Reducing plastic packaging waste in Ireland: How can biodegradable bioplastics be used in a circular packaging economy?

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Abstract

In Ireland plastic packaging waste is causing serious environmental degradation and reducing this waste is essential for the development of a circular economy. The need to design packaging that is more conducive to a circular economy has led to an interest in biodegradable bioplastics as a tool for improving packaging sustainability. This paper aims to investigate the potential of biodegradable bioplastic packaging (BBP) and how they can be used in a circular packaging economy. To do this a literature review was conducted to outline current research on the topic. A summary of the Irish government's waste action plan for a circular economy strategy was assessed to give an indication of how the plastic packaging waste issue is being managed. Perspectives of different stakeholders were analysed to gauge the potential for a circular packaging economy using biodegradable bioplastics. A framework for its use was then proposed to provide a vision for what a circular packaging economy might look like using biodegradable bioplastics. Finally, policy recommendations were made to highlight the actions needed to ensure the effectiveness of biodegradable bioplastics in reducing plastic packaging waste. The findings of the research suggest that although biodegradable bioplastics should not be seen as a silver bullet for plastic packaging waste, they do have potential in contributing to the circularity of Ireland's packaging system and the reduction of plastic packaging waste if managed in a closed-loop system.

Background

Plastic packaging waste is a global issue that has serious ramifications for our climate and ecological sustainability. In Ireland plastic packaging waste is a by-product of unsustainable manufacturing practises and the way consumers have been conditioned to engage with society, treating packaging as an afterthought. Ireland is one of the biggest producers of plastic packaging waste in Europe and this waste ends up in landfills, incinerators or is embedded into natural environments. The level of plastic packaging waste produced in Ireland is simply not environmentally viable. Although various strategies to reduce this waste have been investigated by policymakers, the issue remains a serious concern for Ireland's aspirations for an environmentally sustainable economy Ireland is currently targeting an approach to waste management that fits into the concept of a circular economy. This model is regenerative by its nature and utilises principles like reduce, reuse, recycle in tackling the plastic packaging waste issue. In a circular economy the origin and end of life of the materials used matters. When it comes to packaging in a circular economy, materials that can be sustainably sourced and reused are preferable. This push for more sustainable alternatives has led to increased interest in the utility of biodegradable bioplastics for use as packaging materials. So far, the exploration into the use of biodegradable bioplastics in a circular economy has been limited in an Irish context. Since plastic packaging waste continues to be an ongoing challenge for policymakers the potential of these packaging materials requires further examination.

Literature Review

Introduction

This literature draws on scientific journals/reviews as well as reports from environmental institutions. The review is divided into key sections including a breakdown of Ireland's plastic packaging waste problem, an explanation of bioplastics and their utility, a description of their production and waste management, and outline of the opportunities and challenges that they present. The intention of the review is to provide insight from scientific analysis to public perceptions, to determine how it can be utilised to tackle Ireland's plastic packaging waste problem.

Breakdown of Ireland's plastic packaging waste problem

Plastic packaging waste is a serious problem in Ireland. According to the EPA's findings' Ireland produced over one million tonnes of packaging waste annually. Their 2018 annual report on waste statistics shows that Ireland's recycling rates have been decreasing on a yearly basis, trending down from 74% in 2012 to 64% in 2018 and this coincides with an increase in the quantity of packaging sent to

incineration (Environmental Protection Agency, 2018). Unfortunately, this trend contradicts the desire for Ireland to move towards a green economy. According to the EPA's research, one-third of plastic waste is recycled in Ireland and over 260,000 tonnes of plastic packaging waste is managed annually, which accounts for 54 kg per person, and this coupled with the issue that 66% of plastic waste in kerbside bins was not widely recyclable (Environmental Protection Agency, 2018). This makes Ireland one of biggest producers of plastic packaging waste in Europe as the EU average is around 33 kg per person. However, recently the Minister of State responsible for a circular economy Ossian Smyth announced in September 2021 that some plastics are to be accepted into recycling bins. It is hoped that this will improve Ireland's recycling rates in the coming years.

Plastic packaging waste that isn't recycled can end up in a number of destinations, whether it is incinerated, sent to landfills or finds its way into our local environments, none of these destinations are conducive to a circular packaging economy (Morrissey and Phillips 2007). Leberton's research highlights how easy it is for plastic packaging to escape our waste collection systems as plastic packaging brought to landfills or tossed in municipal garbage bins are usually lightweight and durable and are easily transported into the surrounding environment by wind, rainwater runoff, and storm water drains. (Lebreton et al. 2017). The Geographical Society of Ireland research on marine plastics assessed the state and scale of plastic waste pollution. They highlight 2015 estimates that humans had generated 6,300 million tonnes of plastic waste. Of that plastic waste, 9% had been recycled, 12% incinerated, and 79% was either in landfills or the natural environment (Black et al. 2020). Their research explained that due to the lightweight, durable, and commercially inexpensive nature of plastic materials, it has become ubiquitous in modern society. The same properties that have made plastics such a convenient consumer good, have also perpetuated their pervasiveness and persistence in the environment, particularly in the marine environment (Black et al. 2020). Plastic litter can now be found in nearly every marine ecosystem, from coastal estuaries to the deepest depths of ocean (Black et al. 2020). This means that plastic packaging waste is present throughout our ecosystems even in areas that are distant from human activity. For example, research has revealed that plastics were prevalent throughout the year at cormorant roosting sites in Ireland even with sites that are relatively distant from human activity (Acampora et al. 2017).

In addition to the environmental degradation caused by plastic packaging, there are serious concerns around its production. The majority of plastic packaging materials are produced using non-renewable sources like petroleum, coal and natural gas, making them not only non-renewable materials but also contributors to global rising Co2 levels (Laxmana Reddy et al. 2008), (Shamsuddin 2017).
Much of the plastic packaging used in Ireland is petroleum-based which means that its use has a dual effect of contributing to global warming and pollution of our environments due to its very low degradability (Shamsuddin 2017).

