

Article

Acceptability and Societal Impact of the Introduction of Bioplastics as Novel Environmentally Friendly Packaging Materials in Ireland

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Received: 12 December 2019; Accepted: 2 March 2020; Published: 18 March 2020



Abstract: Novel environmentally friendly alternatives for packaging materials such as bioplastics are being developed to mitigate problems with petrochemical plastics but low acceptance of these bioplastics among consumers and others have delayed their adoption. Through a mixed method approach, this work aims to assess the factors contributing to the low adoption rates of bioplastics as a way to inform development of more highly accepted bioplastics. Stakeholders with a variety of links with the packaging/plastic industries were interviewed using a semi-structured interview approach and the results were analysed to discover recurrent themes and perceptions regarding packaging. From this thematic analysis, a survey was conducted to explore consumer opinion. The findings indicate that although the population is aware and interested in changing to environmentally friendly packaging, confusion exists as to what that means and what are the best ways to effect that change. The teenager group was identified as the most susceptible to be involved in the change. Frequently cited barriers to acceptance centred on separation of waste and access to correct waste bins. The characteristics likely to lead to a higher acceptance of novel bioplastics by composters were time of decomposition, small thickness, and possibility of being introduced in current processes of packaging preparation, among others.

Keywords: bioplastics; environmental packaging; acceptability of environmental technologies

1. Introduction

The environmental damage linked with the excessive use of single-use plastic in the packaging industry has created the need for the development of bioplastics that decompose rapidly into water, carbon dioxide and biomass [1,2].

The increase of consumer awareness of sustainability and pollution problems associated with high volumes of single-use plastic [3,4] in the packaging industry has led to a significant development of alternative plastics with higher biodegradability properties in the last decade [5]. Uptake of alternative materials by the packaging industry has been slow and it still uses and discards a great volume of single-use plastics with significant negative impact for both marine and terrestrial environments [2,6].

In Europe, it has been estimated that out of the three disposal streams (recycling, recovery, and landfill), up to 14% leakage of polymeric material has occurred into the wider environment [7]. The ultimate fate of these polymeric materials is yet unknown but it is already clear that fragmentation of these polymeric materials results in the generation of high volumes of micro-plastics [8]. There are

indications of large-scale and persistent marine contamination by these micro-plastic materials, with the impact of plasticizer leaching yet unknown [9]. Many of these polymeric materials have no obvious degradation pathway, so at the micro-/and macro- level, these plastic materials also present significant risks. All these impacts compound the detrimental aesthetic effects of plastic detritus in our oceans and our beaches [7].

The detrimental effects of a high volume of usage and the short life-cycle use of plastics are well summarised in the EU Communication on Plastics in a Circular Economy (European Commission, 2018), with particular attention to packaging material; this has led to the European Union's Plastic Strategy, aiming to ban single-use plastics by 2030 (European Commission, 2018) [10]. For this reason, in the last decade, the packaging and distribution industries have been exploring compostable/biodegradable materials as an alternative for the commonly used plastics [6].

In discussing bioplastics and biodegrading, it is important to draw clear distinctions between the terms. Work by Vert [11] sets out clear definitions around the areas of bio-related polymers. Biopolymer are polymeric materials, the precursors of which are derived from biomass sources (as tested for under CEN/TS 16137:2011). The term "biodegradable" entails that the material undergoes chain scission as a result of enzymatic processes resulting from the action of cells. This degradation is distinct from other environmental degradation processes such as scission by hydrolysis or abiotic enzymatic degradation. Ultimate biodegradation resulting in fully oxidised or reduced simple molecules differs significantly from processes of bio fragmentation, which result in problematic micro-plastic particles.

There are numerous examples of biopolymers which are not biodegradable (e.g., bio-PE and bioethanol-derived polypropylene) and counter examples of artificially derived polymers which do biodegrade (e.g., PCL/polycaprolactone). That being said, biodegradable biopolymers tend to exhibit more complete biodegradation as the metabolic pathways to break down their precursor materials frequently exist in the ecosystem [1].

The timeframe and conditions for biodegradation of materials vary and the current standard (EN 13432) sets out a broad range of conditions and a 12-week timeframe of degradation for a material to comply with the standard. Compostable and, indeed, home compostable materials are a subset of those covered by the EN 13432 and relate to the utility of the resulting compost material and the breakdown of the material at the lower temperatures normally encountered in a home compost environment.

