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The sustainable transition of flexible packaging producers in the food and beverage industry: the Irplast S.p.A. case.

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Introduction

Problem statement

The plastic regulatory framework is facing its biggest transformation since the creation this game changer material. The new legislative green transition wants to cut the negative environmental and social impacts that plastic have on our planet, posing new challenges and objectives to the flexible packaging producers. Furthermore, the COVID-19 pandemic has caused delays and other serious problems across supply chains, highlighting how vulnerable many supply chains are to unexpected disruptions (Trabucco and De Giovanni 2021). Consequently, flexible packaging producers should start making fundamental strategy changes to address the pandemic effects and the new legislative framework to remain sustainable from a business point of view. However, it is not still clear whether the private sector is ready for this change and whether it is effectively possible to shift to another material in some applications such as the flexible packaging in the food and beverage industry. The evidence shows that the firms transition is slow (Phelan et al. 2022). Specifically, the proportion of the literature covering each value-chain phase indicates a knowledge gap in the design and production phase (Johansen et al. 2022), which may hinder both the transition to circular and the waste-management procedures in the plastic end-of-life phase. Indeed, most of the literature focus its attention on the waste management phase, without considering the impacts that the design and the production phases have on it. Furthermore, Johansen et al. (2022) claim the necessity for an holistic approach that comprehends all the plastic value chain phases for the implementation of a circular economy strategy.

Research purpose and research questions

The research wants to investigate the gaps found by Phelan et al. (2022) and Johansen et al. (2022) in the implementation of a circular economy for plastic producers, using the case study of Irplast S.p.A., an Italian BOPP film producer. The purpose of the research is trying to fill the literature gaps found in the design and production phase for the flexible packaging producers and to understand how the regulatory framework is pushing them towards the implementation of a circular economy. Indeed, the case study investigates theoretically and practically which are the best practices and strategies implemented by Irplast S.p.A. that might lead to a better implementation of a circular economy, giving a benchmark for the flexible packaging producers in the food and beverage industry. The focus of the case study is on the design and production phases because these are the main phases in which Irplast S.p.A. is directly involved. The food and beverage sector is considered because it is one of the most complex due to its Food Contact Material Regulations, which poses higher quality standards to reach for plastic.

The paper takes in consideration just the flexible packaging producers in the food and beverage sector because it wants to underline the complexity and peculiarities of the plastic industry. Indeed, the purpose is to narrow the search field in order to provide more specific and detailed strategies and actions.
The research questions considered are the following:

- Q 1: How can flexible packaging producers implement a circular economy strategy in the food and beverage sector?
- Q 1.1: How can the product design and production phases be part of a circular economy strategy in the value chain of flexible packaging?
- Q 1.2: How is the new sustainable European legislative framework promoting circular economy strategies for flexible packaging production?

Disposition of the paper

The paper is divided into seven main chapters. The literature review provides a general overview about the themes analysed by the paper and it is divided into eight sub-paragraphs that speak about flexible packaging, regulatory innovation, plastic value chain, alternative feedstock to virgin plastics and the company Irplast S.p.A.. Section three explains the methodology used in the research. Section four gives a general overview on the Company Irplast S.p.A. and presents the results of the case study. Section five elaborates the results and presents the discussion. Finally, the last paragraph points out the conclusions of the case study.

Delimitations and further research

The case study analyses a specific application of plastic for a precise industry. Therefore, the conclusions and the reasoning that come out from this paper are related only to the flexible packaging in the food and beverage industry and cannot be generalised to all the plastic applications and industries. Furthermore, the research considers only the design and production phases outlined by Johansen et al. (2022) in the plastic value chain. Therefore, to broader the research two directions can be chosen. On one side, the research can be integrated with the other phases of the plastic value chain, in order to have the broader and more comprehensive view on how can a circular economy be implemented in the flexible packaging applications for the food and beverage sector. On the other side, there is the need of extending the case study analysis to other plastic applications and sector, which might have different solutions and strategies to implement.

Problem statement	Research questions
Design, production and holistic approach gaps in the implementation of a circular economy in the plastic industry (Johansen et al. 2022) (Phelan et al. 2022).	Q 1) How can flexible packaging producers implement a circular economy strategy? Q 1.1) How can the product design and production phases be part of a circular economy strategy in the value chain of flexible packaging? Q 1.2) How is the new sustainable European legislative framework promoting circular economy strategies for flexible packaging production?

Figure 1: Problem statement and Research questions

Literature Review

Flexible packaging

Considering all the plastics end-use markets in the EU, packaging represents the largest one with more than 40% of the total (Plastics Europe 2021) and about 60% of post-consumer plastic waste (EU Commission 2018). Within the plastic packaging, there is flexible packaging. Flexible packages are the ones made from elastic and flexible materials which are easily formed after filling them with a product. To the flexible packages belong films and flexible laminates used as wrapping of the product and the package. They are mainly used in retail and institutional food and non-food as well as in industrial applications, retail, consumer storage and trash bags, bags, wraps, shrink, and stretch films (Selke and Hernandez 2001). The flexible packaging is mainly made of polypropylene, which represents about 30% of all plastic material in the world thanks to its countless applications and due to its technical properties. From packing cigarette packs on high-speed machines to food packaging, to labels, thanks to its transparency and heat-shrink characteristics that allow it to meet high quality standards by adapting to different needs. The barrier properties against atmospheric elements allow its application for the food sector, guaranteeing the safety of products and extending the shelf-life, i.e. postponing the expiry date of packaged foods.

This paper focuses on its application in films for the food and beverage industry: Bioriented Polypropylene (BOPP). Biaxial orientation means that the plastic film is pulled in two different directions during production, in order to improve its strength, flexibility and brightness. BOPP is a type of film that is produced by extruding the plastic through a circular die followed by expansion cooling (Maddah 2016). This kind of film provides resistance to moisture vapour to keep snacks crisp and fresh tasting and provides a heat-sealable layer (Maddah 2016). It is mostly used in packaging of bakery products, adhesive tapes and snack food packaging. The BOPP physical, chemical and mechanical characteristics, plus its relatively cheap price, have made this material the most used for flexible packaging in the food and beverage industry application.

The increasing role of sustainability within the plastic European regulatory framework

During recent years, a new sustainable regulatory framework that sets the rules and the guidelines in the plastic packaging market in Europe has been developed and it is still in development. Indeed, plastic legislations and normative trends have evolved embracing social and environmental values, with the aim of decreasing the negative impacts of the plastic world on society and the environment. In December 2015, the Commission adopted an EU Action Plan[1] for a circular economy. There, it identified plastics as a key priority and committed

[1] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

itself to ‘prepare a strategy addressing the challenges posed by plastics throughout the value chain and taking into account their entire lifecycle’. In 2017, the Commission confirmed it would focus on plastics production and its use, working towards the goal of ensuring that all plastic packaging is recyclable by 2030 (EU Commission 2018).

In 2018 the Commission presented the European Strategy for Plastics in a Circular Economy[2] that shows the key commitments for an integrated action. The Strategy wants to build a new plastics economy, where the design and production of plastics and consequentially of the plastic products fully respect the three R’s rule: reuse, repair and recycling (EU Commission 2018). According to the Strategy, the actors involved in the plastics industry should: improve design and support innovation to realise plastic products easier to recycle; expand and promote the separate collection of plastic waste, to ensure quality inputs to the recycling industry; expand and modernise the EU’s sorting and recycling capacity; create viable markets for recycled and renewable plastics.

While setting the targets and the strategy to follow, the Commission stresses the importance of Extended Producers Responsibility (EPR) to reach the objectives. According to the Organisation for Economic Co-operation and Development (OECD), EPR can be defined as an environmental policy approach in which a producer’s responsibility for a product is extended to the post-consumer stage of a product’s life cycle. EPR legislation, in principle, shifts the responsibility for, and costs of, negative environmental externalities of products from tax payers to producers, consistent with the “polluter pays” principle (IEEP 2017). EPR is intended to achieve environmental improvements throughout the product life cycle and has two primary environmental goals. The first is to provide incentives for manufacturers to design resource efficient and low impact products (referred to in this report as ‘eco-design’). The second is to ensure effective end-of-life collection, environmentally-sound treatment of collected products and improved reuse and recycling (IEEP 2017). EPR principle was already indirectly invoked by the Packaging and Packaging Waste Directive[3] (94/62/CE) in Article 7, that requires the Member States to take necessary measures to ensure that systems are set up for the collection and recycling of packaging waste. Then, it has been explicitly mentioned in the Single Use Plastic Directive[4] (2019/904) in Article 8, that states that Member States shall ensure that extended producer responsibility schemes are established for a precise list of products.

The development of EPR in Europe has contributed to improvements in waste prevention, reuse and recycling (OECD, 2016). Related to plastic, in the EU it is possible to summarise the EPR schemes in three macro

[2] https://ec.europa.eu/info/research-and-innovation/research-area/environment/circular-economy/plastics-circular-economy_en
[3] https://ec.europa.eu/environment/topics/waste-and-recycling/packaging-waste_en
[4] https://ec.europa.eu/environment/topics/plastics/single-use-plastics_en

categories: 1) the first one is product take back requirements, that commonly involve establishing either mandatory or voluntary recycling and collection targets for specific products or materials, and assigning responsibility to producers or retailers for end-of-life management to achieve these targets. 2) The second one is advanced disposal fees (ADF), that are fees levied on individual products at the point of purchase, based on estimated costs of collection and treatment. The fees may be used to finance end-of-life management of the products in question (OECD, 2016). 3) The third one is Deposit Refund Systems (DRS), that adds a surcharge on individual products at the point of purchase. The entire fee, or a portion of it, is refundable when the used product is returned to the point of sale or at specified waste management sites. The aim is to encourage take-back of the used product rather than to cover costs.

To evaluate EPR role and effectiveness, an article published in 2020 by four scientists of the Technical University of Denmark analyses 40 management scenarios focused on plastic packaging waste generated by Italian households were investigated, and their environmental performance (via a consequential life cycle assessment) and the economic sustainability of their waste value chain (via a cost-benefit analysis for each stakeholder) were compared to the recycling targets. The research states that extended producer responsibility policies (EPR) are crucial to reach environmental and economic sustainability because they are the connection link between the different stakeholders and can influence all of them.

Furthermore, EPR plays an important role in assessing the requirements for recycling plastics, which is the fundamental step in implementing a circular strategy for this material, and observing food safety requirements, that is a conditio sine qua non for the Food Contact Material[5] (FCM). On one side plastic packaging reduces food waste by extending the shelf-life (Ellen MacArthur Foundation et al., 2016; White and Lockyer 2020) and prevents spoilage from microorganisms which are one of the main causes of food attack from microorganisms. On the other hand, as stated by Matthews et al. (2020), 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. Furthermore, Matthews et al. (2020) highlight plastic recycling limitations when it comes to using recycled plastic for FCM. As demonstrated also by Geueke et al. (2018), different groups of contaminants, oligomers, additives and their degradation products, as well as chemicals derived from previous (mis)uses, have regularly been reported in recycled plastic. Indeed, virgin and recycled plastic packaging have to observe respectively the EU food contact material (FCM) regulations and the Regulation 282/2008 (European Commission, 2008) on recycled plastic materials and articles intended to come into contact with food. The goal of these regulations is to lay down the criteria that ensure plastic packaging and recycled plastic packaging can be safely used for food contact.

