCM and promotes recycling and waste prevention in alignment with the EU's strategies on the sustainable use of raw materials. One of the main objectives of the regulation is to lay down criteria which will ensure recycled plastics can be safely used as a FCM; this will also encourage participation in and opportunities for recycling plastics for food contact.

Recital 4 of the regulation (European Commission, 2008) explains that plastic packaging may contain contaminants from misuse or from non-authorised substances. This would be in breach of Article 3 of Regulation 1935/2004, it is therefore necessary to ensure that a recycling process is authorised before recycled materials or articles can be placed on the market; this is covered in Article 3 of Regulation 282/2008. The European Commission (2008b) reports that the dossiers of the applicants will be managed by the Commission but the risk assessment of the recycling processes will be carried out by the European Food Safety Authority (EFSA).

Article 4 of Regulation 282/2008 (European Commission, 2008) sets out the conditions that a recycling process must comply with in order to be authorised, this includes the inputs of plastic materials and articles. The inputs must originate from materials and articles that have been manufactured in accordance with FCM legislation. The plastic input must come from a closed loop, where any contamination can be ruled out or the process must be able to demonstrate in a challenge test or other appropriate scientific evidence that the process can reduce contamination to levels that do not pose a risk to human health.

As part of the EU's drive towards a circular economy legislative changes were introduced with the intention of providing the necessary framework to compel member states to increase plastic packaging waste recycling and decrease landfill or incineration of recoverable waste. As a result Directive 1999/31/EC on the landfill of waste was amended with Directive (EU) 2018/850 (European Union, 2018a). Article 1 expresses that there is a progressive reduction of landfilling of waste that is suitable for recycling or recovery. Similarly, the Waste Framework Directive 2008/98/EC was rewritten and amended with Directive (EU) 2018/851 (European Union, 2018b). Amendments to Article 3 provide the framework for waste management which includes the recovery of waste. Article 10 stipulates that necessary measures are taken "to ensure waste undergoes preparing for re-use, recycling or other recovery operations." Whereas the Packaging Waste Directive 94/62/EC was amended with Directive (EU) 2018/852 (European Union, 2018c). Recital 4 specifies that the most effective way of reducing wastes' environmental impact is waste prevention and therefore stipulates that measures are taken by Member States to encourage the increased share of reusable packaging placed on the market and its increased usage. Reusable packaging is described in Article 1 as packaging "which has been conceived, designed and placed on the market to accomplish within its lifecycle multiple trips or rotations by being refilled or reused for the same purpose for which it was conceived."

4. Reality of plastic recycling efforts

On the surface, it looks like there is a robust and functioning system where recycled plastic is being utilised for FCM on a regular basis. But in October 2017, more than 9 years after Regulation 282/2008 was adopted, Plastics Recyclers Europe (Sustainable Plastics, 2017) raised concern about the lack of progress made in authorising plastic recycling processes. EVIRA the Finnish Food Authority (2018) notes that it is not currently possible to use mechanically recycled plastic as a food contact material except behind a barrier. In autumn 2018, about 140 applicants (most concerning PET recycling) were waiting for authorisation from the European Commission. However, in July 2018 at the 6th meeting of the Scientific Network of the food ingredients and food packaging (FIP) Unit on (FCM) (EFSA, 2018) (Stieger, 2018), the European Commission revealed that adoption and application of the recycling processes is planned for early 2019. Misko (2019) points out that despite EFSA issuing over 140 favourable scientific opinions on the safety of plastic recycling processes, the European Commission has not authorised any of the processes.

Is the Commission right to be cautious when it comes to authorising recycled plastic for FCM? Floriana Cimmarusti secretary general of Safe Food Advocacy Europe (SAFE) (Simon, 2018) describes some of the issues associated with using recycled plastics as FCM. For recycled plastics the levels of oligomers (by-products of plastic that can migrate into food) and also non-identified contaminants are higher than virgin plastics. Through cross-contamination during waste management, many plastics absorb these chemicals because currently there is no segregation of food contact plastic and non-food grade plastic. The risk of exposure to toxic substances and possibly banned chemicals is much higher with recycled old plastics. Groh et al. (2019) explain that residues from manufacturing substances such as solvents and non-intentionally added substances such as impurities, oligomers or degradation products can be present in plastic packaging. To characterise the risks from these substances comprehensive information on all chemicals involved is needed. Because of these quality issues Hahladakis and Iacovidou (2018), point out that the recycling rates of post-consumer plastic packaging remains low despite plastic packaging being theoretically highly recyclable. Geueke et al. (2018) note that using recycled plastic for FCM may lead to greater levels of these possibly hazardous chemicals, which in turn can migrate into the food. Geueke et al. (2018) maintain that it is highly important to adequately assess the safety of recycled packaging due to the association between the exposures of certain chemicals migrating from food packaging with chronic disease.

Casper van den Dunger, from Plastics Recyclers Europe PET working group (Misko, 2019) contends that the years of delay in authorising recycled plastic for FCM have led to uncertainty leaving businesses in legislative no-man's land, which reduces investment and more seriously a conceivable scepticism of legislation regarding FCM.

However, Radusin et al. (2020) found that recycled material could be utilised in food packaging behind a layer manufactured from virgin materials, increasing the use of recycled materials without exceeding chemical migration levels.

5. Why plastic food packaging

Plastic is a diverse and ubiquitous material with incomparable functionality that has many measurable benefits making it an important part of our daily lives. The EU European Commission (2018) points out that because of its lightweight it can help reduce CO_2 emissions, when used for automotive parts, and when used for insulation it improves energy efficiency. Bio-compatible plastics can also help save lives with innovative medical devices. The Ellen MacArthur Foundation et al. (2016) claims that plastic's diversity and low cost have contributed to its widespread use with 2016 usage levels expected to double within 20 years. This is also underlined by PlasticsEurope (2018) who's figures show European plastic production increased by 7.3% from 2016 to 2017 and globally by 3.9%. Packaging at 39.7% accounts for the largest plastic sector on the market (Fig. 1) of this Groh et al. (2019) point out that approximately 60% is used for food and beverages.