Though the negative impacts of artificial polymers are becoming clearer, their attractiveness as a food packaging material arises from the beneficial properties of these materials including mechanical strength, optical clarity and low permeability to water vapour vapor oxygen and CO₂ [12]. Biodegradable biopolymers have historically struggled to match the performance of traditional petroleum-based polymer materials, particularly at the price point currently demanded for packaging material [13].

In looking at biopolymers, these can be broadly broken down into three groups [14]. The first group, the so-called "drop in" alternatives, which utilises plant oils or plant resins as a replacement of petrochemical-derived precursors [15], are the longest established. The two remaining groups comprise of protein-based biopolymers (e.g., collagen, soy isolate, whey protein) and polysaccharide-based biopolymers (starch, cellulose, pectin), which appear to be more advanced. Thermoplastic-like starches (TPS) are particularly attractive as they leverage existing thermoplastic processing technology and can be heat welded. Though cost-effective relative to many biopolymer materials, these TPS biopolymers are however significantly limited by their higher cost by comparison with their high volume petrochemical polymer competitors [5]. This higher economic cost and significant life-cycle cost is attributed in part to the high cost of feedstock materials and the costs associated with feedstock production. A potential solution to this challenge is the approach of valorising waste streams such as vegetable food waste to access lower cost and lower impact feedstock materials [16]. Despite the challenges of processing, the protein-based bioplastics do offer an interesting proposition as, by comparison with the starch-based biopolymers, protein-based materials and their natural network forming capability offer the possibility of improved mechanical performance in film applications [17].

Importantly these materials need not impact on current food stocks as a large tonnage of marine-harvested material is landed every year and, of this, some 14% output as by-product material going either to waste or low value-added product streams [16].

The sustainability of any biopolymer is a crucial question as these materials currently only constitute approximately 1% of the current yearly production of polymer material. Of this 1%, only 43.2% are biodegradable materials [18]. Therefore, production of biodegradable biopolymers represents only a small fraction of total polymer production within the EU and there are a limited number of players commercially active in the field. Current uptake of biodegradable polymers centres predominantly in its use as organic compost recovery bags. One commercially available material (MATER-Bi) produces grades of biodegradable biopolymer using a TPS material and industrially-compostable organic waste bags dominate production. Uptake of food packaging solutions by major UK retailers has only recently shown some increase in this segment [19].

Prior investigations into the slow adoption of biodegradable bioplastics have identified a number of frequently cited barriers to adoption [20]. Firstly, the cost of the production and cost of process migration to bioplastics needs to be low, in addition to the cost of transitioning to bioplastic packaging. Currently, with low production volumes and lack of competition within the sector, the production costs of bioplastics remain high. This coupled with high costs of input materials has made the transition to bioplastics unpalatable to many producers [21]. Secondly, increased consumers awareness is required to facilitate informed choice of environmentally friendly plastic packaging. Current recycling systems in Ireland are regarded as being cumbersome, with various instructions to the consumer of the preparation and separation of waste. This is thought to contribute to poor levels of compliance from the consumer and behaviours such as illegal dumping, burying and burning of plastics by the consumer instead of choosing to recycle [22]. A lack of clarity and understanding on the part of the consumer contributes to the contamination and degradation of the recycling waste stream [22]. This lack of an effective and intuitive recycling system leads to the frustration of the consumers when choosing environmentally friendly disposal options [22] and there is significant risk of new materials compounding this confusion and bioplastic contamination of the recycling waste stream.

The development of bioplastics is crucial for the future of the environment, but the application of this technology is at a critical stage. The opportunities for the application of this technology are vast, but for high impact, focused material development is required.

The aim of this study is to develop an understanding of stakeholder motivations and user behaviours so that we can identify specific characteristics and functions that will remove barriers to the adoption of bioplastics. Further work seeks to employ a concurrent design process that will ensure that the development of bioplastics increases material acceptance by packaging industries, retailers and consumers, and consequently will create a higher positive environmental impact.