[5] https://ec.europa.eu/food/safety/chemical-safety/food-contact-materials_en

The impact of plastic packaging is often misinterpreted by consumers. Otto et al. (2020) demonstrate how the consumer perception differs highly from the scientific conclusion of environmentally friendly sustainable packaging. According to their research, the environmental impact of paper/cardboard and metal are rated in line with the scientific measure by consumers, whereas plastic packaging is underestimated and glass and biodegradable plastic packaging are highly overestimated (Otto et al. 2020). Indeed, the tendency highlighted shows that for most consumers plastic represents a low quality product which is associated with negative perceptions and feelings (Fernqvist et al., 2015), whereas for the scientific facts plastic represents overall the most sustainable packaging choice (Otto et al. 2020) compared to metal, glass and paper. It is common for consumers to think about the packaging itself but not about its function and its importance for food. Many LCA's have been conducted for food packaging, but few consider the interaction between the packaging and packaged food, although it is widely acknowledged that this interaction plays a key role for the environmental performance of food packaging (Pauer et al. 2019). Furthermore, another study conducted by Kan and Miller (2022) shows the plastic packaging environmental responsibility in food products, considering its climate change and energy use impacts. The study carries out an analysis of 28 studies that conduct an LCA of food products to quantify the impact of plastic packaging relative to the total life cycle impact of food products. For most of the 13 environmental indicators reported, plastic packaging is responsible for less than 10% of total life cycle emissions of 23 out of the 30 foods studied (Kan and Miller 2022).

Following the European Strategy for plastics, in 2019 the European Commission adopted the Single-use Plastic Directive[6] (EU 2019/904). EU rules on single-use plastic products aim to prevent and reduce the impact of certain plastic products on the environment, in particular the marine environment, and on human health. They also aim to promote the transition to a circular economy with innovative and sustainable business models, products and materials, therefore also contributing to the efficient functioning of the internal market (EU Commission 2019). Besides the EPR schemes mentioned before, the Directive comprehends different provisions: an EU-wide ban of specific single-use plastics products; a ban of products made from oxo-degradable plastics; consumption reduction of certain single-use plastic items; requirements for beverage bottles; labelling of certain products and awareness raising measures.

The Balearic Islands have been one of the pioneers in implementing a circular strategy in plastic packaging management. Through a combination of measures on generic waste generation and specific waste streams such as single-use plastics or food waste, the Ley 8/2019 "*De residuos y suelos contaminados de las Illes Balears"*[7] offers a strong example of how to adopt a law that has a comprehensive approach to the problem of pollution from waste generation. The main objective of the law is to tackle the problem of waste generation through

[6] https://ec.europa.eu/environment/topics/plastics/single-use-plastics_en
[7] https://www.boe.es/buscar/doc.php?id=BOE-A-2019-5577

prevention and improved recycling. It aims to promote waste prevention and reuse through specific measures and binding targets, which also aim to tackle the most problematic and visible waste streams, such as single-use products, plastic packaging and food waste. Even in this innovative law, Extended Producer Responsibility (EPR) schemes put further pressure on producers to fully support the transition.

Another innovative measure has been taken by the French Government in 2020 with the Loi no 105 "*Objectifs stratégiques de gestion et de prévention de la production de déchets"*[8]. The law bans plastic packaging on most fruit and vegetables, indeed from 2021 the country banned plastic straws, cups and cutlery, as well as polystyrene takeaway boxes. A total of 30 types of fruit and vegetables are banned from having any plastic wrapping, including bananas, pears, lemons, oranges and kiwis. The President of the Republic said the law 105/2020 shows the country's commitment to phase out single use plastics by 2040, however some claims came out because of the short notice and the food waste issue. Philippe Binard, from the European Fresh Produce Association, said that the removal of plastic packaging from most fruit and vegetables at such short notice does not allow alternatives to be tested and introduced in a timely manner and stocks of existing packaging to be cleared (BBC 2021), pointing out the short period of time that is given to the flexible packaging producers to innovate their production.

Eventually, in April 2022 in the UK a Plastic Packaging Tax[9] was introduced by the Government. This tax too is designed to encourage the use of more recycled plastic and applies to plastic packaging produced in, or imported into, the UK and that does not contain at least 30% recycled plastic. The rate of the Plastic Packaging Tax is set at £200 per tonne of plastic packaging placed onto the UK market. The Tax will apply to businesses that manufacture or import plastic packaging components or import packaged goods into the UK.

Plastic value chain from a circular economy perspective: overview.

The plastic circular economy approach that is promoted by the new sustainable European regulatory framework is an alternative to the traditional linear system. The circular economy approach wants to close the loop of the plastic life cycle, increasing also the amount of plastic that is reused or recycled back into the system (Calleja 2019; European Commission 2018). A circular plastic economy could contribute to less plastic being downcycled, incinerated and landfilled, and following the direction of making plastic waste a resource for new products in a closed-loop production and consumption system (Johansen et al. 2022). The transition to the circular economy should be made across the entire plastics value chain in order to ensure circular design, production, use and waste management (Johansen et al. 2022). Despite the circular economy is gaining increasing levels of attention, only 30% of plastic waste is collected for recycling in Europe and most of the

[8] https://www.legifrance.gouv.fr/loda/id/LEGISCTA000041554510
[9] https://www.legislation.gov.uk/uksi/2022/117/contents/made

waste is downcycled into materials with a lower value than that attributed to the original product (Calleja, 2019). Johansen et al. (2022) made a review of the existing literature about plastic circular economy strategies and gaps, dividing the plastic value chain in six main phases: raw materials, polymer design & production, product production, retailer, use & demand and waste management. According to their review, the downcycling of plastic in the economy is caused by contamination with organic and inorganic matter, and from product designs that combine different materials, like the combination of plastic and paper or aluminium, and thereby inhibit and complicate technical and economically feasible pathways for plastic-waste recycling. Furthermore, the existing knowledge tends to emphasise research focused on the ‘end-of-life’ phase, aimed at improving recycling and recovery of plastic waste (Nielsen et al., 2020). However, according to M. T. Brouwer et al. (2018), the cause of mixed polymers in recycling is not only sorting and recycling processes but the initial design of plastic products and packaging. Packaging and other post-consumer plastics are often designed with multiple polymers, which makes recycling unfeasible from a technical as well as an economic perspective. The results of the literature show an unequal distribution of research across the different phases of the value chain. The majority of published articles focus on the waste-management phase, with a comparatively small number of studies dealing with product design, production, and use. This highlights an important knowledge gap, as most research has been focused on the end-of-life phase, despite increased political and scientific emphasis on the circular economy that, ideally, would include recycling as just one aspect of an overall strategy (Johansen et al. 2022). Indeed, the transition towards a circular economy cannot be achieved solely through changes within the waste-handling system but must be combined with changes in the entire value chain, including the product design and the production phase(Johansen et al. 2022).

Plastic value chain from a circular economy perspective: design phase.

The design is one of the initial phases of the packaging value chain. This phase is extremely important for the implementation of a circular economy strategy as it is outlined by the European Commission with the Extended Producer Responsibility schemes. This stage is crucial because functionality and features of the product are decided, such as colour, recyclability, recipe of the product (Iacovidou et al. 2019). Furthermore, the company marketing strategy has a key role in the design phase (Rundh 2016), where the brand has to communicate its product identity, but also the packaging itself. In a circular economy strategy, the packaging itself acquires more importance, even from the consumers point of view. Indeed, the attention of the consumers is now focused also on the environmental impact of the packaging and its recyclability. Especially for food contact applications, the design of flexible packaging is a key phase. As it is pointed out by the regulatory review, food contact plastic applications have to follow precise quality standards and cannot be contaminated by other substances. Indeed, this problem is also reflected in the literature, where a common theme regarding the implementation of circular economy strategy is the challenge of producing packaging with recycled plastics. The main constraints are the high quality standards, but also low migration of toxins, being light-weight and having the ability to keep food fresh (Masmoudi et al., 2020). Many authors assess that recycled plastic can be difficult to use in new products owing to the contamination of polymer types, which may affect aspects such as durability, toxicity and weight (Civancik-Uslu et al., 2019; Foschi et al., 2020; Gall et al., 2020; Iacovidou et al., 2019; Masmoudi et al., 2020). When trying to incorporate recycled plastic into new products, contamination and mixed polymers are, according to Gall et al. (2020) and Iacovidou et al. (2019), two of the most problematic impediments (Johansen et al. 2022).

Plastic value chain from a circular economy perspective: production phase.

The production of flexible packaging covers several differentiated stages, from the production of the virgin film towards the reels cutting and the storage. The literature review made by Johansen et al. (2022) shows how only 3 papers out of 60 address this phase of the plastic value chain, highlighting a lack of knowledge in this specific phase. In these papers the main challenge outlined about circular economy strategies is that recycled plastic is most often composed of different polymer types and contaminated with non-plastic materials, such as additives, inks and glues. Therefore, this causes a range of complications, which reduces the value of the final product made by a mix of virgin and recycled plastic (Getor et al. 2020). Indeed, plastic products are designed with mixed polymers and the waste stream becomes therefore contaminated, affecting the properties of the recycled plastic (Getor et al., 2020).

This technical problem is a key issue not only for the production phase, but for all the implementation of a plastic circular economy strategy. Indeed, the quality of the feedstock impacts all the plastic value chain and poses the company an important limit, as it has been shown even in the design phase.

	The European legislative framework	**Plastic value chain**
		Design and production
Bullet point	EU Action Plan for a Circular Economy; European Strategy for Plastics in a Circular Economy; Extended Producer Responsibility schemes; Food Contact Material Regulations; Plastic Tax (UK and EU).	Recyclability of the product; polymer mix; quality of the product; quantity of the product; process efficiency; production phases; alternative feedstocks to virgin plastics.
Key issues for implementing a Circular Economy	Compliance of the products to the new legislations	Rethink the design with an holistic circular economy perspective; reduce environmental impacts; industrial production of market competitive alternative feedstocks to virgin plastic.

Figure 2: the European Legislative framework and plastic value chain.

Alternative feedstocks to virgin plastic

During recent years, many studies have been published to review possible non-fossil based alternatives to BOPP and circular economy strategies to adopt. However, it is difficult to draft a comparative analysis of the alternative non-fossil based materials (Walker and Rothman 2020), due to methodological problems. Walker and Rothman (2020) review the state-of-the-art in comparative Life Cycle Assessment of fossil-based and bio-based polymers. According to the authors, no published articles were found to fully meet the European Union Product Environmental Footprint (EU PEF) standards, but the critical review method was used to classify the articles by their level of compliance. 25 articles partially met the PEF standards, giving 39 fossil-based and 50 bio-based polymer case study results. In addition, the comparison between the different LCAs was difficult because of the different feedstock sources and processing methods assumed (Walker and Rothman 2020). It was possible to compare seven bio-based polymers and seven fossil-based polymers across seven impact categories (energy use, ecotoxicity, acidification, eutrophication, climate change, particulate matter formation and ozone depletion), nevertheless it was not possible to highlight 'best performing' polymers, or to suggest whether fossil-based or bio-based polymers perform best in any impact category, due to the methodological problems (Walker and Rothman 2020).