It is not surprising that being so widely used for food packaging, plastic plays an important role in food safety and waste reduction. "Plastic packaging can reduce food waste by extending shelf-life and can reduce fuel consumption for transportation by bringing packaging weight down" (Ellen MacArthur Foundation et al., 2016). Sharma and Ghoshal (2018) explain that traditionally the objectives of food packaging systems were containment, protection, convenience and communication but more recently the emphasis has shifted towards quality, safety and extended shelf-life. This has led to the development of active and intelligent packaging, which de Oliveira Filho et al. (2019) state are mostly based on polymers from non-renewable sources. Yucel (2016) explains that active packaging systems modify the food or environment it is held in for example modified atmosphere packaging (MAP) and intelligent packaging systems use a sensor or an indicator to inform consumers about any changes to the quality or safety of the food for example time-temperature indicators (TTI).

In order to ensure compatibility between the product and the packaging it is important to understand the nature of the product and what the requirements are. Packaging cannot improve quality, but the correct packaging solution can maintain it. Containment is one of the main objectives of packaging; Robertson (2013) explains that adequate containment allows the product to move from one place to another without polluting the environment through leakages. Robertson (2013) further notes that because of the range of optical, mechanical and barrier properties there is widespread use of plastic for food packaging. The bursting strength, impact strength, tear strength, stiffness and crease or flex resistance can all be tailored making plastic packaging an ideal solution for food packaging needs.

Robertson (2013) observes that protection is often considered the primary function of packaging, offering foods protection from the external environment such as water, water vapour, gases, odours, microorganisms, dust, shocks, vibrations and compressive forces. For most foods packaging forms an integral part of the food preservation, for example vacuum packed meat can only reach its shelf-life if the packaging prevents O_2 from entering. In most cases once the packaging integrity is compromised the preservation of the food is compromised.

Packaging plays an important role in preventing spoilage from microorganisms which are one of the main causes of food spoilage. Lee (2010) comments that multi-layer plastic pouches are now used for retortable food packaging; this aseptic packaging keeps the decontaminated food in a sealed environment preventing recontamination from microorganisms. The multilayers of plastic allow food packaging to be easily adapted to meet the various requirements of different food types and prevent microbial growth. For example, dry foods utilise low a_w (water activity) to inhibit microbial growth, plastic packaging can incorporate a water vapour barrier preventing moisture transfer into the food. However, the food may also require barriers against gas, volatile or light permeability; multilayer plastic packaging can offer effective solutions to these needs.

McMillin (2017) points out that appearance, colour, lipid stability, nutritive value and palatability (texture, flavour, aroma) are also significant factors that must be considered when choosing a

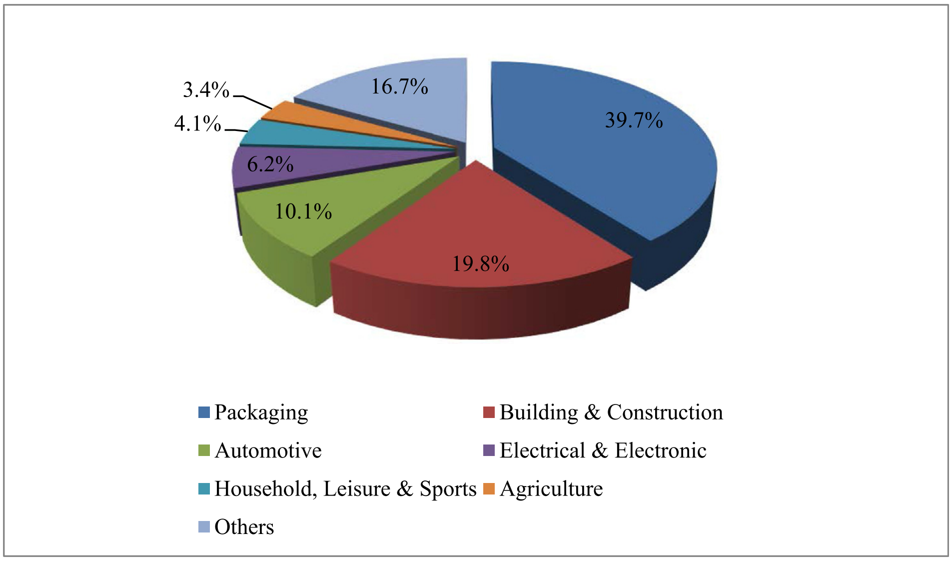

Fig. 1. Plastic converter demand main market sectors (PlasticsEurope, 2018).

packaging solution. To meet these requirements packaging from plastic polymers are the most widely used and are the foundation for the major advancements in packaging solutions.

5.1. Effects of inadequate food packaging

The Food and Agriculture Organisation of the United Nations (FAO) (Manalili et al., 2014) maintain that food packaging in developing countries is often inadequate, this is because low domestic demand leads to low investment, which consequently leads to limited technical solutions. The FAO shows the impact this can have with 40% of developing countries food lost between harvest and processing (Gustavsson et al., 2011). Globally the FAO estimate that one third of food production is either lost between the producer and the market or wasted amounting to about 1.3 billion tonnes per year (Gustavsson et al., 2011). In medium and high-income countries these losses mainly occur at consumption level.

The production of this food can have a detrimental impact on the environment which, according to Scherhaufer et al. (2018), uses fuels, land, water and raw materials such as fertilisers. The further along the supply chain that the waste occurs the greater the negative environmental impact for example more resources are used for transport or further processing.

Packaging is not the only cause of these losses, the FAO (Manalili et al., 2014) highlight poor handling, distribution, storage and purchase/consumption behaviour as other causes. However, they also point out that losses could be reduced by using suitable packaging which they see as an essential part of a long-term solution. Advances in packaging can not only reduce losses but also improve food quality and safety. To offer the best food protection the FAO suggests that a packaging solution could include more, but better packaging rather than less packaging.

It could be argued that if it prevents waste the environmental impact of producing the plastic packaging is offset by preventing food loss. For example Robertson (2013) argues that the total energy required to produce 1 kg of bread from farm to fork is 15.8 MJ whereas the LDPE (low density polyethylene) packaging requires 1.4 MJ of energy, therefore 1 unit of energy used to produce the packaging protects 11 units of energy used to produce the product. The EU Commission (Monforti-Ferrario et al., 2015) points out that in 2014 food production in the EU accounted for 28% of total energy use, 100 million tonnes or 5% of this food was wasted at household level and manufacturing. Fig. 2 gives a breakdown of the total energy consumption of a variety of food products, taking into account energy consumption during agriculture, processing, logistics, use, end of life and packaging. With the exception of the bottled products such as beer or olive oil, the energy used to produce the packaging is a small percentage of the food's total overall energy consumption.