2. Methodology

The study was conducted using a sequential exploratory mixed approach with a social constructivist outlook [23,24]. In this study, the quantitative phase was followed and was informed by the qualitative phase of the study. The findings from both phases were then integrated in the analysis and the qualitative phase took a design-led approach to data capture and analysis [25]. Issues of informed consent, anonymity and data management were managed in accordance with the institute's ethics policy.

Study design: The study was executed in six steps:

1. Iterative stakeholder mapping
2. Semi-structured interviews
3. Qualitative analysis through peer debriefing and affinity mapping
4. Design and deployment of quantitative survey instrument informed by the qualitative phase
5. Quantitative analysis

6. Combination of insights and triangulation of results

2.1. Iterative Stakeholder Mapping

1. Initial stakeholders identified through prior knowledge and literature review
2. Collaborative mapping with initial stakeholders to identify their stakeholders until no new stakeholders are uncovered at that level
3. Each stakeholder analysed in terms of their tasks, pains and gains with regards to a change in packaging materials

2.2. Semi-Structured Interviews

1. Thematic areas for enquiry identified from stakeholder mapping and interview candidates identified
2. Interviews conducted through a series of open questions and recorded through notetaking
3. Data analysis through peer debriefing and affinity mapping techniques

2.3. Survey Instrument

1. Instrument design and target cohort informed by qualitative study
2. Instrument piloted with a representative 10% of the target cohort and adjusted and validated
3. Survey was deployed using Google forms (Google LLC 2018, California, USA).

2.4. Statistical Analysis

The results were analysed by one-way or two-way analysis of variance (ANOVA) with a significance level of $p = 0.05$ when appropriate. Independent sample t -test and Tukey's multiple comparison tests were used, where applicable. The software employed for statistical analysis was Excel 2016 (Microsoft Excel 2016 MSO, California, USA) and SPSS Statistics (IBM SPSS Statistics 2015, New York, USA). Significant difference between gender and age group were assessed for all questions as well as significant difference between attitude towards waste separation at home and away from home.

3. Results and Discussion

3.1. Stakeholder Mapping

Iterative stakeholder mapping identified 6 thematic areas and, from these areas, 38 stakeholders were identified for interview (Table 1) regarding the characteristics and their red line issues with the acceptance and implementation of bioplastics as an alternative for single-use plastics as packaging material.

3.2. Interviews

Execution of interviews:

Interviews were conducted between January and March of 2019. Informed consent was secured at the outset of each interview. Of the 38 interviews, 34 were conducted face to face with 4 conducted over Skype. Interviews ranged from 30 to 45 min in duration. Contemporaneous notes were transcribed promptly following each interview. No interviews were terminated early nor was consent withdrawn in any instance.

Analysis of qualitative data was conducted through peer debriefing and affinity mapping. Cross tabulation of these resultant insights was grouped by stakeholders (Table 2) such that emergent themes could be identified.

Table 1. Detailed separation of the stakeholders interviewed within the groups selected at the touch point analysis.

Stakeholder Group	Number of Stakeholders Interviewed
Raw material/ plastic production and Packaging production	4 (of which 2 raw material/plastic production and 2 packaging production)
Retailers (Packaging handling, transport and storage)	12 (of which 2 are artisans, 4 and small/medium companies and 6 and large companies)
Consumer (Packaged product use and discarding)	10 (consumers across different age, gender and social group)
Packaging waste management and composting	5 (linked with both composting as with recycling)
Policy involvement	3 (of which 1 senator, 2 local politicians?)
Environmental activists and educators	4 (of which 3 members of an environmental group, 1 science and nature convenor)

Key Findings of qualitative analysis:

1. Confusion as a prevalent theme across all groups, leading to a lack of confidence which may in turn factor in to reported poor compliance.
2. Each group perceived barriers to adoption existing with other stakeholders and many of these cited barriers to adoption were based on assumption.
3. General desire or pressure to migrate to more sustainable packaging products with a broad recognition that the status quo cannot persist.
4. Lack of clarity regarding framework or structure to allow largescale migration to compostable material.
5. Packaging films were highlighted as the area with most positive potential and confusion of the current recycling stream was highlighted as a risk.
6. Uncertainty regarding technical barriers to entry centred on scalability and security of supply coupled with a recognition of high capital and process development costs associated with the adoption of a new material. Therefore, high confidence in material characterisation required.