The methodological problem brought the European Commission to entrust the Joint Research Centre with a comparative analysis, through the means of life cycle assessment, that assesses the potential environmental impacts of the use of alternative feedstock for plastic films in comparison to using current feedstock. This report is really precious for the literature about flexible packaging, even if it comes from a political organisation, because it is the only one that uses the Product Environmental Footprint (PEF) methodology for all the materials. Within the report, PP film is mostly considered as a reference, being the benchmark that needs to be outperformed. The others non fossil-based polymers considered are Bio-LDPE, which is derived from Sugarcane in Brazil; PLA, which is derived from maize in the U.S.A.; starch-based polymer from corn. The impacts considered, according to the Product Environmental Footprint (PEF 2018) methodology used are: climate change, ozone depletion, human toxicity (cancer and non-cancer), particulate matter, ionising radiation, photochemical ozone formation, acidification, eutrophication terrestrial, eutrophication freshwater, eutrophication marine, ecotoxicity freshwater, land use, water use, resource use (minerals, metals and fossils) (JRC 2018). The overall results show that the bio-based LDPE film has averagely the highest impact compared to the other materials, mainly due to the relevant polymer production impacts. Therefore the use of bio-based ethylene derived from dedicated crop (sugarcane) does not appear to be an environmentally sound alternative. CO_2-based PP also shows high impacts in many categories. This appears related to high energy consumption in polymer production (e.g. in Climate Change, Ionising Radiation, Resource Use fossils), or chemicals used in CO_2 capture and methanol synthesis. The overall performance of the use of this alternative feedstock for PP production is thus worse compared to its fossil-based counterpart in the majority of the categories (JRC 2018). Similar reasoning can be made for the PLA and starch-based polymers. PLA has a higher impact than fossil based PP in most of the cases, specifically for what concerns climate change, ozone depletion, particulate matter and land use. At the same time, PLA has less impact on fossil resource use and human toxicity. Starch-based polymers show higher impacts than fossil based PP in climate change, producing more than double the CO_2 kilograms in its lifecycle. Starch-based polymers also have more impacts than fossil based PP in ozone depletion, particulate matter and land use, however they show less impact in human toxicity, eutrophication and fossil resource use (JRC 2018).

Within the non-fossil alternatives available in the market, bio-plastics seem to be the most used, but also controversial. This is due to mainly two reasons: methodological problems with the LCAs analysis and an ethical issue that poses in conflict the bio-based plastic production with the agricultural production and sustainability. A Review[10] conducted in 2019 by the Irplast S.p.A. Research and Development in collaboration with the Istituto di Management of the Scuola Superiore Sant'Anna within the Eco.Re.Label project co-financed by Regione Toscana, compares the scientific literature about bioplastics. The characteristics of bioplastics make this product competitive to fossil based plastics from a theoretical point of view, but the literature highlights controversial facts of bioplastics. In particular, what emerges from the review of four LCAs (Alvarez- Chavez et al (2012) Hottle et al. (2013), Yates et Barlow (2013); Grabowski et al. (2015)) is that bioplastics have several critical points. Firstly, the land occupation for agricultural production, which poses an ethical question. Indeed, occupying the space for the bioplastic production means to not use that space for food production. Secondly, the implementation of industrial agriculture for production with consumption of water, energy and pesticides. Thirdly, the production processes from feedstock to plastics with consumption of energy, water and chemical and biological agents (GMOs). Fourthly, the compostability of biopolymers could be reduced by their mixing with polymers of fossil origin, that is in most of the case mandatory to reach the mechanical performances for different applications, or by the reduced availability of suitable infrastructure for composting. Therefore, from the comparative analysis of the LCAs comes out that the introduction of bioplastics makes possible to reduce environmental impacts, in particular for GHGs emissions and consumption of non-renewable resources, compared to polymers of fossil origin, however the advantage is uncertain for other impact categories such as acidification and eutrophication, which are significantly affected by the processes included in the production phase, both in agriculture and in processing. In addition, the studies which include all phases of the life cycle from cradle to grave, thus including the end-of-life phase, have shown that the choice of the end-of-life scenario of the biopolymer is decisive in the assessment of the overall

[10] This Review cannot be shared by the Company.

environmental impacts. Indeed, different end-of-life options, which should be modelled with data of adequate quality, result in different environmental impacts (Bishop et al. 2021).

The results shown are confirmed by Kakadellis and Harris (2020) and Mendes and Pedersen (2021), which include into the analysis the importance of keeping into account the food shelf life into the packaging LCAs. Indeed, in their research Kakadellis and Harris (2020) clearly state that the LCAs included in their study do not provide enough evidence to state which polymer is best at reducing food waste. The environmental impacts of the food waste due to the reduced shelf life of the product are often significantly higher than those associated with packaging, regardless of the nature of the plastic material (Kakadellis and Harris 2020). Also Mendes and Pedersen (2021) state that plastic packaging materials have reduced climate impact, but there are other environmental impacts (e.g. eutrophication, use of water and pesticides, effects on biodiversity) that are less favourable for using bio-based materials and should also be considered (Mendes and Pedersen 2021).

Mechanical and chemical recycling

Besides the non-fossil based alternatives, plastic can be recycled through mainly two processes: mechanical recycling and chemical recycling. Mechanical recycling is used widely in Europe and elsewhere, the process involves sorting, washing, shredding and melting of plastic waste to produce granulate and finally new plastic products (Ragaert et al., 2017). Mechanical recycling does not change the chemical structure of the material, however it is a generally environmentally-friendly approach for waste plastic disposal (Lazarevic et al., 2010; Al-Maadeed et al., 2012; Wäger and Hischier, 2015). Indeed, substituting virgin plastics with recycled plastics has been proved to be economically and technically viable (Sommerhuber et al., 2015; Gu et al., 2016b; Sommerhuber et al., 2016), and environmentally advantageous in many cases (Rajendran et al., 2012; Rajendran et al., 2013; Stichnothe and Azapagic, 2013; Kozderka et al., 2016). Lazarevic et al. (2010) found that mechanical recycling of waste plastics is more preferable to incineration and landfill, provided that a certain recycled material substitution ratio is achieved. The cost and the GHG emission of plastic recycling can be further reduced by implementing optimisation strategies (Sheriff et al., 2016; Rahim and Raman, 2017), which could make recycled plastics more competitive. Aside from environmental benefits, mechanical plastic recycling is an economically viable practice, as recycled plastics represent a savings of 20–50% in terms of the market prices when compared to virgin counterparts (Gu et al., 2016a; Gu et al., 2016b) (Gu et al. 2017). However, the plastic obtained by mechanical recycling cannot be used for film production in the food and beverage industry because the process can degrade the mechanical properties of plastic materials (Yin et al., 2015). This means that the mixed plastic waste is usually ‘down-cycled’ into secondary and less valuable products. As the mechanically recycled raw materials are downgraded during the recycling process, this kind of raw materials are not suitable for several manufacturing processes. For example, the sequential or simultaneous stretching extrusion cannot be executed, otherwise the material would be unusable. Further, the efficiency of mechanical recycling is hindered by the difficulty in recovering large amounts of targeted plastic from mixed municipal solid waste (UNEP, 2020). Moreover, it is inefficient for difficult-to-recycle plastics, such as multi-layered or heterogeneous plastic used, for example, for packaging (Singh et al., 2017). In addition, depending on the quality of the incoming waste plastic and the efficiency of the sorting process, residual materials, including plastics, still need to be either incinerated or landfilled (UBA, 2018) (Jeswani et al. 2021).

Chemical recycling is the process of converting polymeric waste by changing its chemical structure and turning it back into their functional units that can be used as feedstocks for the production of new virgin like polymers and manufacturing of plastics or other products. There are different chemical recycling technologies, e.g. pyrolysis, gasification, hydro-cracking and depolymerisation (Plastics Europe 2022). Studies assessing chemical recycling in the UK (Gear et al., 2018), the Netherlands (CE Delft, 2020) and Europe (Somoza-Tornos et al., 2020) suggested that the climate change impact of pyrolysis and other chemical recycling technologies was significantly lower than that one of incineration. Also Bora et al. 2020 determined through their study that the chemical recycling pathways such as fast pyrolysis and gasification have the potential to mitigate climate change and other environmental impacts posed by plastic wastes. On the other hand, some LCA studies on pyrolysis based on simulations (Gracida-Alvarez et al. 2019) (Somoza-Tornos et al. 2020) claims that chemical recycling has an higher environmental impact than mechanical recycling, even if these studies do not consider the difference in the quality of the outputs which could disadvantage options that produce a better quality recyclate (Jeswani et al. 2021). Especially for the food and beverage films production, this aspect cannot be excluded from the analysis since it is related to the food quality and safety. Indeed, chemical recycling is nowadays the only process that allows flexible packaging producers to use recycled plastic for food contact films because of its quality and upcycling characteristics. Chemical recycling has also been accepted by the EU Taxonomy as a green practice, however, chemical recycling facilities are not widespread and still have to develop on a large scale.

Gap analysis

Phelan et al. (2022) conducted a systematic review of 68 corporate sustainability reports to examine how major multinational companies in the food and beverage sector are addressing the environmental issue. According to the research, most companies do not directly acknowledge plastic pollution as an issue. The findings show an insufficient pace of adoption and that the horizon of planning towards sustainable packaging is limited. Only a quarter of the companies are addressing the following key issues: packaging design innovation, increasing effectiveness of recycling, reducing single-use plastics, managing product end-of-life processes, and driving stakeholder engagement on plastic waste topics. Approximately half of the companies make broad statements affirming their support for the circular economy, however, many of the same companies maintain that consumer education and increased recycling are still their primary focus areas when it comes to plastic waste (Phelan et al. 2022). Furthermore, Johansen et al. (2022) highlights the lack of an holistic value-chain approach when implementing circular economy, that is necessary to ensure an efficient and effective transformation of the current linear value chain. The proportion of the literature covering each value-chain phase indicates a knowledge gap in the design, production and use phase (Johansen et al. 2022). This knowledge gap may hinder both the transition to circular and the operation of waste-management procedures 'symptom treatment' in the end-of-life phase, with limited attention consequently given to opportunities for redesign and prevention of plastic waste, despite the fact that these aspects are often regarded as the most desirable in the circular-economy literature (Johansen et al. 2022). Furthermore, going into the practical outputs, the literature clearly shows that a feasible and industry wide spread alternative to virgin plastic still has to be found. The LCAs analysis of the alternative feedstocks demonstrates that also from environmental point of view polypropylene is still competitive with the non-fossil-based alternatives. Furthermore, the chemical recycling technologies are growing up and they seems to be an efficient and effective alternative to virgin plastic. The path toward a circular economy in the plastic industry is still in development and it is facing practical challenges. This paper wants to provide a case study that shows how a flexible packaging producer might implement a circular economy strategy for the food and beverage industry, which is particularly involved due to the Food Contact Regulations restrictions for quality standards.

Methodology

The paper proposes a case study as a benchmark for plastic packaging circular economy in the food and beverage industry. The case study analyses the strategy of Irplast S.p.A., one of the world company leaders for the production of BOPP films. Irplast has been the first one to commercialise chemically recycled plastic films and non-fossil based films and it is nowadays the world leader in this market. Furthermore, Irplast is one of the flexible packaging world leaders for the implementation of a circular economy strategy in this industry. Therefore, the Company has been evaluated as the right candidate for this case study.

The elected research strategy is an inductive approach as it is focused on deducing how and which circular economy strategies can flexible packaging producers implement from the Irplast case study. The strategy wants to state general conclusions starting from a specific case. To address the research purpose and answers the research questions, a qualitative approach has been chosen for this study, which is composed by secondary and primary data.

To provide a theoretical background to the study, a review of secondary data was performed as part of the literature review. The review was conducted in a narrative and systematic way, because on one side the case study needs to be integrated in the new legislative framework narrative and on the other side the review identifies the literature gap and finds out what the research could add to the existing knowledge. The individuation of the existing literature occurred through the utilization of the Google Scholar source, mainly through the following key words: “Circular Economy”, “Plastic circular economy strategies” “Flexible packaging”, “BOPP film for food contact applications”, “plastic recycling”, “plastic value chain”, “Virgin plastic alternatives”, “plastic regulations”.

The primary data collection was conducted through unstructured interviews to Irplast human resources during a four months period between February and May 2022. This data analysis method appears the most suitable one since the argument treated in the research is very specific and with various technical and non-technical aspects to consider. Therefore, the aim of the unstructured interviews was to follow the knowledge of the interviewed without any prior fil rouge planned by the interviewer. Indeed, with this method was possible to make the respondent free to express themselves freely and it was possible to ask additional questions to deepen the topics. The main Company human resources interviewed were the Sustainability Manager, the Sustainability Officers, the Research and Development Director and the Sales Director.