6. Why should we avoid using plastic packaging?

The Ellen MacArthur Foundation et al. (2016) note that while plastic packaging has numerous benefits there are also drawbacks that could have a detrimental effect on the environment. The majority of plastic used for packaging is single-use with 95% of material value lost to the economy each year with a value of up to USD 120 billion. 90% of all plastics (not just packaging) are derived from virgin fossil feedstocks and account for about 6% of global oil consumption which is equivalent to the global aviation sector. It is estimated that plastic production will account for 20% of total oil consumption by 2050.

While the soup like confetti-sized plastic ocean debris known as The Great Pacific Garbage Patch was discovered by Captain Charles Moore as far back as 1997 (Cho, 2011) it has been the more recent publicity surrounding plastic waste that has caught the attention of the public who are now demanding action from their governments. The Ellen MacArthur Foundation et al. (2016) maintain that annually 8 million tonnes of plastic leaks into the ocean, this is the equivalent to one bin lorry per minute, which is expected to double by 2030 and double again by 2050.

6.1. Plastic recycling limitations

Bocken et al. (2016) explain that there are four methods of recycling namely primary, secondary, tertiary and quaternary. In primary (also known as closed loop) recycling method, the recyclates are reprocessed into goods with equal or improved properties. In secondary or down-cycling method, the recyclates are reprocessed into goods of lower properties, such as industrial grade rubber being reprocessed into a general grade rubber. In tertiary (also known as chemical or feedstock) recycling method, the

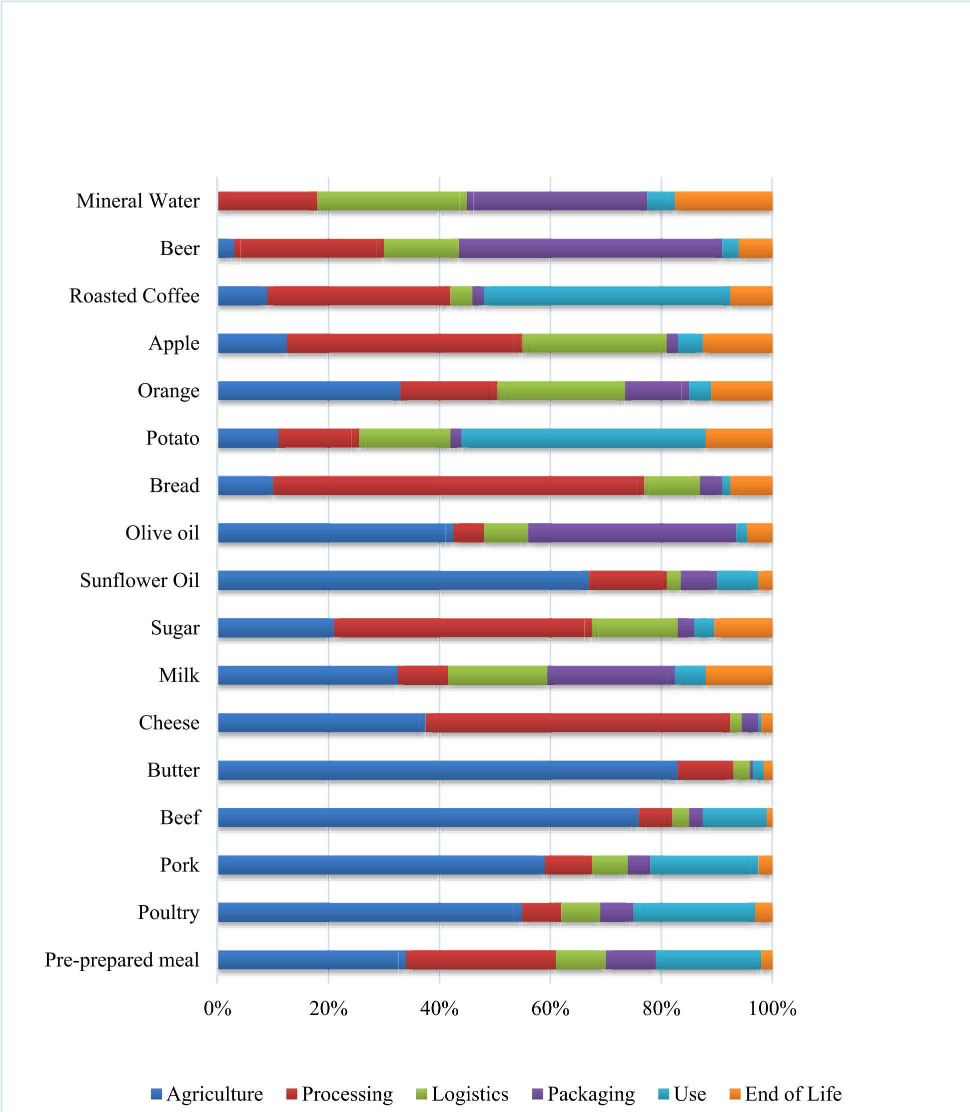

Fig. 2. Shares of energy embedded along the production steps of a kilogram of 17 products (EU Commission (Monforti-Ferrario et al., 2015)).

original chemical constituents are extracted from the recyclates and reused to construct goods with equal properties (for example depolymerisation of materials into their original raw core components and then consecutive repolymerisation of material with properties equal to the original material), where as in quaternary (also known as thermal recycling, energy recovery, and energy from waste) recycling method, recyclates are used for energy recovery; this method is not considered as recycling in a true circular economy (Bocken et al., 2016).

However, how effective these recycling methods are for today's complex food packaging is questionable. According to Hahladakis and Iacovidou (2018), plastic packaging is theoretically highly recyclable but due to quality issues recycling rates remain low. There are a wide variety of plastic resin types on the market (Fig. 3) with varied applications; as pointed out earlier packaging is the largest sector, responsible for almost 40% of plastic placed on the market. PlasticsEurope (2018) notes that the polymer types mostly used for food packaging are polypropylene, low density polyethylene, linear low-density polyethylene, terephthalate polyethylene, medium density polyethylene and polystyrene for a small number of applications. However not all plastic is recyclable, some rigid plastics are recyclable (these would be made up of mostly food containers, pots, tubs and trays made from various polymers), some flexible plastics are recyclable (these are mainly LDPE film for stretch wrap or shrink wrap) while some are non-recyclable (these are mainly film from various polymer types found in your bin at home e.g. PP sweet or biscuit wrappers, PVC labels, bags etc.)