3.3. Discussion of Qualitative Findings

Through the interview process, the theme of “confusion” emerged as a clear cross-cutting element across all stakeholder groups. This was seen from the perspective of consumers who are not clear where or how to discard package waste, upstream to the producers who are unclear as to user requirements and on to the waste management sector that deals with the result of that confusion. For instance, in the group of stakeholders from waste management and composting, the interviewees mentioned the difficulty of managing recycling and composting streams due to contamination by non-recyclable or non-compostable waste that consumers inadvertently introduce in the system. In respect to groups of stakeholders such as packaging producers and retailers, they mentioned that the confusion of the consumers influences their choice of utilizing or not different types of packaging. Both large and smaller companies notice that consumers try to make an effort to change to more environmentally friendly packaging but that the consumers often seem to prefer the most economic option, or the one packaged vs. non-packaged in some cases. This leaves the retailers and packaging producers uncertain of what does the consumer really prefers. When talking to people that are linked with the education of the population, such as environmental activist groups or an education convenor, they seem to be assured that the confusion of where and how to discard the waste is a major problem and one they try to focus on. The stakeholders in the policymaker groups also mentioned the confusion from industries and retailers in terms of the correct manner of complying with regulations and procedures. Although the presented results corroborate ones found in previous studies in European countries

in what concerns consumer confusion and behaviour [26,27], few studies have mentioned that this confusion is part of and influences all the other stakeholders.

Another common theme across some of the stakeholder groups is the lack of alternative environmentally friendly packaging that can fulfil the needs of their companies. That is linked with the fact that, although most commercially available hard plastics are recyclable, some products need to be packaged with thinner films. The majority of current commercially available plastic films are not recyclable or compostable. The compostable hard plastics and films commercially available might only be compostable under specific industrial conditions that do not satisfy the needs of the composting companies interviewed. Packaging some products with paper/cardboard packaging instead of plastic is also not suitable for some products with high moisture content, especially for food products. Moreover, there is a high level of confusion among the consumers if they should discard paper/cardboard packaging in the recycling or compostable bin. A bioplastic could work as a good alternative for the packaging of some of these products, but further work needs to be done on the development of bioplastics suitable for each product type, especially in terms of bioplastic films. Furthermore, by opting to develop bioplastic films instead of hard bioplastics, it would be possible to avoid confusion linked with hard plastics that are currently highly recyclable. For that reason, some stakeholders mentioned not having any environmentally friendly alternative to substitute the packaging of their products. The stakeholders interviewed in the packaging production group mentioned that it is fundamental that new alternative environmental packaging fits the currently-used production machines to some extent since completely changing their manufacturing process to suit the new alternative packaging materials will not be possible for economic reasons.

A further perceived barrier to acceptance centres around decomposition time in both industrial and domestic composting settings. With regards to the industrial decomposition of packaging material, the harmonised standard EN 13432 pertains and specifies controlled conditions for decomposition and a timeframe for both disintegration and decomposition. The interviews with industrial composter indicated that their strong preference would be for a material that disintegrates in a timeframe shorter than the 12 weeks specified in the standard and should be closer to the 8 weeks they find sufficient for their other input materials. It was of note here that their customer rejection of the compost material was subjective and based on the visual appearance of fragments within the compost of that material. As the EN 13432 standard has been developed through extensive testing, a design requirement to exceed the standard may be overambitious; however, consideration for the appearance of disintegration within an 8-week timescale may be attractive to the commercial compost sector.

Where the EN 13432 refers to the control conditions of industrial composting, home composting does not lend itself to standardisation in the same way and it is therefore unsurprising that standard development lags in this area. Though a harmonised standard may be some way off, some national standards exist, such as AS 5810-2010, which specifies lower temperatures and longer durations for disintegration and decomposition than those specified in the industrial composting scenario. In a European context, industry bodies such as European bioplastics, in collaboration with notified bodies (TUV), are driving the development of labelling [28] and standards around home composting, such as the "OK compost home" logo, and supporting test conditions developed on from the French standard NF T 51-800 [29].

Table 2. Key outcomes from the one-to-one interviews with stakeholders possibly involved with environmentally friendly packaged products.