European research on plastics in a circular economy notes that every year, the production of plastics in the EU is responsible for emitting 13.4 million tonnes of Co2, which is about 20 % of the chemical industry's emissions EU-wide. The production of plastics also emits substances such as toxic metals and organic compounds, which accumulate in animals and plants and may negatively affect their health (Mortensen et al. 2021). Plastic packaging is the largest sector of the plastics industry, representing almost 40% of total plastic consumption, making it the largest contributor to carbon emissions caused by plastics (Mortensen et al. 2021). Additionally, lockdown measures as a result of the Covid-19 pandemic have led to a significant increase in the consumption of single-use plastic packaging from restaurants moving towards single-use disposable plastic packaging and supermarkets covering food products with plastic film (Patrício Silva et al. 2020), (Mortensen et al. 2021).

Literature on the state of plastic packaging waste overwhelmingly points towards the need to find solutions to the environmental degradation it induces, and policymakers in Ireland have a responsibility to find solutions. Commenting on the figures outlined in the EPA's 2018 report Dr Tara Higgins, EPA Senior Scientist said, "Each tonne of packaging releases greenhouse gases during extraction of raw materials, manufacture, transport and waste management process. The quantity of packaging waste generated needs to be reduced to bring about environmental and climate benefits" (Environmental Protection Agency, 2020).
She goes on to say that "the Government's forthcoming Waste and Circular Economy Action Plan provides an opportunity to set out concrete actions that will address the worrying trends highlighted in these figures and help Ireland meet challenging new EU targets in the coming years." (Environmental Protection Agency, 2020). Higgin's quote demonstrates that reductions in our plastic packaging output is critical in the creation of a circular economy.

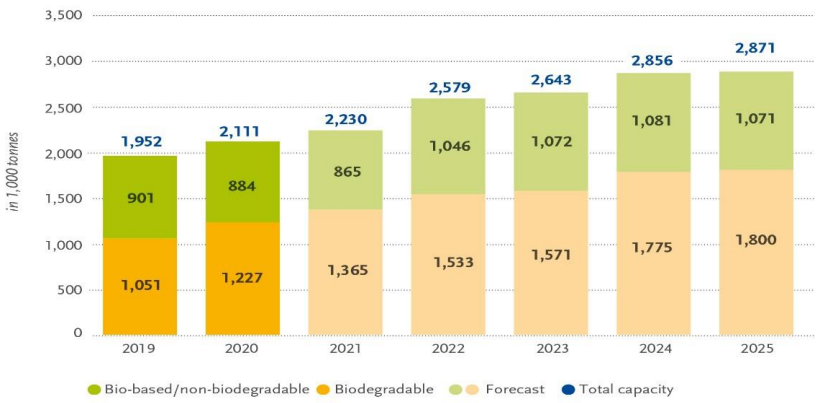
Bioplastics explanation & utility

The literature is clear that our reliance on Petroleum-Based Plastics (PBP) in our packaging system is causing serious environmental degradation (Mortensen et al. 2021). This issue has led to a concerted interest in the scientific community to find alternatives in order to reduce the amount of plastic packaging waste going into landfills and to mitigate the rising Co2 levels caused by PBP (Antonopoulos et al. 2021). This move towards sustainable alternatives has opened up the market for biodegradable bioplastics as an alternative packaging material (Lamberti et al. 2020). Research on BP is plentiful as there is a large array of organic materials that can be used to create it, thus spurring ever growing technological advances with its production (Kawashima et al. 2019). Shamsuddin's review on bioplastics explains that biodegradable bioplastics have a wide breadth of packaging applications which includes bottles, films, cartons and loose-fill; they can also be used to create collection bags, carrier bags, mulch film and cutlery (Shamsuddin 2017).

It is important to note that not all bioplastics are biodegradable and although bioplastics can be made from organic materials, they are not necessarily biodegradable or recyclable. (Jõgi and Bhat 2020). What determines whether a bioplastic material is biodegradable or not, depends on the type of manufacturing and biopolymers used in its production. Examples of biodegradable polymers include starch, cellulose, hemicellulose, polypeptides, polylactic acid and polyhydroxyalkanoates (Jõgi and Bhat 2020). There are a range of biodegradable bioplastic products, many of which can be recycled by mechanical methods and others that can be organically recycled and repurposed for agricultural use. This means that BBP packaging no longer becomes waste as its end of life and is renewable unlike some of its petroleum-based counterparts (Shamsuyeva and Endres, 2021).

In Europe biodegradable bioplastics have to meet minimum requirements in order to be deemed compostable. These requirements are as follows: (1) the material must be degraded by at least 90% in weight in 6 months in a carbon dioxide rich environment; (2) at least 90% of the mass of the material must be reduced to fragments of less than 2 mm if in contact with organic materials for a period of 3 month; (3) the presence of material should not lead to any type of negative effects on composting process, and (4) the amounts of heavy metals presence in the composted materials should not surpass the specified limits (Jõgi and Bhat 2020).

Global production capacities of bioplastics



Source: European Bioplastics, nova-Institute (2020)
*More information: **www.european-bioplastics.org/market** and **www.bio-based.eu/markets***

Global plastic production reached almost 360 million tons in 2018 whilst bioplastics production capacity in 2018 was only 2.01 million tons, representing 0.56% of world's plastic production (European Bioplastics, 2019). These statistics suggest that there is a significant amount of room for this industry to grow in the coming years. Jõgi and Bhat's research suggests that cost-effectiveness is the

main aspect that limits the production and usage of bioplastics (Jõgi and Bhat 2020). To lower the production costs of bioplastics, cheap and abundant raw materials, such as food wastes and by-products can efficiently be explored and as the production quantities of bioplastics are expected to grow, more emphasis should be placed on developing sustainable recycling routes for bio-based materials (Jõgi and Bhat 2020).