6.2. Contaminants in recycled plastics

Hahladakis and Iacovidou (2018) explain that the way plastic packaging is segregated, sorted and recovered for recycling can affect the quality; plastic for recycling may come into contact with impurities and contaminants during disposal. Geueke et al. (2018) point out that "different groups of contaminants, e.g., oligomers, additives and their degradation products, as well as chemicals derived from previous (mis)uses, have regularly been reported in recycled plastic." The typical groups of contaminants found in recycled plastic derived from and/or intended for FCM is further highlighted by Geueke et al. (2018). Flavour, aroma and odour

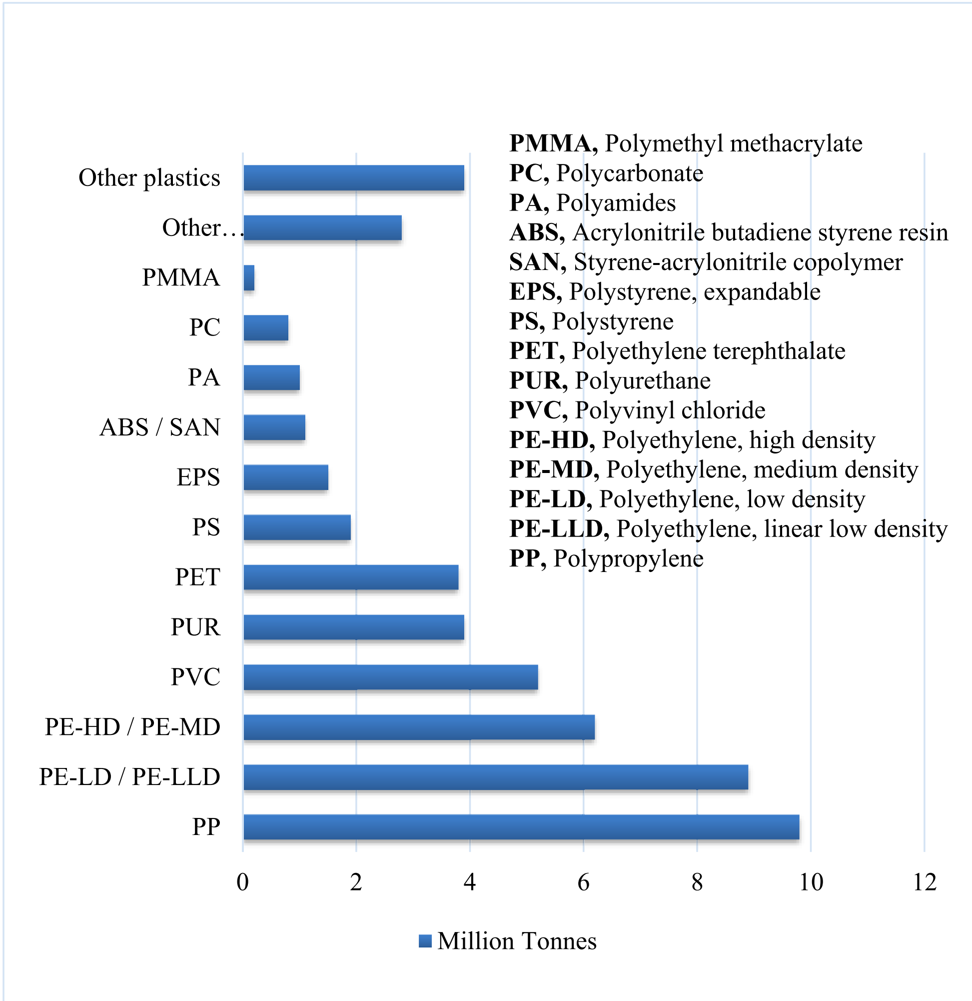

Fig. 3. Distribution of European (EU28 + NO/CH) plastic converter demand by resin type (PlasticsEurope, 2018).

compounds are common contaminants found in post-consumer plastic packaging, these can derive from intended applications, misuse of the packaging by consumers or cross-contamination. Oligomers which are formed during the synthesis of plastics or generated during use and recycling of polymers may be present and migrate into food. Additives are used for a variety of purposes during the plastic production process including appearance and performance of the final product. There are around 600 additives and polymer production aids authorised for plastic FCM. Some additives such as UV stabilisers or antioxidants are degradation products which intentionally degrade during use.

As previously discussed a significant amount of food packaging comprises of multi-layers combining different plastic polymers to achieve optimal shelf-life and prevent spoilage. Dilkes-Hoffman et al. (2018) note that these multi-layer packaging solutions pose a particular challenge for recycling and are currently non-recyclable and non-degradable, but suggest that high-barrier, multi-layer, biodegradable food packaging could be a useful replacement.

7. Bioplastics as a possible alternative to plastic packaging

European Bioplastics (2017) explains that bioplastics encompass a range of materials with differing properties and applications (Fig. 4). A plastic can be defined as a bioplastic if it is either or both bio-based, which means that the material is (partly) derived from plants or biodegradable, which means that microorganisms found in the environment convert the material into natural substances. European Bioplastics (2017) further explains that bio-based does not equal biodegradable because the property of biodegradation is linked to the chemical structure of the plastic rather than the source of the material. Therefore, 100 percent of a bio-based plastic may not be biodegradable and 100 percent of a fossil-based plastic may be biodegradable. However, bioplastics can have benefits such as renewable resources leading to sustainable production and a reduction in the carbon footprint and Greenhouse Gas (GHG) emissions. Payne et al. (2019) maintain that to mitigate rising environmental concerns, it is crucial that the plastics industry proactively shifts from petrochemical feedstocks, with biomass emerging as the most likely alternative. But it could be argued that food producing land should not be used to grow plastic or rain forest cut down to produce plastic.