Stakeholder Group		Key Points		
Raw material/ plastic production and Packaging production	Confusion about new directives	R&D working on alternatives and lack of alternatives to fit current machinery		Cost of production
Retailers (Packaging handling, transport and storage)	Confusion about new directives and confusion about what the consumers want	Lack of alternative that fit products necessity	Marketing of environmentally friendly packaged products to increase consumer purchase	Cost of packaging
Consumer (Packaged product use and discarding)	Confusion about how and where to separate their waste			Cost of product
Packaging waste management and composting	Confusion from consumers on how and where to separate their waste	Lack of alternative that decomposes with rest of compost		
Policy involvement	Confusion from companies about new directives			
Environmental activists and educators	Confusion from consumers on how and where to separate their waste		Marketing/influencers/education	

A misconception noticed in the interviews with consumers was their belief that the reason for the lack of environmentally friendly packaging is due to an unwillingness for the part of companies to invest in a more expensive package for their products with the fear of decreasing their profits. However, when this was discussed with the retailers and packaging producers, it was clear that both groups of stakeholders are willing to invest in slightly pricier environmentally friendly packaging since they believe that the change can be used as a marketing technique, increasing sales and recovering their investment. Moreover, retailers and packaging producers were aware that new European and Irish directives related to environment and sustainability might lead to stronger fines for non-compliant companies. Larger retailers also mentioned the possibility of starting the implementation of environmentally friendly packaging in their specialty range before the economic range of products since retailers have a higher profit margin in specialty range products that can more easily absorb the extra cost of novel environmentally friendly packaging.

From the interviews with people linked with environmental education, both the convener and the members of an environmental group, the target groups of consumers that would lead to a possible change of preference for bioplastic packaging were discussed. The teenage group (between 12 and 18 years old) were thought to be the most valuable group in the change for the consumption of products packaged with environmentally friendly packaging since they are environmentally conscious and will start having some economic power to purchasing products for themselves. Moreover, this group of consumers is easy to reach through schools and “influencers” such as public figures and social media for up-to-date environmental information. Furthermore, research has shown that children and teenagers with environmental knowledge have a high influence in household purchases and consumption characteristics [30].

3.4. Survey

Following the qualitative analysis, the consumer was identified as a pivotal group. The survey was designed to examine a number of key areas.

1. Consumer relationship with, and perceptions of, single-use packaging material
2. Perceptions and reported behaviours regarding the separation of waste
3. Perceptions and knowledge regarding onward waste management
4. Knowledge and attitudes around existing or potential biodegradable packaging solutions

There was a total of 215 respondents, 58.3% males and 41.7% females, between the ages of 18 and 65 years old. The survey was used to get a better understanding of the consumers' point of view in what concerns their relationship with packaging and waste management as well as consumers' knowledge about bioplastics (Figure 1).

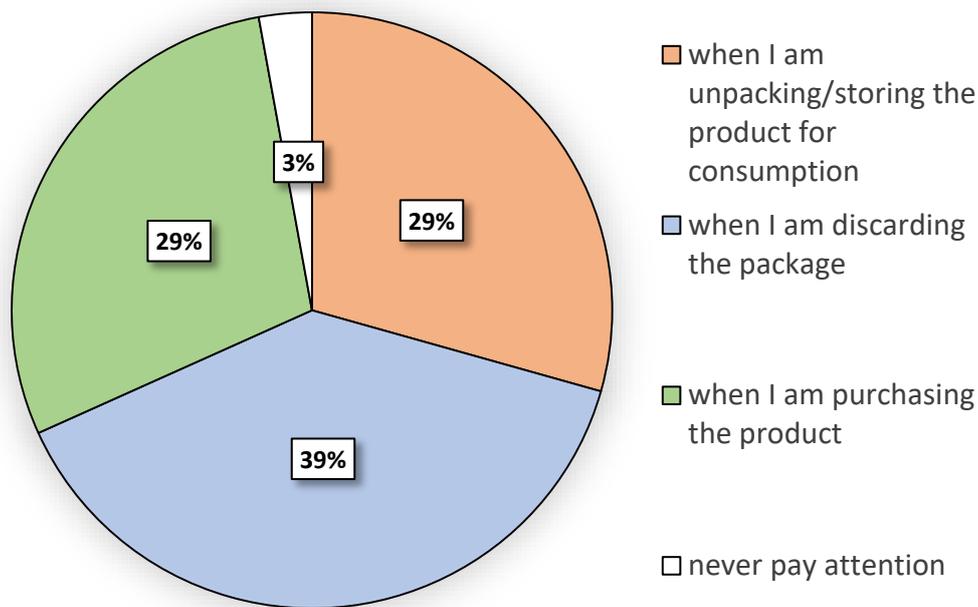


Figure 1. Percentage of responses to the question “When do you pay attention to the package of the products that you purchase?”. N = 215.