Case study results

Research setting

Irplast business model is focused on the reduction of the environmental impacts of the company and its products. The Company operates through three product lines concentrated in the two poles of Atessa (Chieti) and Empoli (Florence), where it handles respectively the initial and final phase of the life cycle of the plastic film, made from the raw material of polypropylene. 380 people are employed in the three manufacturing sites, all based in Italy. In Empoli, the factory has a production capacity of over 500 million square metres, while the two film manufacturing sites in Atessa have a total installed capacity for 44,000 tonnes of BOPP film. The Company generated a turnover in 2021 of around Euro 100 million. 75% of total output is exported to 68 countries worldwide.

Irplast is an established producer of biaxially oriented polypropylene films (BOPP), some of which are converted internally for roll-fed wrap-around labels (for the food, beverage, dairy, personal & home care markets), for printed adhesive tapes and multipack solutions. The three main business units are the label tech division, the print tape division and the BOPP film division. The label tech division counts per the 21% of the total business and it comprehends shrinkable pre-glued roll-fed labels printing for the food, beverage, dairy, personal & home care sector. The print tape division counts per the 35% of the total business and comprehends "Open & Close" linerless labels production for tissue and food, adhesive tape printing, including theft-proof security BOPP Tamper-evident adhesive tapes. The majority of the business is then occupied from the BOPP film division, which comprehends BOPP and S-BOPP specialty film development for cigarette packs, labels and barrier packaging applications.

The Irplast value chain is divided into 10 macro phases that begin with the extraction of the virgin raw material and end with the end of life of the product. The polypropylene cycle begins with the extraction of the virgin raw material and its processing, first in monomers and then in polymers. Irplast, individually or in collaboration with its suppliers and customers, conceives and designs polypropylene products by purchasing the raw material from selected and qualified suppliers, also evaluating environmental criteria. This product creation process is supported by the Research and Development departments of Atessa and Empoli which in 2020 focused their activities on the creation of products characterised by better performance, functionality and lower environmental impact. In the next phase production begins, with the transformation of polypropylene into bi-oriented film (BOPP). This takes place in the Atessa manufacturing site, where the physiological waste of the production is mostly reused thanks to a regranulators which perform a high level mechanical recycling process. The majority of the film produced is sold externally, while the remainder is used vertically in the production of labels and adhesive tapes at the Empoli site. These products are then marketed all over the world and generally sold to large multinational companies. Then follows the collection and disposal phase of the waste produced during the production cycle, a part of which is recovered and reused internally, and a part is upcycled into secondary raw materials for other production processes. A tiny fraction is disposed of for external recycling. Irplast has obtained following certifications: the ISSC PLUS (International Sustainability & Carbon Certification) certification of the sustainable film supply chain; the BRCG-PACKAGING certificate for hygienic conditions of materials destined for food contact; the AIB (American Institute of Baking) certificate, which guarantees the highest manufacturing and quality standards for food packaging safety; the DPG "Zertifikat" for the German labels market. The Company operates according to the quality management system UNI EN ISO 9001:2015, the environmental management system UNI EN ISO 14001:2015 and addresses health and safety with UNI EN ISO 45001:2018.

Irplast Value Chain and vertical integration

The Irplast value chain is divided into ten macro phases that begin with the extraction of the virgin raw material and end with the end of life of the product. The polypropylene cycle begins with the extraction of the virgin raw material and its processing, first in monomers and then in polymers. The following production phase begins with the transformation of polypropylene into bi-oriented film (BOPP). The majority of the film produced is sold externally, while the remained is used vertically in the production of labels and adhesive tapes at the Empoli site. These products are then marketed all over the world and generally sold to large multinational companies. Then follows the collection and disposal phase of the waste produced during the production cycle, a part of which is recovered and reused internally, and a part is upcycled into secondary raw materials for other production processes. A tiny fraction is disposed of for external recycling.

Irplast S.p.A. is the first vertically integrated BOPP producer, from the extrusion of the film to the printing of finished products. Vertical integration is a strategy that allows a company to streamline its operations by taking direct ownership of various stages of its production process rather than relying on external contractors or suppliers. Therefore, the vertical integration gives Irplast S.p.A. the possibility to develop faster than producers that do not have this structure. Indeed, Irplast can directly test its product and process developments directly on the internal next steps on the production chain, without the involvement of a third party. This allows the Company to have a comparative advantage against competitors, reducing the "time to market" for the clients.

Know-how and innovative technology

Irplast can base its film business on several decades of experience in the field. The Company has developed a unique know-how in the design and production of innovative and customised BOPP films. The know-how is combined with investments in human capital with high scientific/technical competences and in innovative technologies for the process and product development. Considering the last seven years, the human resources employed with a technical job that have at least a scientific/technical Bachelor Degree have more than doubled, as the graph shows. This shows the commitment and the will of Irplast in increasing the internal employers quality and know-how.

	Number of human resources with at least a Bachelor Degree in scientific/technical subjects and employed with a technical job							
Year	2015	2016	2017	2018	2019	2020	2021	2022
Number of Human Resources	7	15	15	17	17	19	18	19

Figure 3: qualified human resources

In order to improve the process development and the efficiency, the Company implemented a trigeneration system in both Empoli and Atessa sites, for which it annually receives grants by the Government for the electricity Sector. The trigeneration systems allow Irplast to simultaneously self-produce electricity, heating and cooling, drastically reducing the purchase of electricity from the grid. The trigeneration plant, which has been in operation since 2016 at plant B in Atessa, has made it possible to self-produce the energy needed to meet approximately 70% of the plant's needs. As regards the Empoli plant, the commissioning of the new trigeneration plant took place in February 2020 and immediately had a strong impact on energy savings. In fact, the new plant made it possible to cover 70% of the electricity needs and 100% of the cooling and thermal energy needs of the plant. As a result of these investments, the company also has the ability to sell part of the electricity produced by the plants back to the market.

During 2020, Irplast also installed a new distiller, which makes it possible to improve the solvent recovery process by reducing the amount of sludge sent for disposal, for details refer to the paragraph "Extended responsibility for our production activities". In the same year, a new silo was also installed to collect the sludge and a new collection tank for the distilled solvent. The plant as a whole, which came into operation in the second half of 2020, contributed to the decrease of about 20% of the sludge sent for disposal. Lastly, a new regenerative thermal oxidizer has been installed that increases the efficiency of the solvent abatement system and a reduction of atmospheric emissions of pollutants.

During 2020 and 2021 many investments have been made and planned for the product development, also thanks to the Ministero della Transizione Ecologica "Transizione 4.0"[11] incentives. Indeed, Irplast has been the first in Europe to engineer and install a simultaneous stretching Bruckner-LISIM line for the production of BOPP films for flexible packaging, an innovative technology that gives Irplast a competitive advantage in the market due to the possibility of reaching specific technical features with this kind of technology. During 2021, the revamping of this innovative machine has been made thanks to the "Transizione 4.0 incentives".

R&D

The Research and Development department plays a key role in the sustainable innovation of Irplast S.p.A. Indeed, the product creation process is supported by the Research and Development departments of Atessa and Empoli which focus their activities on the formulation of products characterised by better performance, functionality and lower environmental impact. However, the R&D department involvement also has a broader purpose that is not limited to the company. In fact, the R&D departments participate in three co-financed projects with public entities and academic institutions: EcoReLabel, NONIAS and Tex-Style. To underline the Irplast R&D department quality, it should be noted that the projects, in order to be eligible for co-funding, are assessed by experts in the field and deemed worthy of subsidy by virtue of their technical and scientific content.

Tailor made products and stakeholder relationship

Irplast, individually or in collaboration with its suppliers and customers, conceives and designs polypropylene products by purchasing the raw material from selected and qualified suppliers, also evaluating environmental criteria. Irplast focuses its design process on the collaboration with suppliers and customers. The continuous interaction allowed Irplast to increase clients satisfaction for the final product, to follow the new requests and developments, but also to strengthen the relationship with the stakeholders of the value chain. Flexible packaging is characterised by a high level of innovation and these products are created appositely to match with other components of the customers final packaging. Therefore, the collaboration upstream and downstream during the design phase of the product is a strategic element for Irplast to implement more sustainable products. The evidence of the quality of suppliers and clients is shown also by the Irplast launch of ISCC Plus certified products. ISCC Plus is an extension of the application of the ISCC standard, a sustainability certification system linked to the sustainability goals included in the 2030 Agenda presented by the United Nations and in particular n°12, aimed at ensuring sustainable patterns of production and

[11] https://www.mise.gov.it/index.php/it/transizione40

consumption. ISCC is a sustainability certification system that covers the entire supply chain and all kinds of feedstocks: bio, bio-circular and circular.

Furthermore, the stakeholder relationship importance is underlined also by the co-financed initiatives in which Irplast S.p.A. took part with its R&D department. Indeed, the initiatives give Irplast the chance to strengthen the collaboration with public entities such as Regione Toscana, Regione Abruzzo and Ministero dell'Istruzione, dell'Università e della Ricerca.

Sustainable and innovative design

As the literature has shown, design is a key phase in implementing a circular strategy. Irplast product design strategy is aimed at promoting closing resource loops through recycling, optimising resource use and design for recycling. Indeed, Irplast developed four main solutions that bring this strategy into practical solutions.

Firstly, thanks to its know-how, Irplast realises a thickness reduction of all its products. The aim of this solution is to reduce the amount of raw material used while ensuring the same product yields, in order to offer a sustainable alternative that does not require any change in the expected quality. Reducing film thickness allows not only to optimise the quantity of raw material used, but above all to save large quantities of CO_2 per m^2 of film that would have been emitted with films of greater thickness, and to reduce the quantities of plastic waste, deriving from the end of life of the product. Between 2019 and 2020, approximately 760 tons of raw material were saved and consequently 2,350 tons of CO 2 eq. compared to product lines previously made with greater thicknesses.

Secondly, Irplast develops monomaterial products. One of the biggest problems when dealing with the issue of pollution by plastics in the environment is the fact that the products are not made in such a way that they can be easily recycled. An example of an activity started by Irplast is that of replacing products typically made with different layers of different materials (multilayer multi-material) with those entirely composed of polypropylene (multilayer mono-material) which, thanks to its adaptability, lends itself to this type of applications. Thus, the stand-up pouches, which in their classic format can have three or more types of different materials/plastics, in the version proposed thanks to the Irplast film, are completely in polypropylene, easily 100% recyclable.

Thirdly, Irplast develops multi-packaging bands, a practical and eco-friendly alternative to classic shrink wrapping. It is a solution to create multipack packages for the food, beverage and detergent sectors that allows for the packaging of packs of 6 bottles, a saving of about 13g of plastic material, equal to 66% less. The reduction of plastic material also involves the reduction of CO_2 emissions related to it. In addition, the band is easier to remove, leaving no residue or damage to the product.

Eventually, Irplast creates food contact tape, an adhesive label-tape, suitable for direct contact with all foods. Compared to conventional fresh food packaging, this is made from 100% polypropylene, making it fully recyclable. In addition, it allows a reduction of the packaging material of approximately 95%. The latest evolutions of this product have made it more sustainable thanks to the reduction of its thickness, saving further plastic material.

New alternative materials to virgin plastic

Irplast S.p.A. is the first company in its sector to have launched ISCC PLUS certified products made by alternative raw materials in the market. The ISCC PLUS certification guarantees the chain of custody of the entire supply chain involving all players starting from the "feedstock producer" up to the "brand owner". Traceability is obtained through the receipt and issue of sustainability certificates, respectively for each batch of raw material purchased and product sold.