Claims of biodegradability can also be ambiguous if further information regarding the timeframe, the conditions necessary for biodegradation and the level of biodegradation are not provided. For example “single-use plastic shopping bags marked ‘biodegradable’ may require the conditions that commonly occur only in an industrial composter.” (Kershaw, 2015).

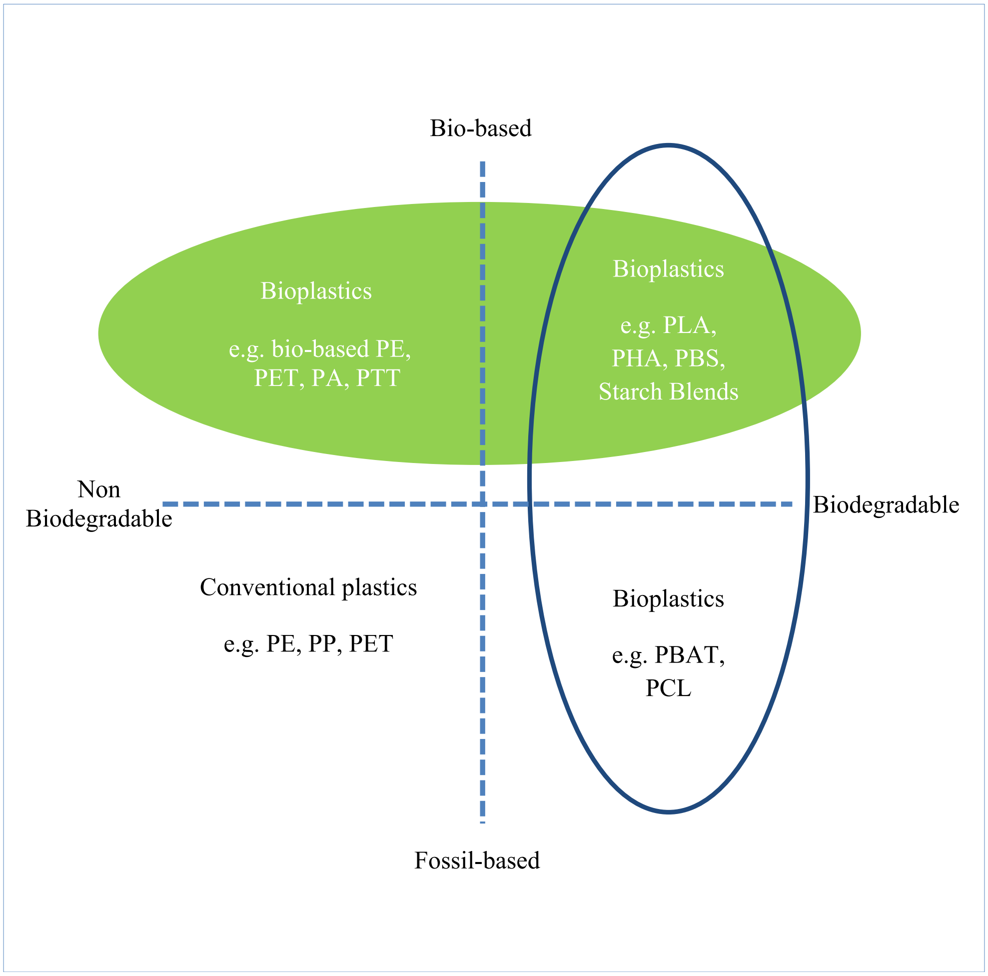

Fig. 4. Classification of biodegradability of common bioplastics (European Bioplastics, 2017).

7.1. Natural biopolymers

Kershaw (2015) describes biopolymers which are very common in nature and form the building blocks of plant and animal tissue. Biopolymers are very large high weight molecules with long chain-like structures. Cellulose ($C_6H_{10}O_5$)n is a key constituent of the cell walls of plants. Chitin ($C_8H_{13}O_5N$)n is found in the exoskeleton of insects and crustaceans while Lignin ($C_{31}H_{34}O_{11}$)n is another important component of plants cell walls which provides strength and restricts the entry of water.

European Bioplastics (2017) divides the family of bioplastics into three main groups: Bio-based or partly bio-based, non-biodegradable plastics such as PE, PP, or PET and bio-based technical performance polymers such as PTT or TPC-ET; both bio-based and biodegradable plastics such as PLA and PHA or PBS; and Biodegradable fossil-based plastics such as PBAT. Domínguez et al. (2018) say that any natural polymers utilised for packaging solutions should meet the same performance standards as synthetic polymers, including physical requirements, sealing properties, hermeticity and barrier release compounds. Payne et al. (2019) explain that PLA is derived from lactic acid, which is a naturally occurring product, has favourable environmentally benign qualities and is inherently biocompatible. PLA is used in a variety of sectors most notably in packaging including food and beverage packaging. PLA's limitations such as brittleness, poor heat resistance and hydrolytic instability have limited its use primarily to single-use disposable applications. Hahladakis and Iacovidou (2018) observer that PLA is one of the most versatile bioplastics on the market, this is because PLA is compostable and recyclable, however currently it is not composted or sorted for recycling. As such it often ends up with other plastics diverted for sorting and recycling where it contaminates the high-value plastics streams and affects their recyclability.

7.2. Starch blends/polysaccharide-based films

Domínguez et al. (2018) point out that because of their excellent mechanical and structural properties polysaccharides can be utilised as alternatives to synthetic polymers, however there are limitations to their applications because they offer poor barriers to water vapour. Following their study into compostable cassava starch-based packaging material Casarejos et al. (2018) conclude that cassava starch is a compostable packaging solution offering far better societal and environmental outcomes than petroleum-based packaging. Taking into account the consumption of production factors such as energy and water use and GHG emissions Casarejos et al. (2018) claim that cassava starch packaging is an effective and promising climate change mitigation strategy. But Tumwesigye et al. (2016) point out that while there is great potential for cassava bio-based materials, there are significant challenges to utilising cassava starch for food packaging. These include high cost, food safety, hygiene regulations and limited consumer acceptance.

Another starch based solution is examined by Dilkes-Hoffman et al. (2018) who contend that biodegradable thermoplastic starch (TPS) and polyhydroxyalkanoate (PHA) could be a useful replacement for current multi-layered packaging. By including the function of the packaging (e.g. preventing food waste) into account when carrying out the life-cycle assessment (LCA) Dilkes-Hoffman et al. conclude that PHA-TPS food packaging can reduce GHG emissions but only if it reduces food wastage or increases the viability of biological food waste processing.