Production and Waste Management of Bioplastics

Sidek's review into the future perspectives of bioplastics explains that to produce biodegradable plastics and compostable biopolymers, the renewable raw materials that are commonly used include wood and annual plants (cellulose, lignin, hemicellulose), maize, wheat, potatoes, rice, tapioca, sunflower, rapeseed, etc. (starch, vegetable oils, proteins), sugar from sugar beet and sugarcane (biosynthesis: PLA, PHA, dextran, pullulan, xanthan (Sidek et al. 2019). The likes of starch and cellulose are not plastic in the native form but can be converted to plastics through innovative fermentation or through polymer technology by using techniques such as casting, internal mixing, extrusion and injection moulding (Sidek et al. 2019). The main production benefits of BBP are that they come from renewable sources, cause significantly lower Green House Gas emissions and are compostable (Rahman and Bhoi, 2021). Many biodegradable bioplastics can even break down in natural environments and can potentially reduce the amount of permeate litter in the environment, although this benefit is contested as other research suggests that this may inadvertently lead to BBP littering if consumers do not direct them into appropriate disposal pathways like organic waste bins (Dilkes-Hoffman *et al.*, 2019), (Shamsuddin 2017). The interplay between food and packaging is also important as research into the lifecycle of food packaging explains that the issue of plastic food packaging lies at the heart of sustainable food supply chains. With more extended and complex food supply chains, an increasing amount of food items require packaging to ensure food delivery from farm to fork (Kakadellis and Harris 2020). Considering that over half of the global biodegradable plastic demand is for packaging materials, there is great potential to integrate our food and packaging systems to work sustainability with each other (Jariyasakoolroj et al. 2020), (Karan et al. 2019).

Further review on the end-of-life cycles of bioplastics explain that complications can arise with the end of cycle process that biodegradable plastics go through. There are issues regarding the greenwashing of bioplastic packaging that may not be fully biodegradable. Therefore, it is important that distinctions are made regarding the biodegradability of packaging with strict labelling requirements to ensure that consumers are not inadvertently composting non-biodegradable bioplastics (Kakadellis and Harris 2020). Thus, clear labelling is required to tackle the issue of green-washing and to boost public trust in these products (Kakadellis and Harris 2020).

Neves's research suggests that Irish consumers are in favour of using BBP when presented with packaging options, but there are reports of public confusion regarding the levels of biodegradability expected from bioplastic packaging (Neves et al. 2020). This research also found that low rates of packaging separations by consumers can be attributed to the lack of access to waste separation bins in public places. For effective improvement of these rates with an introduction of novel bioplastic packaging, it would be fundamental to increase the number of composting bins in public spaces (Neves et al. 2020). Similar research in Australia highlighted the role that governments and local councils can play in driving the development of the standards, labelling and waste management options that will need to be introduced to accommodate for the wider use of bioplastic materials (Dilkes-Hoffman et al. 2019).

Opportunities and challenges in Ireland

European research into the best pathways for the production and waste management of these BBP materials are ongoing, but there are some resources that have potential in Ireland (Mortensen et al. 2021). Starch-based bioplastics can have a high level of biodegradability and can decompose in anaerobic conditions in 5 days and 45 days in industrial compost and can also decompose in water (Flieger et al. 2003). These starch-based bioplastics are also known as thermoplastic starch (TPS), due to their production method (Flieger et al. 2003). Starch is considered to be the second most abundant biomass material on Earth as it is produced by a variety of plants as a stored energy source. Some examples of starch producing plants include wheat, corn, potato, rice, rye, buckwheat and barley. Starch is also one of the most used plant polysaccharides for bioplastic production at present (Jõgi and Bhat 2020). In Ireland there are companies looking to utilise unused feedstock, by extracting starch from feedstock. This starch can be produced in a powder form and can be utilised to create thermoplastic starch packaging. For example, the 'Meade Potato Company' uses its leftover potato stock that doesn't meet market standards to create its very own potato starch (Meade Farm, 2021). Innovation such as this has potential in adding value to agricultural-food waste and creating renewable packaging in the form of BBP.

Before Ireland can move towards a circular packaging economy using BBP there are several challenges and critiques of these materials that need to be addressed. Some common concerns that are prevalent throughout the literature is the cost-effectiveness of producing BBP. A global demand for bioplastics is continuously growing and the need to reduce the costs to meet market demands is ongoing (Jõgi and Bhat 2020). Although petroleum plastics are cheaper to produce than bio-based alternatives, prices of production are significantly influenced by scale of production so the cost of production will reduce as

manufacturing scale increases (Laxmana Reddy et al. 2008). In addition to this more emphasis should also be put on developing sustainable recycling routes for bio-based materials (Jõgi and Bhat 2020). The issue of composting options in public spaces being of particular concern in Ireland and a lack of public organic waste bins may prove to be a hindrance to its effectiveness in reducing packaging waste (Neves et al. 2020).

The labelling of BBP and the influence of greenwashing can also negatively affect the pathways for these materials. For example, some non-biodegradable bioplastics may be labelled as if they are biodegradable, which can cause confusion for consumers who may dispose of said packaging in the wrong waste management pathway (Neves et al. 2020). Finally, there are concerns over the land use as changes associated with agricultural feedstocks for bioplastic production can cause loss of habitat and increases in greenhouse gas emissions, if rainforests, grasslands, or peatlands are being displaced for its production (Piemonte 2011). To mitigate these potential impacts, it is recommended that biodegradable bioplastic should be produced using run off feedstock, or second-generation biomass in the agricultural industry (Sidek et al. 2019).