The first line of products presented by Irplast is called Natural Oriented Polypropylene (NOPP), this film is derived from Tall Oil obtained as a by-product of the Kraft softwood pulp process. Compared to classic BOPP, NOPP allows a reduction of 50% of resources of non-renewable origin in the fossil resource scarcity impact category, with a consumption equal to 1.04 Kg of oil eq. compared to traditional 2.02 Kg of oil eq. (Irplast S.p.A.). Replacing 1Kg of classic BOPP product with one from sources of natural origin allows to eliminate CO2 eq. emissions, effectively making the film carbon neutral. The film offered by Irplast contains 87% of raw material of renewable origin compared to the total raw material used. This innovative film gives the possibility to replace classic packaging production with a more sustainable product, not in competition with the agri-food chain. Indeed, as it is shown by the Scuola Superiore Sant'Anna review in the literature, one of the main problems of bio-based plastic is the fact that for a massive production a high percentage of agricultural fields should be dedicated. Bio-plastics are usually alternative and competitive to food production, but it is not the case of the Tall Oil used from Irplast, because it is generated from the waste of another production chain. Furthermore, the Irplast know-how has created these productions without changing anything either in the quality of the film or in the packaging methods.

The second line of products presented by Irplast is the LOOPP film, made with chemically recycled plastics. Irplast offers this range of films created in collaboration with SABIC, using raw materials from the chemical recycling of post-consumer plastic materials, according to the attribution of the characteristic of sustainability through the "mass balance" approach. This line is also guaranteed by the ISCC PLUS certification. According to the LCA conducted by Spinlife (Università degli Studi di Padova) on the LOOPP film, chemical recycled PP has a carbon footprint comparable to fossil PP. However, when including in the assessment the benefits of using and valorising plastic waste - otherwise destined for disposal - chemical recycled PP is more advantageous than fossil PP in terms of impacts in the Climate change category. Specifically, the decrease of the impacts in climate change in comparison with a standard PP production are around 32/40% according to the thickness of the film considered (Spinlife LCA 2020). The LCA conducted by Spinlife has a cradle to gate system boundary, because it is up to the gate that Irplast can define its environmental impacts. However, in 2022 another LCA on behalf of The Consumer Goods Forum by Sphera has been conducted about chemical recycling for food contact film and it states the same result. Indeed, the plastic-to-plastic pyrolysis based chemical recycling product system shows lower impacts in climate change and fossil resource usage. The pyrolysis-based chemical recycling technology investigated in this study is capable of reducing the amount of mixed plastic waste sent to incineration and landfilling and enabling a high-quality recycling of a low-quality waste stream that would be otherwise not suitable for mechanical recycling (Sphera 2022).

Waste regeneration

In order to maximise the use of the raw material recycled internally, Irplast implements waste regeneration. The production process of the bi-oriented film generates physiological waste classified as a by-product, however the application of the principles of circular economy to its value chain has made it possible to almost completely eliminate such waste at the Atessa plant. About 23.5% of the waste is sold to third parties, and intended for use for production in other sectors. The remaining part is instead recycled internally - through the regranulation process - and reused in the production cycle, ensuring an average recycled content of around 15%. This means that only 0.30% of the initial raw material actually becomes processing waste. From the recovery of materials at the Atessa factories, Eco + Tape was born in Empoli, a line of products made with a film composed of 34% regranulated polypropylene. To date, Irplast offers this solution for printed adhesive tape, but in the future it could also be applied to the labels business unit. This product allows to reduce the use of virgin raw material and consequently save fossil resources, NOx necessary for the transformation processes and CO_2 that would have been generated in the polymerization activity. Most of Empoli's waste is instead conferred to external companies specialised in the collection, recycling, regranulation and manufacturing of products for the agri-food, automobile, and packaging industries, using post-consumer and post-industrial plastic in their industrial processes.

The Irplast four Rs: renewable, recycle, reduce and reuse.

To summarise the results of the case study, it is possible to enclose the Irplast circular economy actions into four drivers.

“Renewable” because the Company is using raw materials from renewable sources (tall-oil) or from chemically recycled post-consumer waste allows Irplast to reduce CO_2 emissions, reduce fossil fuel consumption and to make a valuable contribution to kick-starting the circular economy for plastic usage (NOPP and LOOPP films). In this way, the company is able to produce products with the same characteristics, but with a lower CO_2 footprint.

“Recycle” because BOPP is “100% designed for recycling” material. Irplast develops eco-friendly products by using post-industrial recycled BOPP film. To facilitate the recycling process, Irplast produces BOPP labels with specific density below that of PET bottles: this makes bottle and label separation easier in the waste recovery stream. When combined with shrinkable film and pre-applied adhesives, these labels become an eco-friendly alternative to PET-G shrink-sleeves. Furthermore, Irplast uses special anti-bleeding inks and wash-off adhesives to avoid R-pet contamination and it manufactures a range of 100% recyclable BOPP films for mono-material packaging, contributing to higher value and recovery rates for the recycled material.

“Reduce” because Irplast has undertaken a process of reducing the thickness of its films. This allows less plastic weight to be used per square metre of film. Innovative products have also been developed that can replace complex traditional packaging, performing the same function but requiring much less plastic. These solutions make it possible to reduce the relative emissions of greenhouse gases and, more generally, to reduce the consumption of natural resources. Furthermore, the company reduces its fossil fuel consumption with the NOPP and LOOPP alternative feedstocks.

“Reuse” because thanks to special adhesives and to proprietary know-how, Irplast produces pre-glued labels for returnable PET bottles. Irplast’s pre-adhesive labels, made in such a way that they can be easily removed from the package without leaving residues, allow the containers to be recovered to use them again, as in the case of glass, or to simply to recycle them separately and efficient.

Discussion

The European Commission, the single member States and the United Kingdom are innovating their legislations in order to promote circular economy. The new framework involves intensely the flexible packaging world, which is considered with all the plastic industry a key priority for the ecological transition. Indeed, packaging is destined to change rapidly in these years, embracing the sustainable and circular perspective and abandoning just its physical and marketing purpose. Summarising the regulatory innovation that is facing the industry, the three main actions which are impacting the flexible packaging producers are the implementation of extended producer responsibility schemes, the ban of single use plastic and the imposition of a percentage of recycled material content in the products. These three actions indicate the necessity of decreasing virgin fossil-based material, eliminate the unnecessary material and incentivise the recycling of plastic.
Guided by the new legislative requirements, the new market necessities and its policy, Irplast S.p.A. has implemented a circular business strategy to reduce the plastic production impacts in all the value chain. The case study results indicate that Irplast circular economy business model is based on three building blocks: resource recovery, design for recycling and circular supplies. The resource recovery is obtained through additional uses from resources and to extract more value from them by avoiding final disposal for as long as possible. As it is shown in the results, the regeneration process through the regranulation of the film waste in the Atessa plant gives new life to the film waste. The design for recycling wants to follow the extended producer responsibility schemes, designing products that are easier to recycle. As the results show, the four key actions undertaken by Irplast are the thickness reduction, the mono material solutions, the multipack solutions and the food contact tape that allows 95% material reduction in food contact packaging. The Circular Supplies business block goal is to lessen dependence on virgin fossil-based resources. Irplast has been a pioneer in the sector in commercialising non-fossil based materials and chemically recycled materials. As the results have shown, the NOPP and LOOP films are a competitive and sustainable alternative to virgin plastic in flexible packaging. The quality and the environmental friendly characteristics of these products are proved by the ISCC Plus certifications and by the LCAs conducted by Spinlife. Indeed, these products overcome one of the main problems linked with plastic recycling for food contact applications, which is the quality of the recycled material, thanks to the chemical recycling technology.
Furthermore, the results show that, in order to implement this business model, Irplast has made clear strategic choices. First of all, the Company vertical integration structure. Irplast takes advantage of the industrial symbiosis between the Atessa and Empoli sites which fosters eco-innovation, creates and share knowledge, improves business and technical processes (Maranesi and De Giovanni 2020). The vertical integration brings benefits to the Company in terms of cost reduction, increased revenues and competitive advantage (Maranesi

and De Giovanni 2020). Secondly, Irplast has invested in innovative technologies both for the product and process development, in order to increase the efficiency and reduce environmental impacts. In fact, innovative technologies can foster the circular economy through efficiency and transparency (Maranesi and De Giovanni 2020). Thirdly, the Company has a qualified Research and Development department that collaborates with the production in developing tailor made innovative solutions. The R&D department plays a strategic role in developing the tailor made products for Irplast customers, which continuously adapt their demand according to the market requests. Eventually, another important factor to achieve these results has been the relationship with the stakeholders. Indeed, the relationship between all the actors of the value chain is the key factor in order to implement a circular economy strategy. The relational dimension of circular economy is fundamental to pursue mutually supporting progress and a higher level of competitiveness, especially within the supply chain members. The collaboration and interaction with suppliers and customers lead Irplast to superior operational and environmental performances.

Irplast S.p.A. case shows a virtuous circular business model that embraces these new regulations and changes its production and process towards a more sustainable perspective. The circular business model adopted can represent a benchmark for the flexible packaging producers in facing the transition and the difficulties in implementing the circular economy. The case study overcomes the design and production gaps found by Johansen et al. (2022) and represents a virtuous case in the plastic private sector that is struggling to implement a concrete circular economy strategy (Phelan et al. 2022). Firstly, the Irplast case demonstrates that there might be alternative feedstocks to virgin plastics, which overcome the problems claimed by the literature (Civancik-Uslu et al., 2019; Foschi et al., 2020; Gall et al., 2020; Iacovidou et al., 2019; Masmoudi et al., 2020). Furthermore, the Company demonstrates that the design and production phases might play a key role in reducing the impacts themselves through new efficient technology, waste recovery and innovative design, but also they can increase the waste recycling efficiency at the end of the value chain through the products development thanks to the R&D department quality. Indeed, Irplast case demonstrates that investments in new technologies, investments in high quality human resources, a high qualified Research and Development department that collaborates with the production in innovating its design and production value chain phases are the solid base in implementing the ecological transition. In addition, the vertical integration plays a key role in accelerating the internal development in the production and the launch to the market. Eventually, the case highlights the need for a strong stakeholder relationship to embrace a holistic perspective as required by Johansen et al. (2022). Indeed, the relationship with all the actors in the value chain are key to communicate the needs and requirements for the implementation of a circular economy. From the feedstock suppliers to the waste managers, the virtuous relationships between the stakeholders are crucial in order to optimise investments in research and technologies, and design recyclable products. In this sense, the prior commercial relationship that Irplast set up become a really valuable asset in the new circular economy business model, where the dialogue and transparent communication with the other stakeholders is needed more than before.