The first question asked was when consumers pay attention to the package of the products they purchase. Only 3% of the respondents said that they never pay attention to the packaging. That shows that the biggest percentage of the respondents were, to some extent, aware of the packaging of their products. However, only 29% of the respondents mentioned that they pay attention to the packaging of their products at the time of purchase. Additionally, 68% will pay attention to the packaging of their products after having purchased them, either when unpacking or storing the product (29%) or when discarding the packaging (39%). These findings corroborate the findings in the one-on-one interviews with the consumers, as it was mentioned in these interviews that often consumers pay attention to the packaging of the products they purchase only when trying to decide where to discard them. For this reason, it is important that the attention to packaging is shifted to the moment of purchase of products for a more effective replacement of single-use plastics in packaging to a bioplastic or other environmentally friendly alternative. Consumers will then have more power in their purchasing choices, being able to notice and opt for not purchasing products packaged with single-use plastics.

The next questions aimed to find out if consumers separate their waste and the difference in attitude when separating waste at home and away from home (Figure 2). In Ireland, home waste disposal is done by separating into three main bins: recycling, composting and general waste [31]. When asked if consumers separate their waste when they are at home, 57% of the respondents answered that they always separate the waste in the appropriate bin, 37% answered that they mostly separate the waste and only 5% answered that they seldom or never separate the waste in the appropriate bin. However, when the same question was asked but regarding the separation of waste away from home, only 28% of the respondents answered that they always separate their waste. Instead, 45% of the respondents said that they mostly separate the waste, and 23% said that they seldom separate their waste. The significant difference of the respondents that say they always and seldom separate their waste makes it clear that there is more work to be done in what concerns especially away-from-home waste separation.