Review of literature

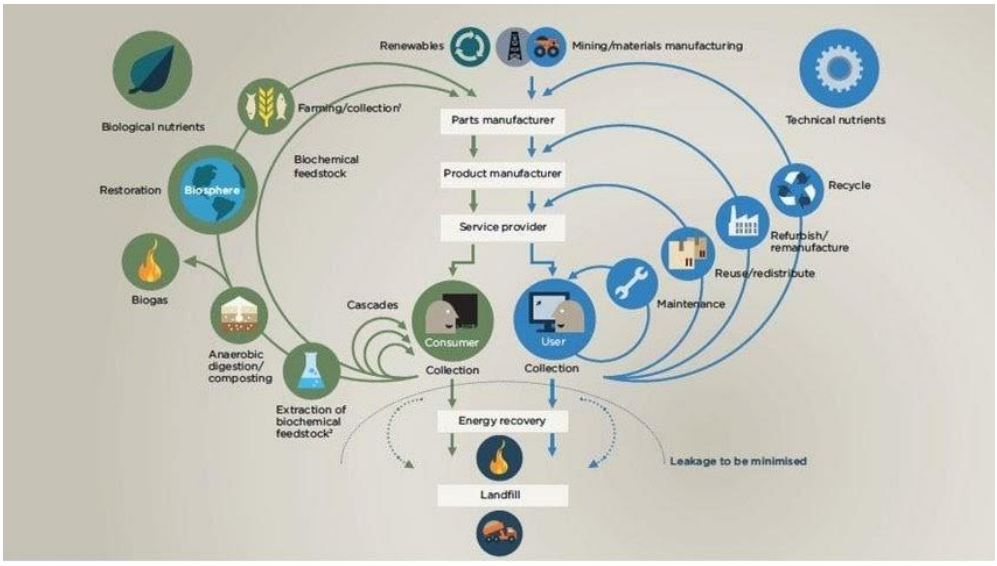
A number of key findings emerge from the literature. Firstly, plastic packaging waste is a global problem causing severe environmental degradation and is a major contributor to global warming. Ireland has a particularly concerning plastic waste issue with one of the highest rates in Europe. As plastic packaging makes up the highest percentage of waste produced in the country, it is imperative that policymakers are informed about technologies that can improve sustainability of Ireland's packaging system. Biodegradable bioplastics are considered as a promising tool for combating this issue and have preferable production benefits in a circular packaging economy when compared with their petroleum-based counterparts. The implementation of BBP has challenges when considering cost and waste management logistics, however, its prospects in contributing to a circular packaging economy means that its utility warrants further exploration.

The Waste Action Plan for a Circular Economy

When examining the Irish government's approach to a circular economy it's important to understand why circular economy is important and how packaging fits into it. The Ellen MacArthur Foundation explains that our industrial economy has moved to a liner model of resource consumption that follows a ‘take-make-dispose’ pattern. Companies harvest and extract materials, use them to manufacture a product, and sell the product to a consumer who then discards it when it no longer serves its purpose (MacArthur et al., 2013). This model is inherently unsustainable, and companies are increasingly noticing the linear

system increased exposure to risks, most notably higher resource prices and supply disruptions. With reliance on non-renewable resources and no plan for end-of-life regeneration market volatility increases and acceptances of excessive waste lends itself to the environmental crisis we are in today.

A circular economy, however, is an industrial system that is restorative or regenerative by intention and design (MacArthur et al., 2013). It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models. Many biodegradable bioplastics can be recycled but when it comes to their end-of-life treatment, they are able to fit into the circular economy concept due to their regenerative properties making them a renewable resource (Kakadellis and Harris, 2020). It is evident that most plastic packaging currently does not fit into the circular economy concept as even recyclable PBP's are limited in their recyclability and can often only be recycled
2-3 times before the quality of the material deteriorates beyond a point of reusability. This means that recyclable plastics can end up becoming waste (Antonopoulos, Faraca and Tonini, 2021). To further illustrate how the circular economy model works the diagram below gives an outline of how biological and technical nutrients can be sourced and collected for regeneration and restoration.



Source: The circular economy, an industrial system that is restorative by design (Ellen MacArthur, 2013).

The Irish Government published their five-year National waste policy plan on the 4th of September 2020. The document titled 'A Waste Action Plan for a Circular Economy' outlines their strategy for evolving Ireland's waste management systems. It expresses the governments dedication to the idea of a circular economy and explain that "In a circular economy, waste and resource use are

minimised; the value of products and materials is maintained for as long as possible through good design, durability and repair; and when a product has reached the end of its life, its parts are used again and again to create further useful products." A number of key policies are emphasised in the hopes of reducing Ireland's waste output. These measures include the introduction of a deposit and return scheme for plastic bottles and cans, a ban on certain single use plastics from July 2021, and a levy on disposable cups. The government is looking at applying green criteria and circular economy principles in all public procurement, a waste recovery levy to encourage recycling, and ensuring all packaging is reusable or recyclable by 2030. Minister Ryan says: 'Waste Action Plan for a Circular Economy' goes beyond the management of waste and addresses how we look at resources more broadly, capturing and maximising the value of materials that may in the past have been discarded.

The action plan also looks at how Ireland can better utilise waste to create useful resources. It defines end-of-waste as a process where material which is recovered or recycled from waste ceases to be waste. This end-of-waste concept has significant value because it allows for the creation of new products from the material and takes it out of the waste regulatory system. It therefore has a significant role to play as Ireland moves to a more circular economy by moving material up the waste hierarchy and extracting value from what would have been discarded previously. This process in turn helps meet recycling targets, facilitates use as a product and reduces pressure on waste infrastructure. A problem for the government's vision here is that there are no specific end-of-waste thresholds or deadlines set out in legislation. However, in recognition of the important role that end-of-waste can play in helping deliver on other targets, such as recycling, there is a commitment to improving the operation of this area. Like the reimagining of the end-of-life concept defined by Ellen MacArthur Foundation, end-of-waste shifts attention from how the likes of packaging is disposed towards how its use is reconfigured. All packaging should be thought of in this light when it comes to the circularity of BBP, the waste ceases to be waste when appropriate pathways are designed to give it a secondary use that feeds back into a closed-loop (Kawashima, Yagi and Kojima, 2019). Ireland is far away from this zero-waste system at present, but it is hoped that policies like the ones mentioned above will help make significant strides in that pursuit.

When examining the policies towards organic waste it points towards the EPA's estimates that correct use of the three household bins could reduce the volume of the general waste bin by a third, and that municipal recycling including organic waste for composting and anaerobic digestion through the organic bin rate could then be increased to 50% from 40%. It goes on to note that enhanced segregation by households and the commercial sector will be addressed as a matter of urgency. From this statement it is clear that the intention to increase the amount of waste that is compostable is a priority, however it is interesting to note that biodegradable materials are not mentioned at any point in this new

strategy. This may be an oversight as the literature on the use of biodegradable bioplastics indicate that they can have a positive role in contributing to a circular packaging economy. The bio-recycling of BBP is not only compatible with the sustainability goals outlined in the strategy document but the literature has shown that it has the potential to reduce dependency on PBP's while better utilising waste resources to create new value-adding products that are renewable (Shamsuyeva and Endres, 2021). To understand how BBP fits in a circular packaging economy, stakeholder perspectives can give insight into their role and how they can best be applied.