7.3. Protein based biopolymers

Domínguez et al. (2018) explain that proteins can offer promising solutions as biopolymers. The advantages of protein based biopolymers include good mechanical, physical (resistance and flexibility) and optical properties, and strong barriers to aromas, oxygen and organic vapours. Sogut et al. (2019) suggest that “carrageenan is one of the promising biopolymers due to its unique colloidal nature, abundance, low cost and moderate oxygen permeability.” However, biopolymers made from proteins are not without their limitations. Sogut et al. (2019) explain that polymers made from proteins are subject to water sensitivity, which restricts their use as alternatives to synthetic polymers. However, researchers are trying to overcome these obstacles by blending protein polymers with other biopolymers such as polysaccharide biopolymers.

8. Product design

Bocken et al. (2016) point out that once a product has been designed a certain way and activities, infrastructure and resources are committed, it is difficult to make changes. Therefore, the recyclability of plastic packaging should be considered during the design phase. Bocken et al. (2016) explain that the term design for disassembly is about ensuring that products can be easily separated which is vital for materials that will enter different cycles, for example composting or recycling. For recycling to be successful it is imperative that all materials can be sufficiently separated, for example Reed et al. (2018) report that a load of PET could be ruined if contaminated by PVC as small as 50 ppm. This could be relevant where food packaging needs to be multi-layered to maintain the food’s quality and shelf-life. But Reed et al. (2018) point out that “the technologies developed for sorting materials are often not sufficiently sophisticated in design to separate the multitude of films that are present.” The problems encountered include, not being able to detect or distinguish plastic films that are very thin and/or that have surfaces that are dark coloured or highly glossy.

The Ellen MacArthur Foundation et al. (2016) contend that plastic design choices directly impact the economics, complexity and feasibility of after-use processes. These include:

- Sorting; packaging that comprises of different materials such as labels, caps or multi polymer layers are difficult or impossible to sort.
- Cleaning; contamination can occur from glues or inks that are difficult to remove. Packaging should also be designed to limit product residues.
- Scale; if there are only small volumes of certain packaging formats or materials it may not be worth investing in the necessary recycling equipment.

9. Reuse plastic

The Ellen MacArthur foundation (Lendal et al., 2019) proposes four reuse models incorporating refill (packaging refilled by the user) or return (packaging returned to the business) either on the go or at home (Fig. 5). They maintain that these reuse models are a critical part of the solution to the plastic problem. But what are the food safety issues associated with reusing food packaging? Lemos Junior et al. (2019) point out that returnable PET bottles used in the soft drinks industry may contain contaminants, which will affect the quality and food safety of the repackaged product. These contaminants could be a result of consumer misuse leading to chemical residues or contamination could occur during collection and transportation. However, the beverage manufacturer can take steps to mitigate the risks posed by these contaminants such as washing and utilising technology to detect non-conforming bottles.

While companies can mitigate the risks associated with returned packaging, what about packaging refilled by the user? The Ellen MacArthur Foundation (Lendal et al., 2019) highlights 45 food examples of reuse products that they claim could offer significant benefits to users and businesses. But there are several food safety questions that have to be addressed, for example will consumers undertake adequate cleaning of the packaging before it is refilled? And do consumers understand issues associated with cross-contamination? One item that is routinely reused by consumers is the reusable plastic shopping bag; while not generally in direct contact with food. Consumer behaviour associated with shopping bags could indicate food safety issues that might arise from packaging refilled by the consumer. Williams et al. (2011) note that a third of consumers used their bags to carry a variety of items not just groceries and that 75% of consumers used the same bags for raw meat and other foods. From their microbial analysis of reusable plastic bags Barbosa et al. (2019) found that several genera of *Enterobacteriaceae*, coagulase-negative staphylococci and also *Listeria monocytogenes* were present in the plastic bags. Barbosa et al. (2019) propose that educating the public and printing instructions on the bags could mitigate the health risks posed by utilising reusable plastic bags.

10. Recycling methods

10.1. Mechanical recycling

Ragaert et al. (2017) observe that mechanical recycling is the most common recycling method for plastic packaging. Mechanical recycling typically involves, collecting, sorting, washing and shredding waste plastic before reprocessing the recycled material into new packaging or products. The Ellen MacArthur Foundation et al. (2016) point out that almost all plastic polymer types utilised for packaging can be mechanically recycled with little or no quality impairment. Despite this the Ellen MacArthur Foundation et al. (2016) further report that currently the global average collection rate of plastic packaging for recycling is 14% which reduces to only 5% when losses in sorting and reprocessing are taken into account.

While individual plastic polymers are technically recyclable the multi-layers utilised for many food packaging solutions are currently difficult or impossible to mechanically recycle in a cost effective manner. One solution could be to separate the different polymer types before using conventional mechanical recycling techniques. Kaiser et al. (2017) note that compatibilization whereby suitable molecules are used to separate the multi-layers could offer such a solution. However for this technique to be successful the composition of the multi-layer plastic must be known. “In the case of commingled postconsumer multi-layer packaging waste, a very high degree of sorting would be necessary to provide a consistent product quality that is usually desired by the purchaser” (Kaiser et al., 2017).