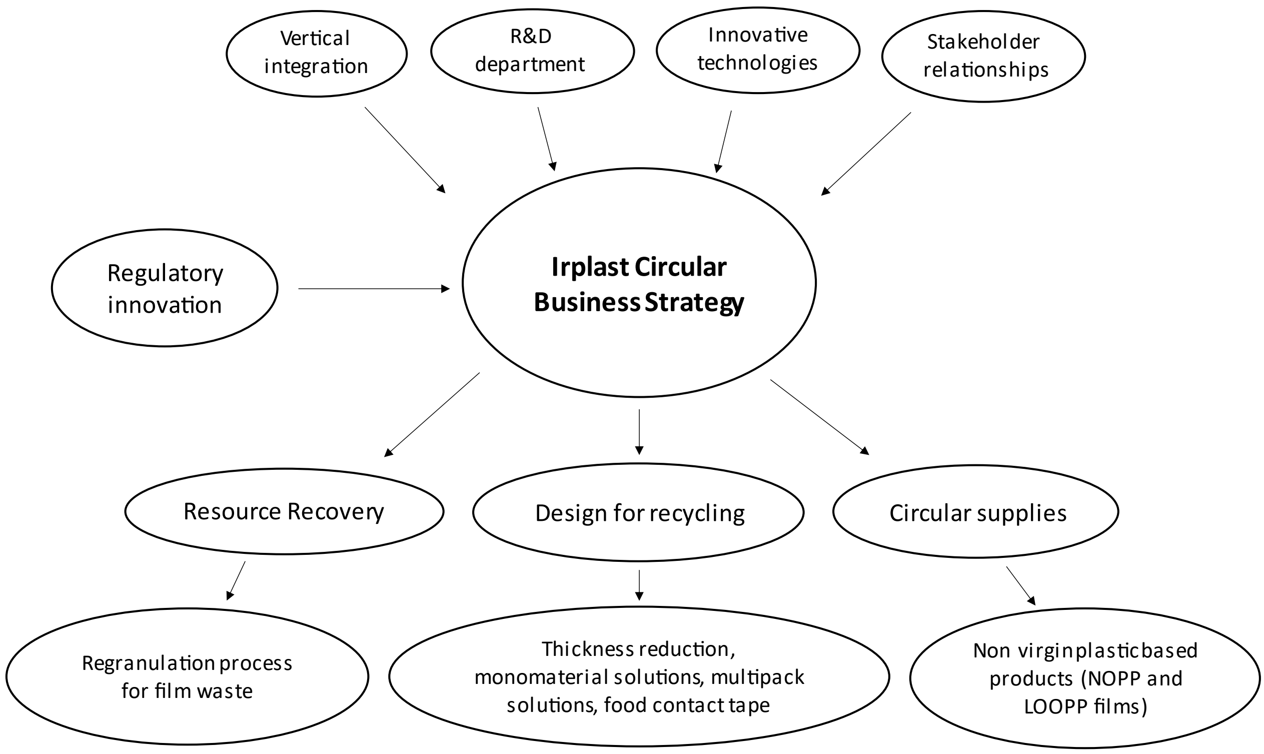

Figure 4: Discussion synthesis.

Conclusion

The Irplast S.p.A. case study shows that the firm implements a circular economy business plan that simultaneously embraces the new legislation, reduces the environmental impacts of the Company and fulfils the market request. The circular economy strategy allows Irplast to diversify its portfolio and enhance its brand reputation, reducing competition risks. The latter aspect is particularly important in the plastic industry, which is characterised by a high innovative rate and a competitive international market.

The case study gives a theoretical and practical answer to the design, production and regulatory issues that a flexible packaging producer have to overcome to implement the ecological transition. Indeed, the literature highlights how the plastic industry is reluctant to embrace the new circular perspective, claiming the difficulty in adopting actions and choices at design and production value chain level. However, the Irplast case demonstrates the opposite, showing possible circular solutions and strategies for flexible packaging producers. Starting from the new framework and the issues found by Johansen et al. (2022) and Phelan et al. (2022), the Irplast case study shows four key actions for the sector to implement a circular strategy.

Firstly, the vertical integration of the Atessa and Empoli sites, that allows the Company to develop faster than competitors. Secondly, the innovative technologies that allows Irplast better environmental and technical efficiency in the production process. Thirdly, the investments and the quality of its R&D department, which collaborates synergically with all the production phase. Fourthly, the stakeholders relationship, which allows Irplast to innovate and satisfy the clients request faster. The stakeholder relationship is crucial for the implementation of an holistic circular economy strategy, because it allows the different firms involved within the production value chain to communicate. These four actions, guided by the Company's sustainable policy, make possible to implement a circular economy business plan that overcomes the main problems highlighted by the literature. Irplast circular business model is based on three building blocks: resource recovery, design for recycling and circular supplies. These three building blocks aim both at increasing the holistic approach in all the plastic value chain, reducing the production waste, designing and producing products that are easily recyclable and using non virgin plastic based feedstocks. Therefore, Irplast case study has provided a successful circular business model that overcomes the literature gaps for the flexible packaging producers, answering to the research question Q1. Furthermore, the case study provides strategies and actions of circular economy implementation that focus on the production and design phases of the plastic value chain, answering to the research question Q 1.1. Eventually, the case study clearly shows how the new regulatory framework is impacting on the flexible packaging producers, with the implementation of extended producer responsibility schemes, the ban of single use plastic and the imposition of a percentage of recycled material content in the products. Therefore, the case study answers also the research question Q 1.2. However, it cannot be extended to the other plastic applications in other sectors, where further research is needed. Furthermore, the circular business model implemented by the Company is based also on the actions of the other actors in the value chain level, such as the waste disposal managers and the brand owners. To broader the research, an analysis with all the other production value chain actors should be conducted.

	Literature	**Irplast S.p.A. case study**
Circular economy business model in plastic industry (Q 1)	Need for an holistic approach in the plastic value chain; reduce product life cycle impacts.	**Building blocks** of the CEBM: resource recovery; circular supply; design for recycling.
Design and production (Q 1.1)	Design packaging in order to increase the recyclability; difficulties in using recycled plastics for food contact applications due to the low quality ouput; difficulting in finding a feedstock alternative to plastic.	**Outputs**: non virgin fossil-based feedstock ISCC Plus certified; monomaterial solutions; thickness reduction; multipack solutions; food contact tape; BOPP film waste regeneration through regranulation process. **Strategic choices:** technology investments; investments in the R&D department; vertical integration; stakeholder relationships
European legislative framework (Q 1.2)	EU Action Plan for a Circular Economy; European Strategy for Plastics in a Circular Economy; Extended Producer Responsibility schemes; Food Contact Material Regulations; Plastic Tax.	**Legislative influences:** extended producer responsibility schemes; ban of single use plastic; imposition of a percentage of recycled material content in the products.

Figure 5: Conclusion.

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THESIS SUMMARY

Thesis Summary Index

Introduction

Problem statement

The plastic regulatory framework is facing its biggest transformation since the creation this game changer material. The new legislative green transition wants to cut the negative environmental and social impacts that plastic have on our planet, posing new challenges and objectives to the flexible packaging producers. However, it is not still clear whether the private sector is ready for this change and whether it is effectively possible to shift to another material in some applications such as the flexible packaging in the food and beverage industry. The evidence shows that the firms transition is slow (Phelan et al. 2022). Specifically, the proportion of the literature covering each value-chain phase indicates a knowledge gap in the design and production phase (Johansen et al. 2022), which may hinder both the transition to circular and the waste-management procedures in the plastic end-of-life phase. Indeed, most of the literature focus its attention on the waste management phase, without considering the impacts that the design and the production phases have on it. Furthermore, Johansen et al. (2022) claim the necessity for an holistic approach that comprehends all the plastic value chain phases for the implementation of a circular economy strategy.

Research purpose and research questions

The research wants to investigate the gaps found by Phelan et al. (2022) and Johansen et al. (2022) in the implementation of a circular economy for plastic producers, using the case study of Irplast S.p.A., an Italian BOPP film producer. The purpose of the research is trying to fill the literature gaps found in the design and production phase for the flexible packaging producers and to understand how the regulatory framework is pushing them towards the implementation of a circular economy. Indeed, the case study investigates theoretically and practically which are the strategies implemented by Irplast S.p.A. that might lead to the implementation of a circular economy, giving a benchmark for the flexible packaging producers in the food and beverage industry. The focus of the case study is on the design and production phases because these are the main phases in which Irplast S.p.A. is directly involved. The food and beverage sector is considered because it is one of the most complex due to its Food Contact Material Regulations, which poses higher quality standards to reach for plastic. Moreover, the purpose of the paper is to narrow the search field in order to provide more specific and detailed strategies and actions, without simplifying the plastic industry in a unique production chain and market.

The research questions considered are the following:

- ➢ Q 1: How can flexible packaging producers implement a circular economy strategy in the food and beverage sector?
- ➢ Q 1.1: How can the product design and production phases be part of a circular economy strategy in the value chain of flexible packaging?
- ➢ Q 1.2: How is the new sustainable European legislative framework promoting circular economy strategies for flexible packaging production?

Disposition of the paper

The paper is divided into seven main chapters. The literature review provides a general overview about the themes analysed by the paper and it is divided into eight sub-paragraphs that speak about flexible packaging, regulatory innovation, plastic value chain, alternative feedstock to virgin plastics and the company Irplast S.p.A.. Section three explains the methodology used in the research. Section four gives a general overview on the Company Irplast S.p.A. and presents the results of the case study. Section five elaborates the results and presents the discussion. Finally, the last paragraph points out the conclusions of the case study.

Delimitations and further research

The case study analyses a specific application of plastic for a precise industry. Therefore, the conclusions and the reasoning that come out from this paper are related only to the flexible packaging in the food and beverage industry and cannot be generalised to all the plastic applications and industries. Furthermore, the research considers only the design and production phases outlined by Johansen et al. (2022) in the plastic value chain. Therefore, to broader the research two directions can be chosen. On one side, the research can be integrated with the other phases of the plastic value chain, in order to have the broader and more comprehensive view on how can a circular economy be implemented in the flexible packaging applications for the food and beverage sector. On the other side, there is the need of extending the case study analysis to other plastic applications and sector, which might have different solutions and strategies to implement.

Literature Review

Flexible packaging

Considering all the plastics end-use markets in the EU, packaging represents the largest one with more than 40% of the total (Plastics Europe 2021) and about 60% of post-consumer plastic waste (EU Commission 2018). This paper focuses on its application in films for the food and beverage industry: Bioriented Polypropylene

(BOPP). Biaxial orientation means that the plastic film is pulled in two different directions during production, in order to improve its strength, flexibility and brightness. BOPP is a type of film that is produced by extruding the plastic through a circular die followed by expansion cooling (Maddah 2016). This kind of film provides resistance to moisture vapour to keep snacks crisp and fresh tasting and provides a heat-sealable layer (Maddah 2016). The BOPP physical, chemical and mechanical characteristics, plus its relatively cheap price, have made this material the most used for flexible packaging in the food and beverage industry application.

The increasing role of sustainability within the plastic European regulatory framework

Plastic legislations and normative trends have evolved embracing social and environmental values, with the aim of decreasing the negative impacts of the plastic world on society and the environment. In December 2015, the Commission adopted an EU Action Plan[12] for a circular economy, where it stated that plastic is a key priority. In 2017, the Commission confirmed it would focus on plastics production and its use, working towards the goal of ensuring that all plastic packaging is recyclable by 2030 (EU Commission 2018). In 2018 the Commission presented the European Strategy for Plastics in a Circular Economy[13] that shows the key commitments for an integrated action. According to the Strategy, the actors involved in the plastics industry should: improve design and support innovation to realise plastic products easier to recycle; expand and promote the separate collection of plastic waste, to ensure quality inputs to the recycling industry; expand and modernise the EU's sorting and recycling capacity; create viable markets for recycled and renewable plastics. While setting the targets and the strategy to follow, the Commission stresses the importance of Extended Producers Responsibility (EPR) to reach the objectives. EPR legislation, in principle, shifts the responsibility for, and costs of, negative environmental externalities of products from tax payers to producers, consistent with the "polluter pays" principle (IEEP 2017). EPR principle was already indirectly invoked by the Packaging and Packaging Waste Directive[14] (94/62/CE) in Article 7, that requires the Member States to take necessary measures to ensure that systems are set up for the collection and recycling of packaging waste. Then, it has been explicitly mentioned in the Single Use Plastic Directive[15] (2019/904) in Article 8, that states that Member States shall ensure that extended producer responsibility schemes are established for a precise list of products. Furthermore, EPR plays an important role in assessing the requirements for recycling plastics, which is the fundamental step in implementing a circular strategy for this material, and observing food safety requirements, that is a conditio sine qua non for the Food Contact Material[16] (FCM). On one side plastic packaging reduces

[12] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en
[13] https://ec.europa.eu/info/research-and-innovation/research-area/environment/circular-economy/plastics-circular-economy_en
[14] https://ec.europa.eu/environment/topics/waste-and-recycling/packaging-waste_en
[15] https://ec.europa.eu/environment/topics/plastics/single-use-plastics_en
[16] https://ec.europa.eu/food/safety/chemical-safety/food-contact-materials_en

food waste by extending the shelf-life (Ellen MacArthur Foundation et al., 2016; White and Lockyer 2020) and prevents spoilage from microorganisms which are one of the main causes of food attack from microorganisms. On the other hand, as stated by Matthews et al. (2020), 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.