Stakeholder Perspectives & Analysis

To expand the knowledge base for how BBP fits into a circular economy a range of stakeholders were contacted. The following section looks at different stakeholder perspectives in Ireland with the hope that it can inform future policy recommendations.

Environmental perspective

One of the key perspectives in the implementation of BBP into a circular economy is the EPA. The EPA is already investing research into the potential of BBP use through their Biopost project. BioPost's aim is to develop sustainable environmentally friendly plastics to address the real-world problems of current plastics. The BioPost project will focus on using commercially available and indigenous novel biodegradable polymers and develop composites suitable for packaging applications and evaluate their end-of-life options; separation from mixed plastic waste, recyclability, compostability and biodegradability under standard industrial conditions. As the EPA is exploring BBP use in Ireland, hopefully more will be revealed about how it can be best implemented into a circular economy, and those findings can be used to build upon and adjust potential frameworks for incorporating BBP into a circular packaging economy (BioPost, 2021).

The EPA's 2013 STRIVE Report suggests that the scale up facilities to support widespread production of BBP is not developed in Ireland and this scale up is required to make BBP competitive in the market (Environmental Protection Agency, 2013). Their findings also suggest that a waste refinery in Ireland would enable universities and industry to come together to eco-innovate, which is a key objective of the eco-innovation action plan (Environmental Protection Agency, 2013). The need to invest in production facilities is a principal initiative that will drive the growth of BBP in Ireland. BBP should be produced in Ireland for them to truly act in a circular manner and to date Ireland is mainly reliant on imports of these materials. The EPA's Circular Economy Programme 2021-2027 notes that tight regulations need to be put on business to reduce waste and ensure that

industry outputs like packaging fit into circular economy principles (Environmental Protection Agency, 2021). For a circular packaging economy significant pressure must be applied to manufacturers and retailers to implement sustainable packaging practises be it through the removal of excess packaging or conversion to renewable materials.

Supplier perspective

Down2earth Materials are a major supplier of compostable packaging in Ireland and gave their input on the state of BBP and their use. Down2earth Materials is an Irish company that works alongside UK based Vegware to supply Irish business packaging products, food business, catering, and events all of which are fully customizable. Their packaging can be broken down within 90 days when commercially composted, which means they meet European biodegradability standards (Jõgi and Bhat 2020). They have expressed concern over the recent ban on certain single-use plastics including PLA plastics which are used in some of their products. They explained that removing sustainable alternatives will only increase the cost of compostable packaging for the consumer, as it will drive up demand for remaining products and therefore costs will increase.

The ban on certain single use plastics is in line with the government's focus on reusability and when it comes to a circular economy it can be argued that the notion of single use packaging is at odds with circular economy principles.
However, biodegradable PLA packaging which are sustainably sourced and can be industrially composted are not necessarily equivalent to other non-renewable petroleum plastics that are included in the ban. In particular, packaging that is used in food stalls require some form of packaging and packaging that have a secondary use like BBP can be desirable. An added benefit of BBP for food stalls and catering is that they can be disposed of in organic waste bin without the need for separation and cleaning while even recyclable takeaway packaging cannot. If food residue is left on recyclable packaging it can contaminate the material, which means it will be redirected into general waste disposal (Karayılan *et al.*, 2021). This is coupled with the issue that oftentimes there is little option for public food waste separation, which means that food packaging is put into general waste regardless of its recyclability. If organic waste bins are made easily accessible for consumers, they can put their food and packaging into organic bins together without the need for separation and cleaning.

Research perspective

Dr Kevin O'Connor from UCD's School of Biomolecular and Biomedical Science has spent time researching properties of biopolymers and has written extensively about biodegradable bioplastics and their utility. He provided some insight into what measures are necessary to reduce Ireland's Plastic waste issue and how BBP should be used in creating a more sustainable packaging system. One of the key messages he highlighted was that Ireland needs to prioritise ways of radically

reducing the amount of plastic we produce in order to tackle the plastic packaging waste issue. The unnecessary plastic that is used in packaging is a bad habit that is pervasive throughout society and all Irish companies need to reassess what plastics are necessary in their packaging. Tightening industry regulations should accelerate this process.

The necessity of looking at policies that improve consumer behaviours and their relationship to plastic packaging waste was also highlighted. This should be installed from early childhood education where children are taught to dispose of waste properly and to be more conscious about their consumption. Public awareness and education campaigns should be regularly promoted and the scale of said campaigns needs to be ramped up to ensure better community buy-in.
Finally in relation to BBP potential in creating a circular packaging economy, he supports the idea that BBP do fit into a circular economy as long as any products made from the soil make their way back into the soil. However, they should not be seen as a panacea for plastic pollution as his research findings suggest (Narancic *et al.*, 2018). If the system ensures that BBP does not end up in general waste and are appropriately composted, then they can contribute to a greener economy. It is also important to point out that BBP should not be treated as if they can be left in any environment to biodegrade, as there is a danger that public attitudes in support of such attitudes could lead to further packaging pollution (Neves et al. 2020). This reinforces the importance of education campaigns and clear labelling to ensure BBP are managed in appropriate collection pathways.