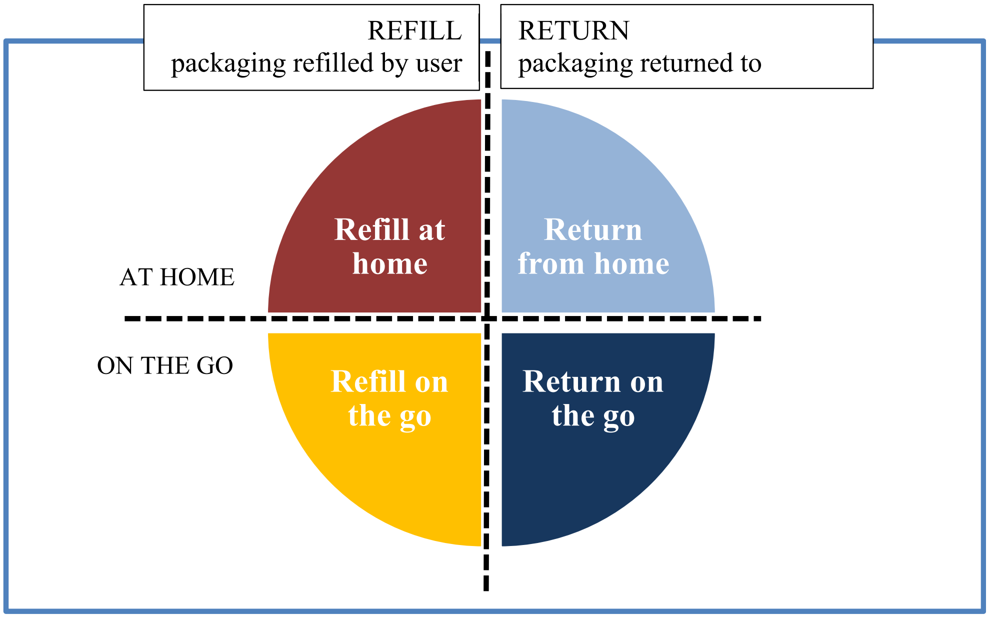

Fig. 5. The four reuse models (Lendal et al., 2019).

10.2. Composting

Composting is an emerging alternative to recycling particularly for a number of bioplastics, which can have minimal environmental impact. But as Payne et al. (2019) point out "composting conditions are inherently complex, relying on a number of different factors, including humidity, ventilation and pH." This is underlined by van de Nadort (2018) who insists that it is highly important for plastics marked as compostable to break down in the environment without needing industrial composting. This is backed up by EU Directive 2018/852 (European Union, 2018c) which stipulates that "Packaging waste processed for the purpose of composting shall be of such a biodegradable nature that it does not hinder the separate collection and the composting process or activity into which it is introduced." Nevertheless the Ellen MacArthur Foundation et al. (2016) contend that industrial compostable plastic packaging could be a viable solution for certain plastic applications. Conceivably where packaging is likely to be contaminated with the food it contained (which limits recycling) composting could help bring the nutrients of the food back to the soil. In order for composting to be a viable option appropriate collection and recovery infrastructure would have to be in place.

10.3. Chemical recycling

Ragaert et al. (2017) claim that chemically recycled plastics are well-suited for food applications and are also an accepted recycling method for sustainable development. They state that there is a steadily growing interest in using chemically recycled feedstocks this is because there is a close link to the quality of conventional petroleum elements. However, Ragaert et al. (2017) also note that the costs of chemically recycled polymers are significantly higher than virgin materials due to the high cost of raw material, capital investment and the scale of operation required. Furthermore Partridge and Medda (2019) explain that converting plastic waste into refined petrochemicals requires high-temperature and energy use which increases the carbon footprint of chemical recycling. This will have to be taken into account when carrying out the life cycle assessment of the true impacts of chemical recycling compared with incineration and mechanical recycling.

Pyrolysis is described by Ragaert et al. (2017) as chemical recycling system whereby multi-layer packaging which cannot be recycled by conventional depolymerisation or mechanical methods can be recycled into its separate components. German chemical company BASF, within the scope of its ChemCycling project are developing a chemical recycling technology that will enable mixed and multi-layer food packaging to be recycled (Plastic News Europe, 2019). BASF (2019a,b) explains that the plastic waste is transformed into raw material using thermochemical processes, resulting in products of equal quality to those derived from fossil feedstocks. However, BASF (2019a,b) also points out that there are questions relating to the acceptance of thermochemical recycling from the market and regulations. BASF in conjunction with Borealis, Südpack and Zott (BASF, 2019a,b) have now produced a prototype packaging which they claim is a hygienic, high-tech, multilayer food packaging consisting of up to 11 ultra-thin layers made entirely from chemically recycled material.

11. Plastic marking

The codes found on some plastic packaging (see Table 1) are known as Resin Identification Codes (RIC), Cramer (2017) explains that these codes were created in the 1980s by the Society of the Plastics Industry to help develop consistency in plastics manufacturing and plastic recycling. Codes 1–6 represent packaging made from one specific type of plastic with code number 7 representing a catch-all category incorporating all other plastics or mixed plastics. The information provided by these codes is very limited especially given the increasingly complex multi-layer polymers utilised in today's food packaging. The Ellen MacArthur Foundation et al. (2016) express the need to develop a Global Plastics Protocol to substantially improve collection, sorting, reprocessing yields, quality and economics. The Global Plastics Protocol would investigate the possibilities and economic benefits "of harmonising the labelling and chemical marking across plastic packaging and aligning these standards with after-use separation and sorting systems" (Ellen MacArthur Foundation et al., 2016). 76% of respondents from a survey of European plastic converters (EuPC;

Table 1
Plastic Identification Codes, relevant plastic types, their common uses and demand in the EU28 + NO/CH.

Symbol	Type of Plastic	Common Uses	Demand EU28 + NO/CH
01 PET	**PET** Polyethylene Terephthalate	Bottles for water, soft drinks, juices, cleaners, biscuit trays, etc.	**7.4%**
02	**PE-HD** Polyethylene High Density	Shopping bags, freezer bags, milk bottles, ice cream containers, juice bottles, shampoo, chemical and detergent bottles, buckets, rigid agricultural pipe, crates, toys, etc.	**12.3%**
03	**PVC** Polyvinyl Chloride	Window frames, profiles, floor and wall covering, pipes, cable insulation, garden hoses, inflatable pools, etc.	**10.2%**
04 PE-LD	**PE-LD** Polyethylene Low density	Reusable bags, trays and containers, agricultural film, food packaging film, refuse bags, etc.	**17.5%**
05	**PP** Polypropylene	Food packaging, sweet and snack wrappers, hinged caps, microwave containers, pipes, automotive parts, bank notes, packaging tape, etc.	**19.3%**
06	**PS** Polystyrene	Eyeglasses frames, plastic cups, egg trays, packaging, plastic cutlery, building insulation, etc.	**6.6%**
07 OTHER	**OTHER PACKAGING** Including multi-layer materials e.g. PE+PP	Automotive and appliance components, computers, electronics, cooler bottles, packaging, optical fibres, eyeglasses lenses, roofing sheets, touch screens, building insulation, pillows, mattresses etc.	**26.7%**

Source: Plastics SA, 2018; PlasticsEurope (2018).