Following the European Strategy for plastics, in 2019 the European Commission adopted the Single-use Plastic Directive[17] (EU 2019/904). EU rules on single-use plastic products aim to prevent and reduce the impact of certain plastic products on the environment, in particular the marine environment, and on human health. They also aim to promote the transition to a circular economy with innovative and sustainable business models, products and materials, therefore also contributing to the efficient functioning of the internal market (EU Commission 2019). Within the new legislations that prohibit the use of single use plastic, the Balearic Islands have been one of the pioneers in implementing a circular strategy in plastic packaging management. Through a combination of measures on generic waste generation and specific waste streams such as single-use plastics or food waste, the Ley 8/2019 "*De residuos y suelos contaminados de las Illes Balears"*[18] offers a strong example of how to adopt a law that has a comprehensive approach to the problem of pollution from waste generation. Another innovative measure has been taken by the French Government in 2020 with the Loi no 105 "*Objectifs stratégiques de gestion et de prévention de la production de déchets"*[19]. The law bans plastic packaging on most fruit and vegetables, indeed from 2021 the country banned plastic straws, cups and cutlery, as well as polystyrene takeaway boxes. Eventually, in April 2022 in the UK a Plastic Packaging Tax[20] was introduced by the Government.

Plastic value chain from a circular economy perspective: overview.

The plastic circular economy approach that is promoted by the new sustainable European regulatory framework is an alternative to the traditional linear system. The circular economy approach wants to close the loop of the plastic life cycle, increasing also the amount of plastic that is reused or recycled back into the system (Calleja 2019; European Commission 2018). The transition to the circular economy should be made across the entire plastics value chain in order to ensure circular design, production, use and waste management (Johansen et al. 2022). Johansen et al. (2022) made a review of the existing literature about plastic circular economy strategies and gaps, dividing the plastic value chain in six main phases: raw materials, polymer design & production, product production, retailer, use & demand and waste management. The results of the literature

[17] https://ec.europa.eu/environment/topics/plastics/single-use-plastics_en
[18] https://www.boe.es/buscar/doc.php?id=BOE-A-2019-5577
[19] https://www.legifrance.gouv.fr/loda/id/LEGISCTA000041554510
[20] https://www.legislation.gov.uk/uksi/2022/117/contents/made

show an unequal distribution of research across the different phases of the value chain. The majority of published articles focus on the waste-management phase, with a comparatively small number of studies dealing with product design, production, and use. This highlights an important knowledge gap, as most research has been focused on the end-of-life phase, despite increased political and scientific emphasis on the circular economy that, ideally, would include recycling as just one aspect of an overall strategy (Johansen et al. 2022).

Plastic value chain from a circular economy perspective: design phase.

Design phase is crucial because functionality and features of the product are decided, such as colour, recyclability, recipe of the product (Iacovidou et al. 2019). Furthermore, the company marketing strategy has a key role in the design phase (Rundh 2016), where the brand has to communicate its product identity, but also the packaging itself. Especially for food contact applications, the design of flexible packaging is a key phase. The main constraints in this phase are the high quality standards, but also low migration of toxins, being light-weight and having the ability to keep food fresh (Masmoudi et al., 2020). Many authors assess that recycled plastic can be difficult to use in new products owing to the contamination of polymer types, which may affect aspects such as durability, toxicity and weight (Civancik-Uslu et al., 2019; Foschi et al., 2020; Gall et al., 2020; Iacovidou et al., 2019; Masmoudi et al., 2020). When trying to incorporate recycled plastic into new products, contamination and mixed polymers are, according to Gall et al. (2020) and Iacovidou et al. (2019), two of the most problematic impediments (Johansen et al. 2022).

Plastic value chain from a circular economy perspective: production phase.

The literature review made by Johansen et al. (2022) shows how only 3 papers out of 60 address this phase of the plastic value chain, highlighting a lack of knowledge in this specific phase. In these papers the main challenge outlined about circular economy strategies is that recycled plastic is most often composed of different polymer types and contaminated with non-plastic materials, such as additives, inks and glues. Therefore, this causes a range of complications, which reduces the value of the final product made by a mix of virgin and recycled plastic (Getor et al. 2020). Indeed, plastic products are designed with mixed polymers and the waste stream becomes therefore contaminated, affecting the properties of the recycled plastic (Getor et al., 2020).

Alternative feedstocks to virgin plastic

During recent years, many studies have been published to review possible non-fossil based alternatives to BOPP and circular economy strategies to adopt. However, it is difficult to draft a comparative analysis of the alternative non-fossil based materials (Walker and Rothman 2020), due to methodological problems. Walker and Rothman (2020) review the state-of-the-art in comparative Life Cycle Assessment of fossil-based and bio-based polymers. According to the authors, no published articles were found to fully meet the European Union Product Environmental Footprint (EU PEF) standards.

The methodological problem brought the European Commission to entrust the Joint Research Centre with a comparative analysis, through the means of life cycle assessment, that assesses the potential environmental impacts of the use of alternative feedstock for plastic films in comparison to using current feedstock. Within the report, PP film is mostly considered as a reference, being the benchmark that needs to be outperformed. The others non fossil-based polymers considered are Bio-LDPE, which is derived from Sugarcane in Brazil; PLA, which is derived from maize in the U.S.A.; starch-based polymer from corn. The overall results show that the bio-based LDPE film has averagely the highest impact compared to the other materials, mainly due to the relevant polymer production impacts. Therefore the use of bio-based ethylene derived from dedicated crop (sugarcane) does not appear to be an environmentally sound alternative. CO_2-based PP also shows high impacts in many categories. This appears related to high energy consumption in polymer production (e.g. in Climate Change, Ionising Radiation, Resource Use fossils), or chemicals used in CO_2 capture and methanol synthesis. The overall performance of the use of this alternative feedstock for PP production is thus worse compared to its fossil-based counterpart in the majority of the categories (JRC 2018). Similar reasoning can be made for the PLA and starch-based polymers. PLA has a higher impact than fossil based PP in most of the cases, specifically for what concerns climate change, ozone depletion, particulate matter and land use. At the same time, PLA has less impact on fossil resource use and human toxicity. Starch-based polymers show higher impacts than fossil based PP in climate change, producing more than double the CO_2 kilograms in its lifecycle. Starch-based polymers also have more impacts than fossil based PP in ozone depletion, particulate matter and land use, however they show less impact in human toxicity, eutrophication and fossil resource use (JRC 2018).

Within the non-fossil alternatives available in the market, bio-plastics seem to be the most used, but also controversial. This is due to mainly two reasons: methodological problems with the LCAs analysis and an ethical issue that poses in conflict the bio-based plastic production with the agricultural production and sustainability. From the comparative analysis of the LCAs comes out that the introduction of bioplastics makes possible to reduce environmental impacts, in particular for GHGs emissions and consumption of non-renewable resources, compared to polymers of fossil origin, however the advantage is uncertain for other impact categories such as acidification and eutrophication, which are significantly affected by the processes included in the production phase, both in agriculture and in processing. In addition, the studies which include all phases of the life cycle from cradle to grave have shown that the choice of the end-of-life scenario of the biopolymer is decisive in the assessment of the overall environmental impacts.

Mechanical and chemical recycling

Mechanical recycling does not change the chemical structure of the material, however it is a generally environmentally-friendly approach for waste plastic disposal (Lazarevic et al., 2010; Al-Maadeed et al., 2012; Wäger and Hischier, 2015). However, the plastic obtained by mechanical recycling cannot be used for film production in the food and beverage industry because the process can degrade the mechanical properties of plastic materials (Yin et al., 2015). Moreover, it is inefficient for difficult-to-recycle plastics, such as multi-layered or heterogeneous plastic used, for example, for packaging (Singh et al., 2017). In addition, depending on the quality of the incoming waste plastic and the efficiency of the sorting process, residual materials, including plastics, still need to be either incinerated or landfilled (UBA, 2018) (Jeswani et al. 2021).

Chemical recycling is the process of converting polymeric waste by changing its chemical structure and turning it back into their functional units that can be used as feedstocks for the production of new virgin like polymers and manufacturing of plastics or other products. Studies assessing chemical recycling in the UK (Gear et al., 2018), the Netherlands (CE Delft, 2020) and Europe (Somoza-Tornos et al., 2020) suggested that the climate change impact of pyrolysis and other chemical recycling technologies was significantly lower than that one of incineration. Chemical recycling is nowadays the only process that allows flexible packaging producers to use recycled plastic for food contact films because of its quality and upcycling characteristics. Chemical recycling has also been accepted by the EU Taxonomy as a green practice, however, chemical recycling facilities are not widespread and still have to develop on a large scale.

Gap analysis

According to Phelan et al. (2022), most companies do not directly acknowledge plastic pollution as an issue. Furthermore, Johansen et al. (2022) highlights the lack of an holistic value-chain approach when implementing circular economy, that is necessary to ensure an efficient and effective transformation of the current linear value chain. The proportion of the literature covering each value-chain phase indicates a knowledge gap in the design, production and use phase (Johansen et al. 2022). This knowledge gap may hinder both the transition to circular and the waste-management procedures in the end-of-life phase, with limited attention consequently given to opportunities for redesign and prevention of plastic waste. Furthermore, going into the practical outputs, the literature clearly shows that a feasible and industry wide spread alternative to virgin plastic still has to be found. The LCAs analysis of the alternative feedstocks demonstrates that also from environmental point of view polypropylene is still competitive with the non-fossil-based alternatives.

Methodology

The paper proposes a case study as a benchmark for plastic packaging circular economy in the food and beverage industry. The case study analyses the strategy of Irplast S.p.A., one of the world company leaders for the production of BOPP films. To address the research purpose and answers the research questions, a qualitative approach has been chosen for this study, which is composed by secondary and primary data.

To provide a theoretical background to the study, a review of secondary data was performed as part of the literature review. The review was conducted in a narrative and systematic way, because on one side the case study needs to be integrated in the new legislative framework narrative and on the other side the review identifies the literature gap and finds out what the research could add to the existing knowledge. The individuation of the existing literature occurred through the utilization of the Google Scholar source, mainly through the following key words: "Circular Economy", "Plastic circular economy strategies" "Flexible packaging", "BOPP film for food contact applications", "plastic recycling", "plastic value chain", "Virgin plastic alternatives", "plastic regulations". The primary data collection was conducted through unstructured interviews to Irplast human resources during a four months period between February and May 2022. This data analysis method appears the most suitable one since the argument treated in the research is very specific and with various technical and non-technical aspects to consider. Therefore, the aim of the unstructured interviews was to follow the knowledge of the interviewed without any prior fil rouge planned by the interviewer. Indeed, with this method was possible to make the respondent free to express themselves freely and it was possible to ask additional questions to deepen the topics. The main Company human resources interviewed were the Sustainability Manager, the Sustainability Officers, the Research and Development Director and the Sales Director.

Case study results

Research setting

Irplast business model is focused on the reduction of the environmental impacts of the company and its products. The Company operates through three product lines concentrated in the two poles of Atessa (Chieti) and Empoli (Florence), where it handles respectively the initial and final phase of the life cycle of the plastic film, made from the raw material of polypropylene. 380 people are employed in the three manufacturing sites, all based in Italy. In Empoli, the factory has a production capacity of over 500 million square metres, while the two film manufacturing sites in Atessa have a total installed capacity for 44,000 tonnes of BOPP film. The Company generated a turnover in 2021 of around Euro 100 million. 75% of total output is exported to 68 countries worldwide. The three main Company business units are the label tech division, the print tape division and the BOPP film division.