Government perspective

The Government Department in charge of a circular economy headed by Minister Ossian Smyth provided feedback on the use of BBP and their place in a circular economy. They pointed towards research from Eunomia and a separate scientific advisor group reports on biodegradability of bioplastics and found that they have a role to play in addressing the issue of plastic generation and waste. However, they may be best applied to specific items mainly food packaging (Group of Chief Scientific Advisors, 2020), (Eunomia, 2020). This point strengthens the notion that BBP should be considered in food retail and service industries. Some of these industries particularly in food stalls are already supplied with BBP by businesses like Down2earth Materials. The use of BBP can be targeted for further expansion for these industries. The department also explained that EU and Irish waste policy is grounded in the waste hierarchy, where prevention and reuse are the first actions for consideration before other options are evaluated. In this context, there is some concern that substitution with biodegradable plastics may impede the consideration of prevention and reuse. This hierarchy puts compostable materials like BBP lower down in the waste management hierarchy. However, biodegradable bioplastics can also be designed with reuse principles in

mind as many biodegradable bioplastics can also be mechanically recycled or returned through deposit schemes with their end-of-life management focusing on renewal (Shamsuyeva and Endres, 2021). The EU packaging directive is currently reviewing the role of compostables in the context of circular packaging and more advice on the use of these materials should be made available from their report.

A key concern that is flagged is the varying rates of biodegradability among bioplastics and the confusion that can cause from a perspective of waste management. The Rx3 programme highlights some of these issues and notes the importance that BBP conform to the EN13432 standard of compatibility (McGovern, 2013). As confusion over the biodegradability of bioplastic materials is persistent this may call for further review to ensure proper management of BBP from a consumer perspective. They're feedback concluded with the point that the management of BBP is complex and is a developing policy area. This means ongoing policy examination is required to understand how BBP can work in a circular economy.

Framework for Biodegradable Bioplastic Packaging in a Circular Packaging Economy

When building a framework for BBP use it is important to understand its position in a circular economy. A circular packaging economy involves reimagining the life cycle of materials in the pursuit of a zero-waste system. With biodegradable bioplastics there is an opportunity to increase the circularity of packaging products be it through mechanical recycling of biomaterials or the conversion of the end-of-life management towards regeneration. The source of these biomaterials also must be considered when formulating a framework that is sustainable. Biodegradable bioplastics can be sustainably sourced and may also be manufactured using biowaste from the agricultural industry and food waste from other industries like food retailers. To that end a model that looks to address food waste while adding to the circularity of products is worth exploring (Karayılan et al. 2021). A framework by which this is achievable involves the process of 'Food Waste Valorisation' (FWV). FWV is a process of reusing, recycling or composting waste materials and converting them into more useful products including materials, chemicals, fuels, or other sources of energy (Nzihou, 2010). FWV processes food waste or other waste products into raw materials that can be repurposed and manufactured into new products including BBP (Jõgi and Bhat 2020). As food waste is a primary concern in the 'Waste Action Plan' FWV may be an optimal opportunity to reduce food waste and plastic waste simultaneously.

Research suggests that FWV offers sustainable sources of high value-added products and large-scale production of bio-based products may be a necessary

investment to reduce the negative socioeconomic and environmental impacts of food waste (Esparza et al. 2020). As one of the limitations for the growth of BBP in the markets is the current manufacturing costs, utilising waste as raw materials through FWV can contribute to reduced production costs and an increase in BBP competitiveness as an alternative to PBP (Esparza et al. 2020). This model involves gathering food waste biomass from the agricultural industry or food retailers and transporting them to biomes conversion facilities known as biorefineries where the FWV process takes place. (Elmekawy et al. 2013). Biorefineries target the separation of all the added value from the biomass feedstock, with little or no waste. The aim is to lower the total environmental impact of producing biomaterials, besides improving the economic benefits so that these processes can contend with the petrochemical industry (Elmekawy et al. 2013). The cost effectiveness of such an approach requires the establishment of co-production streams with producers of waste from the agricultural industry and food retailers (Karan et al. 2019). Through effective FWV, the waste brought to biorefineries can be optimised to maximise its utility. For example, AgriChemWhey in Tipperary have recently invested in a biorefinery to make by-products from the dairy processing industry, using excess whey permeate (WP) and de-lactosed whey permeate (DLP) and convert them into cost competitive, sustainable lactic acid. This lactic acid can in turn be used to make value-added bio-based products including biodegradable bioplastics for packaging (AgriChemWhey, 2020).

Esparza's research suggests that when looking for an optimal waste management approach, it should consist of an adequate balance between conventional management methods like anaerobic digestion, composting and emerging valorisation technologies (Esparza et al. 2020). To this end when implementing a nationwide FWV system in Ireland, the process should be used as a tool to optimise the resources that can be gathered from food waste alongside the prioritisation of sustainable practices like anaerobic digestion and composting over landfill and incineration (Esparza et al. 2020). A framework for incorporating FWV manufacturing as a part of BBP production is as follows. Step 1: redirect food waste for FWV processing biorefinery facilities, Step 2: Separate usable biopolymers that can be used to create BBP, Step 3: direct waste that is not suitable for the creation of BBP to composting/anaerobic digestion facilities, Step 4: manufacture quality BBP with reuse in mind for the Irish market, Step 5: Ensure that BBP are labelled and are disposed of into appropriate pathways to be collected for either mechanical recycling or composting where biopolymer renewal can take place. This is a closed-loop system that is self-sustaining through its utility in renewing valuable biopolymers from food waste to create packaging that can be repurposed for agricultural use (Rivero et al. 2017). The framework is inline with best practises of low carbon waste management strategies and this 'waste into product' approach is seen as a key aspiration in a circular economy (Zorpas 2020). Public engagement and political investment is key to its success and careful consideration is needed to ensure it can remain

sustainable and cost-effective. The scaling up of BBP production should coincide with reduced dependency on PBP and alongside improved reuse and repair policies set out in the national waste action plan this model can contribute to development of a circular packaging economy.

Policy Recommendations

When moving towards a circular economy, BBP can provide a sustainable solution to the plastic packaging waste issue. BBP should not be viewed as all an encompassing solution to plastic waste but as a valuable tool that can be used in a transition towards a circular packaging economy. The model outlined above gives a framework for how BBP incorporation into a circular economy is achievable and further investigation into potential manufacturing and collection options would be beneficial for future policy considerations. The stakeholder perspectives gathered in this research highlighted the need for increased pressure on business to alter their packaging practises and consider methods of reducing unnecessary packaging. The findings also suggest BBP may be a preferable option in food packaging from a waste separation and renewal perspective. For BBP to be effective in a circular economy, pathways must be insured so that products that come from the soil return to the soil in a closed-loop system.