Polymer Comply Europe, 2019) stated that improvement of collection and sorting of plastic waste was the most suitable way to increase the quality of Recycled Plastic Material (rPM). Respondents also stated that “to improve the quality of recyclates, joint action of the industry is needed in addition to the development of quality standards and chemical recycling.”

To help address the issues associated with separating and sorting plastics for recycling specifically for food applications the EU funded Polymark project was launched in 2014. Pilon et al. (2015) explain that the aim of the three-year Polymark project is to develop a system of marking food contact plastic packaging to enable reliable and efficient large-scale industrial detection and sorting of FCM for recycling. To date the Polymark project has successfully developed chemical food-contact approved markers which are removable by existing recycling plant washing (Reinig, 2017a); the industry ready optical marking is suitable for sorting food grade PET based on UV-excitation and VIS-fluorescence (Reinig, 2017b). The Polymark project has developed a detection unit which is compatible with industrial sorting machines and capable of operating at a speed of 3 m/s on a working width of 1 m at a throughput of 2 t/h (Edar, 2017). The Polymark project coordinator Estela Izquierdo from trade association European Plastic Converters states that “our system is 98% efficient; we believe that sensor-based sorting technology is key to enabling a circular economy for plastics” (European Commission, 2019). Izquierdo (European Commission, 2019) further adds that the partners involved in Polymark are now seeking to develop an alignment of a single global standard or a few compatible standards for tracer or marker-based sorting which is supported by the plastics industry. While the focus of the project was on PET plastics the same technology can easily be applied to other plastic polymers.

12. Costs and quality

Cost is an issue with many of the proposed solutions bearing in mind that the EU directive stipulates that plastic packaging must be either reusable or recycled in a cost-effective manner. Reed et al. (2018) point out that the cost to benefit ratio does not encourage development of improved separation processes even if it is better for the environment. This is echoed by respondents to the plastic converters survey (EuPC; Polymer Comply Europe, 2019) who stated that “more funding is needed to support the development of new applications and converting technologies that can incorporate more rPM”. Governments are in the position to apply fiscal policy which could address this imbalance either through taxation or subsidising research or recycling. In fact “the UK Government is also proposing a new plastics tax on packaging that does not include at least 30% recycled material” (Partridge and Medda, 2019). However, one of the problems with applying a tax is ultimately the consumer will pay the additional costs. But the world is facing an unprecedented environmental crisis that needs to be addressed; therefore it could be argued that consumers need to play their part and pay a little bit extra for food with sustainable packaging.

Quality is another issue with recycled plastics, in order for the EU’s plastic strategy in a circular economy to be successful there needs to be a coordinated approach by all stakeholders in the plastics industry. According to the plastic converters survey (EuPC; Polymer Comply Europe, 2019) 75% of converters are willing to work together to improve the quality of rPM and increase usage. Consumers also need to shift their thinking and play their part in the circular economy. Casarejos et al. (2018) propose that food packaging should be reconceived as services where the used packaging is returned in exchange for credits for new packaging. While that might not be a viable option for all food packaging it does highlight a possible role consumer will have to play in a circular economy.

13. SWOT analysis of food packaging industry

13.1. Strengths

Fossil based plastic food packaging has benefitted from significant research and development over a long period of time; this has resulted in a highly refined material that has clear benefits over alternative food packaging solutions. Fossil based plastics provide a lightweight cost-effective food packaging solution that can be easily tailored to offer a high level of protection to each food type which can extend shelf-life and subsequently reduce food waste.

13.2. Weaknesses

The current food packaging industry is highly reliant on fossil-based plastics from virgin feedstock which is a finite resource. Many of today’s food packaging solutions compose of multi-layer materials which are difficult or impossible to recycle in a cost-effective manner. The inadequacies of the current recycling system (segregation, collecting and sorting of food packaging waste) means that recycled material can only be used behind a protective layer of virgin plastic. Significant investment is required to address both the inadequacies of the current recycling system and to fund research and development to ensure alternative sustainable food packaging materials can meet the food industry's packaging requirements.

13.3. Opportunities

Developing the recyclability of food packaging is essential if the food packaging industry is going to meet the European Union's circular economy requirements. There are opportunities for innovation in both packaging designs that are more recyclable and improvements in recycling technologies. There are also significant opportunities for food packaging organisations to develop sustainable bioplastics that can provide the same level of protection as the current multi-layer fossil-based plastics.

13.4. Threats

Environmental concerns and public perception of current fossil based plastic food packaging poses a significant threat to the food packaging industry. A substantial portion of food packaging cannot be recycled in a cost-effective manner meaning it will not be viable when the European Union's plastic strategy is realised in 2030.

14. Conclusion

With their strategy for plastics in a circular economy, the EU is forcing industry to rethink how plastics are designed and utilised throughout the value chain to make improvements in sustainability. The EU is not condemning all plastic food packaging; on the contrary, they acknowledge the vital role plastic plays in maintaining food safety, shelf-life and minimising food waste. However, it is currently not possible to recycle multi-layer plastic packaging which is widely used throughout the food industry, and there are currently no viable alternatives offering the same level of protection. Removing the benefits of multi-layer plastic food packaging will have dire consequences on the quality and safety of food, will shorten shelf-life, and as a result increase food waste. The environmental impact of producing the food is far greater than producing the multi-layer plastic packaging that protects it; therefore, the increased food waste will have a negative overall environmental impact. The cost of food production will increase because the loss of quality and shorter shelf-life will result in smaller production runs and shorter supply chains which will affect economies of scale. The increased costs will ultimately be passed on to the consumer who will also have to change their buying habits to accommodate the shorter shelf-life. Immediate action is essential requiring investment and collaboration from government and industry to ensure that viable alternatives are developed that can offer our food the same level of protection. It is vital to avoid the situation where food safety and shelf-life is compromised. Without innovation in food packaging, when the EU's plastic strategy comes into effect in 2030, there will be a major step back in food safety and shelf-life, increasing the cost of food and reducing the variety and availability of our food. This review has touched on some promising solutions to the problem, but none of the solutions can offer a definitive answer, each of them having drawbacks that need to be addressed. Further study is needed to explore the true environmental impact of these solutions, taking into account all aspects of production, use and end of life of the packaging but also any environmental impact caused by additional food waste.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.bib_Commission_2019

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