Irplast Value Chain and vertical integration

The Irplast value chain is divided into ten macro phases that begin with the extraction of the virgin raw material and end with the end of life of the product. The polypropylene cycle begins with the extraction of the virgin raw material and its processing, first in monomers and then in polymers. The following production phase begins with the transformation of polypropylene into bi-oriented film (BOPP). These products are then marketed all over the world and generally sold to large multinational companies. Then follows the collection and disposal phase of the waste produced during the production cycle, a part of which is recovered and reused internally, and a part is upcycled into secondary raw materials for other production processes. A tiny fraction is disposed of for external recycling. Moreover, Irplast S.p.A. is the first vertically integrated BOPP producer, from the extrusion of the film to the printing of finished products. Vertical integration is a strategy that allows the company to streamline its operations by taking direct ownership of various stages of its production process rather than relying on external contractors or suppliers

Know-how and innovative technology

The Company has developed a unique know-how in the design and production of innovative and customised BOPP films. The know-how is combined with investments in human capital with high scientific/technical competences and in innovative technologies for the process and product development. Considering the last seven years, the human resources employed with a technical job that have at least a scientific/technical Bachelor Degree have more than doubled (source: R&D department Director).

In order to improve the process development and the efficiency, the Company implemented a trigeneration system in both Empoli and Atessa sites, for which it annually receives grants by the Government for the electricity sector. During 2020, Irplast also installed a new distiller, which makes it possible to improve the solvent recovery process by reducing the amount of sludge sent for disposal, for details refer to the paragraph “Extended responsibility for our production activities“. In the same year, a new silo was also installed to collect the sludge and a new collection tank for the distilled solvent. The plant as a whole, which came into operation in the second half of 2020, contributed to the decrease of about 20% of the sludge sent for disposal. Lastly, a new regenerative thermal oxidizer has been installed that increases the efficiency of the solvent abatement system and a reduction of atmospheric emissions of pollutants. During 2020 and 2021 many investments have been made and planned for the product development, also thanks to the Ministero della Transizione Ecologica "Transizione 4.0"[21] incentives.

R&D

The Research and Development department plays a key role in the sustainable innovation of Irplast S.p.A. Indeed, the product creation process is supported by the Research and Development departments of Atessa and Empoli which focus their activities on the formulation of products characterised by better performance, functionality and lower environmental impact. However, the R&D department involvement also has a broader purpose that is not limited to the company. In fact, the R&D departments participate in three co-financed projects with public entities and academic institutions: EcoReLabel, NONIAS and Tex-Style. To underline the Irplast R&D department quality, it should be noted that the projects, in order to be eligible for co-funding, are assessed by experts in the field and deemed worthy of subsidy by virtue of their technical and scientific content.

Tailor made products and stakeholder relationship

Irplast, individually or in collaboration with its suppliers and customers, conceives and designs polypropylene products by purchasing the raw material from selected and qualified suppliers, also evaluating environmental criteria. Irplast focuses its design process on the collaboration with suppliers and customers. The continuous interaction allowed Irplast to increase clients satisfaction for the final product, to follow the new requests and developments, but also to strengthen the relationship with the stakeholders of the value chain. Furthermore, the stakeholder relationship importance is underlined also by the co-financed initiatives in which Irplast S.p.A. took part with its R&D department.

Sustainable and innovative design

Firstly, thanks to its know-how, Irplast realises a thickness reduction of all its products. The aim of this solution is to reduce the amount of raw material used while ensuring the same product yields, in order to offer a sustainable alternative that does not require any change in the expected quality. Secondly, Irplast develops monomaterial products. Thirdly, Irplast develops multi-packaging bands, a practical and eco-friendly alternative to classic shrink wrapping. Eventually, Irplast creates food contact tape, an adhesive label-tape, suitable for direct contact with all foods.

[21] https://www.mise.gov.it/index.php/it/transizione40

New alternative materials to virgin plastic

Irplast S.p.A. is the first company in its sector to have launched ISCC PLUS certified products made by alternative raw materials in the market. The ISCC PLUS certification guarantees the chain of custody of the entire supply chain involving all players starting from the "feedstock producer" up to the "brand owner". Traceability is obtained through the receipt and issue of sustainability certificates, respectively for each batch of raw material purchased and product sold. The first line of products presented by Irplast is called Natural Oriented Polypropylene (NOPP), this film is derived from Tall Oil obtained as a by-product of the Kraft softwood pulp process The second line of products presented by Irplast is the LOOPP film, made with chemically recycled plastics.

Waste regeneration

In order to maximise the use of the raw material recycled internally, Irplast implements waste regeneration. The production process of the bi-oriented film generates physiological waste classified as a by-product, however the application of the principles of circular economy to its value chain has made it possible to almost completely eliminate such waste at the Atessa plant. About 23.5% of the waste is sold to third parties, and intended for use for production in other sectors. The remaining part is instead recycled internally - through the regranulation process - and reused in the production cycle, ensuring an average recycled content of around 15%. This means that only 0.30% of the initial raw material actually becomes processing waste.

Discussion

The new legislative framework impacts intensely the flexible packaging industry, which is considered a key priority for the ecological transition. The three main legislative consequences that are impacting the flexible packaging producers are the implementation of extended producer responsibility schemes, the ban of single use plastic and the imposition of a percentage of recycled material content in the products. These indicate the necessity of decreasing virgin fossil-based material, eliminate the unnecessary material and incentivise the recycling of plastic. Guided by the new legislative requirements, the new market necessities and its policy, Irplast S.p.A. has implemented a circular business strategy to reduce the plastic production impacts in all the value chain. The case study results indicate that Irplast circular economy business model is based on three building blocks: resource recovery, design for recycling and circular supplies. The resource recovery is obtained through additional uses from resources and to extract more value from them by avoiding final disposal for as long as possible. As it is shown in the results, the regeneration process through the regranulation of the film waste in the Atessa plant gives new life to the film waste. The design for recycling wants to follow the

extended producer responsibility schemes, designing products that are easier to recycle. As the results show, the four key actions undertaken by Irplast are the thickness reduction, the mono material solutions, the multipack solutions and the food contact tape that allows 95% material reduction in food contact packaging. The Circular Supplies business block goal is to lessen dependence on virgin fossil-based resources. Irplast has been a pioneer in the sector in commercialising non-fossil based materials and chemically recycled materials. These products overcome one of the main problems linked with plastic recycling for food contact applications, which is the quality of the recycled material, thanks to the chemical recycling technology.
Furthermore, the results show that, in order to implement the circular business model, Irplast has made clear strategic choices. First of all, the Company vertical integration structure. The vertical integration brings benefits to the Company in terms of cost reduction, increased revenues and competitive advantage (Maranesi and De Giovanni 2020). Secondly, Irplast has invested in innovative technologies both for the product and process development, in order to increase the efficiency and reduce environmental impacts. Thirdly, the Company has a qualified Research and Development department that collaborates with the production in developing tailor made innovative solutions. The R&D department plays a strategic role in developing the tailor made products for Irplast customers, which continuously adapt their demand according to the market requests. Eventually, another important factor to achieve these results has been the relationship with the stakeholders. The relational dimension of circular economy is fundamental to pursue mutually supporting progress and a higher level of competitiveness, especially within the supply chain members.

Irplast S.p.A. case shows a virtuous circular business model that embraces these new regulations and changes its production and process towards a more sustainable perspective. The circular business model adopted can represent a benchmark for the flexible packaging producers in facing the transition and the difficulties in implementing the circular economy. The case study overcomes the design and production gaps found by Johansen et al. (2022) and represents a virtuous case in the plastic private sector that is struggling to implement a concrete circular economy strategy (Phelan et al. 2022). Firstly, the Irplast case demonstrates that there might be alternative feedstocks to virgin plastics, which overcome the problems claimed by the literature (Civancik-Uslu et al., 2019; Foschi et al., 2020; Gall et al., 2020; Iacovidou et al., 2019; Masmoudi et al., 2020). Furthermore, the Company demonstrates that the design and production phases might play a key role in reducing the impacts themselves through new efficient technology, waste recovery and innovative design, but also they can increase the waste recycling efficiency at the end of the value chain through the products development thanks to the R&D department quality. Indeed, Irplast case demonstrates that investments in new technologies, investments in high quality human resources, a high qualified Research and Development department that collaborates with the production in innovating its design and production value chain phases are the solid base in implementing the ecological transition. In addition, the vertical integration plays a key role in accelerating the internal development in the production and the launch to the market. Eventually, the case highlights the need for a strong stakeholder relationship to embrace a holistic perspective as required by Johansen et al. (2022). Indeed, the relationship with all the actors in the value chain are key to communicate the needs and requirements for the implementation of a circular economy. From the feedstock suppliers to the waste managers, the virtuous relationships between the stakeholders are crucial in order to optimise investments in research and technologies, and design recyclable products. In this sense, the prior commercial relationship that Irplast set up become a really valuable asset in the new circular economy business model, where the dialogue and transparent communication with the other stakeholders is needed more than before.

Conclusion

The Irplast S.p.A. case study shows that the firm implements a circular economy business plan that simultaneously embraces the new legislation, reduces the environmental impacts of the Company and fulfils the market request The case study gives a theoretical and practical answer to the design, production and regulatory issues that a flexible packaging producer have to overcome to implement the ecological transition. Starting from the new framework and the issues found by Johansen et al. (2022) and Phelan et al. (2022), the Irplast case study shows four key actions for the sector to implement a circular strategy. Firstly, the vertical integration of the Atessa and Empoli sites, that allows the Company to develop faster than competitors. Secondly, the innovative technologies that allows Irplast better environmental and technical efficiency in the production process. Thirdly, the investments and the quality of its R&D department, which collaborates synergically with all the production phase. Fourthly, the stakeholders relationship, which allows Irplast to innovate and satisfy the clients request faster. These four actions, guided by the Company's sustainable policy, make possible to implement a circular economy business plan based on resource recovery, design for recycling and circular supplies, that overcomes the main problems highlighted by the literature.

Hence, Irplast case study has provided a possible implementation of a circular business model that provide possible strategic solutions for flexible packaging producers, answering to the research question Q1. Furthermore, the case study provides strategies and actions of circular economy implementation that focus on the production and design phases of the plastic value chain, answering to the research question Q 1.1. Eventually, the case study clearly shows how the new regulatory framework is impacting on the flexible packaging producers, with the implementation of extended producer responsibility schemes, the ban of single use plastic and the imposition of a percentage of recycled material content in the products. Therefore, the case study answers also the research question Q 1.2 .

	Literature	Irplast S.p.A. case study
Circular economy business model in plastic industry (Q 1)	Need for an holistic approach in the plastic value chain; reduce product life cycle impacts.	**Building blocks** of the CEBM: resource recovery; circular supply; design for recycling.
Design and production (Q 1.1)	Design packaging in order to increase the recyclability; difficulties in using recycled plastics for food contact applications due to the low quality ouput; difficulting in finding a feedstock alternative to plastic.	**Outputs**: non virgin fossil-based feedstock ISCC Plus certified; monomaterial solutions; thickness reduction; multipack solutions; food contact tape; BOPP film waste regeneration through regranulation process. **Strategic choices:** technology investments; investments in the R&D department; vertical integration; stakeholder relationships
European legislative framework (Q 1.2)	EU Action Plan for a Circular Economy; European Strategy for Plastics in a Circular Economy; Extended Producer Responsibility schemes; Food Contact Material Regulations; Plastic Tax.	**Legislative influences:** extended producer responsibility schemes; ban of single use plastic; imposition of a percentage of recycled material content in the products.

Figure 6: conclusion.