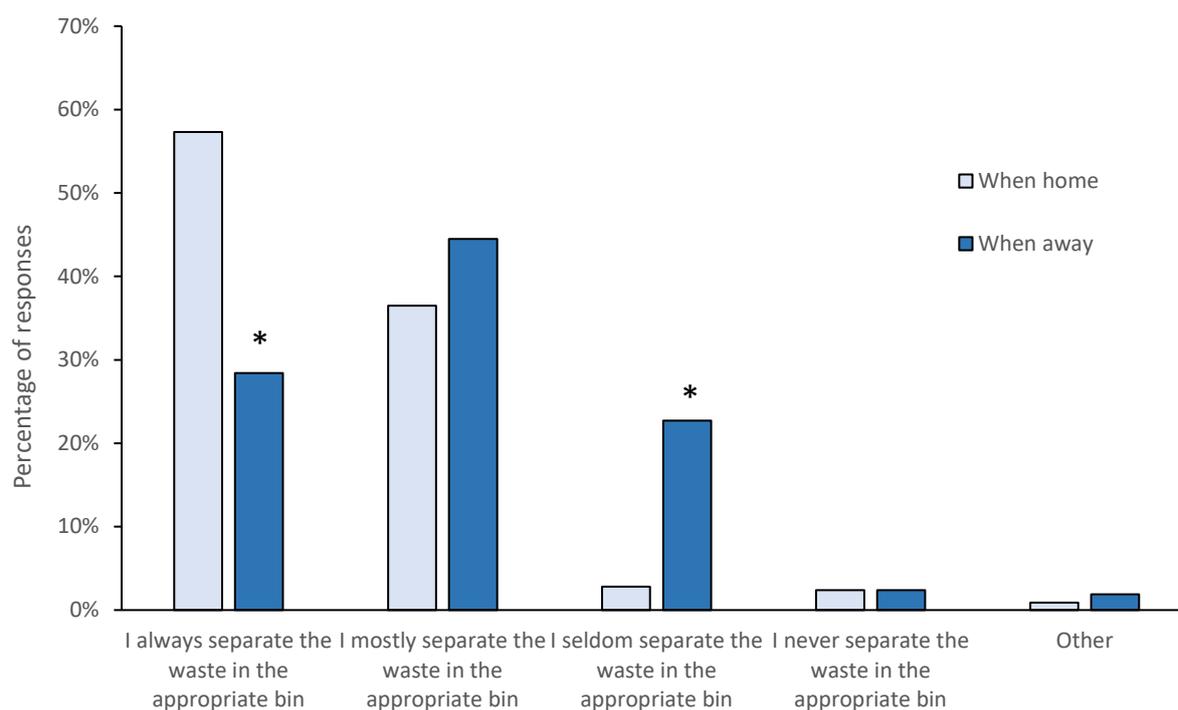


Figure 2. Percentage of responses to completing the phrases “When discarding a package at home” and “When discarding a package away from home”. N = 215. Values with * represent a significant difference for that answer between the attitude at home and away from home.

It is important to understand why some consumers choose not to separate their waste when at home and when away from home (Figure 3). Interestingly, 30.9% of the respondents that do not separate their waste do not do it because they were unclear of how or where to separate the waste. A similar percentage (27.5%) mentioned the same reasoning for not separating waste when away from home. When comparing the survey with the one-on-one interviews, this lack of understanding of the waste separation system seems to be noticed and mentioned by all the stakeholders. Stakeholders such as environmental groups are focusing their efforts on decreasing the lack of understanding in the population about where and how to separate their waste with education campaigns and pressuring policymakers to change to a clearer system. The consumers interviewed mentioned that one of the facts that creates confusion in terms of waste separation is the regional variance of what is recyclable and not. The biggest problem with regional variance is the plastic packaging since recycling of glass, metal and paper is relatively functional across the country, but plastic packaging often has labels that advise checking with the local waste management company to verify if a certain plastic package is recyclable or not. Moreover, this packaging usually is composed of plastic films which are, in their large majority, non-recyclable and need to be separated from other parts of the packaging that are recyclable. Separating properly the films from hard recyclable plastics is often challenging and consumers may choose to not separate them at all or leave pieces of film attached to the recyclable packages. That is highly detrimental to the recycling companies since these films contaminate the recycling system, wrapping around grinding machines or simply leading to the wrong identification of plastic type by the machines’ sensors. In an interview with a company responsible for recycling materials in Ireland, it was clear to understand that the percentage of plastic that is in fact recycled from the recycling bins could largely improve if there were fewer plastic film contamination. Moreover, a recent report from the EPA (Environmental Protection Agency in Ireland) reports that contamination of the household bins with the wrong separation of waste is still very high. Furthermore, it is reported that recyclable plastics, even when in the recyclable waste bin, are often not clean, dry or loose, which adds difficulty in the recycling process [32].