There are a number of challenges that will affect policy making relating to BBP. Firstly, the array of bioplastic materials on the market range in terms of biodegradability and conditions that are needed for biodegradation. This means that heavy market monitoring is required to understand the nuances between different materials, a focus on developing biopolymer blends that are well made reusable and have a high grade level of biodegradability (Gökçe, 2018). Cost is another concern for the effective movement towards BBP in a circular economy. Competing with PBP is a significant challenge due to their low manufacturing costs. Increasing the scale of investment into the production of BBP will be key to reducing manufacturing costs and effective utilisation of FWV means that waste biomass will supply the raw materials needed for its development. Finally, BBP's ability to contribute to a circular packaging economy demands public engagement with proper disposal pathways. If proper management of BBP is not adhered to, packaging will escape the closed-loop system. Policy strategies to improve public awareness of how to manage BBP appropriately will need development as the market size of these products increases.

Ireland's current national 'waste action plan' makes concrete actions on how to reduce plastic packaging waste with the implementation of deposit return schemes and the ban on certain single-use plastics, however it has not accounted for BBP and how they can be utilised in a circular packaging economy. The following policy recommendations should be considered for the future

implementation of BBP infrastructure to ensure that they remain compatible within a circular economy. (1) As the circularity of BBP is predicated on closed-loop management, robust disposal pathways that are easily accessible to the public must be invested in. This means an increase in the number of public organic waste bins and collection routes that reduce chances of littering or BBP diversion into general waste bins. (2) With the risk of improper consumer management of BBP improved labelling and instructions will be important for reducing BBP escaping the closed-loop management system. As research has shown that greenwashing of some products has led to consumers improperly disposing of non-biodegradable bioplastics into organic waste collection. It is therefore, necessary to develop stricter labelling requirements that clearly highlight the biodegradability of bioplastic packaging (Neves et al. 2020). (3) Renewed education campaigns should be considered to help consumers manage BBP properly and this can be integrated into broader messaging campaigns to educate the public about their role in the circular economy. (4) Due to the array of stakeholders and complex management chains, the oversight of BBP in a circular economy should be overseen by a state authority. Regulating the production, distribution and waste management needs to work fluidly. If there are too many competing private interests the system is at risk of becoming disjointed and ineffective. Top-down monitoring and communication with stakeholders will ensure that the BBP can be optimised to reduce plastic waste.

Conclusion

This research examined the utility of BBP in a circular packaging economy. The findings of the research suggest that although there are challenges regarding the cost of production and varying rates of biodegradability among different materials, BBP have a lower environmental impact than PBP and can be more conducive to a circular packaging economy. Stakeholder perspectives suggest that BBP should not be seen as a silver bullet for plastic packaging waste and may be more effectively applied in concentrated areas like the food packaging industry. BBP has additional environmental advantages as they can be sustainably sourced and can contribute to the circularity of packaging materials with the value-adding properties being renewed for agricultural use. A circular economy framework involving 'FWV' means that BBP can not only reduce plastic packaging waste but can also reduce food waste that is collected for BBP production. This closed-loop system allows for packaging materials that are made from the soil to return to the soil and can aid Ireland in its end-of-waste of waste goals. A circular packaging economy using BBP is a prospect that should be seriously considered by policymakers. Alongside other reuse and repair circular economy policies, BBP can contribute to the circularity of packaging while reducing the environmental damage caused by the widespread use of PBP.

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Bibliography

Acampora, H. *et al.* (2017) 'Presence of plastic litter in pellets from Great Cormorant (Phalacrocorax carbo) in Ireland', *Marine pollution bulletin*, 117(1-2), pp. 512–514.

Antonopoulos, I., Faraca, G. and Tonini, D. (2021) 'Recycling of post-consumer plastic packaging waste in the EU: Recovery rates, material flows, and barriers', *Waste Management*, 126, pp. 694–705.

AgriChemWhey (2020) *About ,* Available at: at: https:// www.agrichemwhey.com/about/ (Accessed: 12th July 2021).

BioPost (2021) *About ,* Available at: https://www.biopost.ie/ (Accessed: 10th August 2021).

Black, J, Holmes, D. and Carr, L. (2020) 'A Geography of Marine Plastics', *Irish geography: bulletin of the Geographical Society of Ireland*, 53(1), pp. 58–91.

Department of Communications, Climate Action and Environment (2020) *A Waste Action Plan for a Circular Economy Ireland's National Waste Policy 2020-2025*,29-31 Adelaide Road, Dublin 2,. pp. 1-89.

Dilkes-Hoffman, L. *et al.* (2019) 'Public attitudes towards bioplastics – knowledge, perception and end-of-life management', *Resources, Conservation and Recycling*, 151, pp. 1-8.

Elmekawy, A. *et al.* (2013) 'Valorization of cereal based biorefinery byproducts: reality and expectations', *Environmental science & technology*, 47(16), pp. 9014–9027.

Environmental Protection Agency, (2013) *Resource efficient Ireland – Biodegradable plastic from farm waste plastic*, Johnstown Castle, Co.Wexford, Ireland: Environmental Protection Agency. pp. 1-34.

Environmental Protection Agency (2018) *National Waste Statics: Summary Report for 2018* , Johnstown Castle Estate, County Wexford, Ireland: Environmental Protection Agency. pp. 1-54.

Environmental Protection Agency (2020) *Ireland's packaging recycling rates going in wrong direction says EPA,* Available at: https://www.epa.ie/news-releases/news-releases-2020/irelands-packaging-recycling-rates-going-in-wrong-direction-says-epa--.php (Accessed: 29th June 2021).

Environmental Protection Agency (2021) *Circular Economy Programme 2021-2027*, Johnstown Castle, Co.Wexford, Ireland: Environmental Protection Agency. pp. 1-13.

Esparza, I. *et al.* (2020) 'Fruit and vegetable waste management: Conventional and emerging approaches', *Journal of environmental management*, 265, pp. 1-18.

Eunomia, (2020) *Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy*, Publications Office of the European Union,: Eunomia. pp. 1-238.

European Bioplastics (2019) *Bioplastics market data 2019*, Marienstraße 19-20 10117 Berlin: European Bioplastics. pp. 1-4.

European Bioplastics (2020) *Bioplastics market data 2020*, Marienstraße 19-20 10117 Berlin: European Bioplastics. pp. 1-2.

Flieger, M. *et al.* (2003) 'Biodegradable plastics from renewable sources', *Folia microbiologica*, 48(1), pp. 27–44.

Gökçe, E. (2018) 'Rethinking sustainability: A research on starch based bioplastic', *Journal of sustainable construction materials and technologies*, 3(3), pp. 249–260.

Group of Chief Scientific Advisors (2020) *Biodegradability of Plastics in the Open Environment*, Publications Office of the European Union: European Commission. pp. 1-42.

Jariyasakoolroj, P., Leelaphiwat, P. and Harnkarnsujarit, N. (2020) 'Advances in research and development of bioplastic for food packaging', *Journal of the science of food and agriculture*, 100(14), pp. 5032–5045.

Jõgi, K. and Bhat, R. (2020) 'Valorization of food processing wastes and by-products for bioplastic production', *Sustainable Chemistry and Pharmacy*, 18, pp. 1-10.

Kawashima, N., Yagi, T. and Kojima, K. (2019) 'How do bioplastics and fossil-based plastics play in a circular economy?', *Macromolecular materials and engineering*, 304(9), pp. 1-14.

Kakadellis, S. and Harris, Z. M. (2020) 'Don't scrap the waste: The need for broader system boundaries in bioplastic food packaging life-cycle assessment – A critical review', *Journal of cleaner production*, 274, pp. 1-14.

Karan, H. *et al.* (2019) 'Green Bioplastics as Part of a Circular Bioeconomy', *Trends in plant science*, 24(3), pp. 237–249.

Karayılan, S. *et al.* (2021) 'Prospective evaluation of circular economy practices within plastic packaging value chain through optimization of life cycle impacts and circularity', *Resources, Conservation and Recycling*, 173, pp. 1-13.

Lamberti, F. M., Román-Ramírez, L. A. and Wood, J. (2020) 'Recycling of Bioplastics: Routes and Benefits', *Journal of polymers and the environment*, 28(10), pp. 2551–2571.

Laxmana Reddy, R, Sanjeevani Reddy, V. and Anusha Gupta, G. (2008) 'Study of Bio-plastics As Green & Sustainable Alternative to Plastics', *Website: ISSN*, 2250, p. 2459.

Lebreton, L. C. M. *et al.* (2017) 'River plastic emissions to the world's oceans', *Nature communications*, 8(1), pp. 1–10.

MacArthur, E. and Others (2013) 'Towards the circular economy', *Journal of Industrial Ecology*, 2, pp. 23–44.

McGovern C, Finegan J, Connolly l. (2013) *Bioplastics: Materials, Markets and Management*, Floor 2 Block 2, West Pier Business Campus, Dún Laoghaire, Co. Dublin.: Rx3.pp. 1-108.

Meade Farm Group (2021) *Irish potato starch,* Available at: *http://www.meadefarm.ie/irish-potato-starch* (Accessed: 17th June 2021).

Mortensen, L. F. *et al.* (2021) 'Plastics, the circular economy and Europe′ s environment-A priority for action'. Kongens Nytorv 6, 1050 Copenhagen, Denmark. European Environmental Agency. pp. 1-74.

Morrissey, A. J. and Phillips, P. S. (2007) 'Biodegradable municipal waste (BMW) management strategy in Ireland: A comparison with some key issues in the BMW strategy being adopted in England', *Resources, Conservation and Recycling*, 49(4), pp. 353–371.

Narancic, T. *et al.* (2018) 'Biodegradable Plastic Blends Create New Possibilities for End-of-Life Management of Plastics but They Are Not a Panacea for Plastic Pollution', *Environmental science & technology*, 52(18), pp. 10441–10452.

Neves, A. C. *et al.* (2020) 'Acceptability and Societal Impact of the Introduction of Bioplastics as Novel Environmentally Friendly Packaging Materials in Ireland', *Clean Technologies and Environmental Policy*, 2(1), pp. 127–143.

Nzihou, A. (2010) 'Toward the Valorization of Waste and Biomass', *Waste and Biomass Valorization*, 1(1), pp. 3–7.

Patrício Silva, A. L. *et al.* (2020) 'Rethinking and optimising plastic waste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment', *The Science of the total environment*, 742, pp. 1-6.

Piemonte, V. (2011) 'Bioplastic Wastes: The Best Final Disposition for Energy Saving', *Journal of polymers and the environment*, 19(4), pp. 988–994.

Rahman, M. H. and Bhoi, P. R. (2021) 'An overview of non-biodegradable bioplastics', *Journal of cleaner production*, 294, pp. 1-16.

Rivero, C. P. *et al.* (2017) '1 - Bioplastics From Solid Waste', in Wong, J. W.-C., Tyagi, R. D., and Pandey, A. (eds) *Current Developments in Biotechnology and Bioengineering*. Elsevier, pp. 1–26.

Shamsuddin, I. M. *et al.* (2017) 'Bioplastics as better alternative to petroplastics and their role in national sustainability: a review', *Advances in Bioscience and Bioengineering*, 5(4), pp. 63–70.

Shamsuyeva, M. and Endres, H.-J. (2021) 'Plastics in the context of the circular economy and sustainable plastics recycling: Comprehensive review on research development, standardization and market', *Composites Part C: Open Access*, 6, pp. 1-16.

Sidek, I. S. *et al.* (2019) 'Current development on bioplastics and its future prospects: An introductory review', *INWASCON Technology Magazine*, pp. 03–08.

Zorpas, A. A. (2020) 'Strategy development in the framework of waste management', *The Science of the total environment*, 716, pp. 1-13.