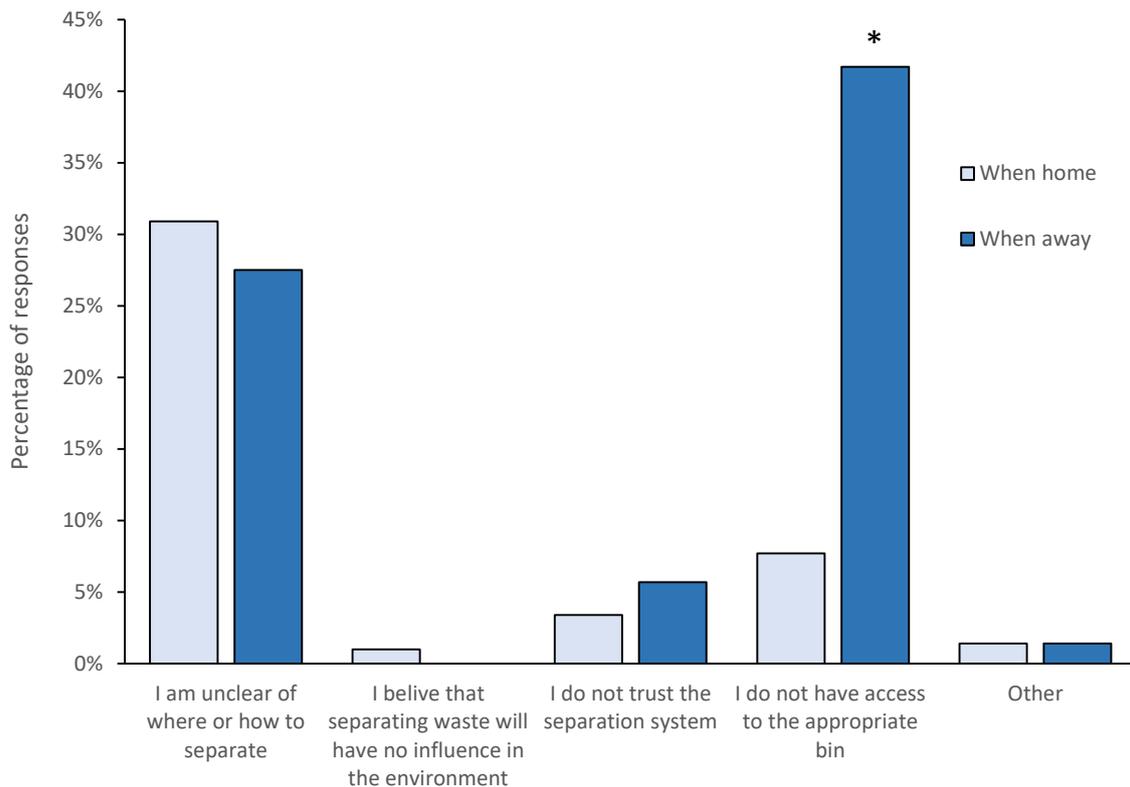


Figure 3. Percentage of responses to the questions “What are the reasons for not separating waste when at home into the appropriate bin?” and “What are the reasons for not separating waste when away from home into the appropriate bin?”. N = 215. Values with * represent a significant difference for that answer between the attitude at home and away from home.

Although small, there is also a percentage of respondents that either do not believe their effort will make a difference to the environment or do not believe in the separation system. From interviewing the consumers, it was possible to understand that the distrust in the system comes especially from a lack of understanding of how the system works paired with confusing information coming from social media and personal contacts.

When away from home, 41.7% of the responders mentioned that if they do not separate the waste, it is because they do not have access to the appropriate bin. This is significantly different from what happens when at home, with only 7% of the respondents mentioning this as the reason for not separating their waste correctly. This was mentioned during interviews with stakeholders such as consumers, environmental groups, educators and waste management and composting companies. In Ireland, it is difficult to have access to recycling, composting and general waste bins in public areas. Instead, it is common to find only general waste bins and they are often not visible or in low numbers. This can mean that, although there are already environmentally friendly alternatives, for example, on-the-go food such as recyclable and compostable containers, the majority of those still end up in landfill instead of in the appropriate waste management system. When away from home, and having on-the-go food, consumers have much easier access to general waste bins and only a very small percentage of consumers will save their containers to later discard them at home. In fact, from all our respondents and interviews, only one person mentioned doing that on some occasions when the container is not too dirty. For that reason, when developing new materials for packaging, it is important to know that there will not be a big impact in developing these materials for on-the-go foods as their main applicability until there is an increase in recycling and composting bins in the streets and public places.

The following questions tried to capture the understanding of the consumers about alternative environmentally friendly packaging alternatives such as bioplastics (Figure 4). Where assessing the respondent's knowledge about what raw materials are used in the formulation of bioplastics, 55.5% of them answered that they believed they were made of renewable raw materials. More than a quarter of the respondents did not know what kind of raw materials were used and 4.27% answered that they believed that bioplastics were made of non-renewable raw materials. Only 14.22% answered that they believed that bioplastics are made either of renewable or non-renewable raw materials. This is the correct answer to this question since for a plastic to be considered a bioplastic, it is not necessary that it is formulated with renewable raw material. There are petrol-based bioplastics that are considered as such because they are biodegradable. In terms of the respondents knowledge about the bioplastic degradability (Figure 5), the higher percentage of the respondents (33%) believe that bioplastics degrade completely under home composting conditions, 24% of the respondents believe that bioplastics degrade under industrial conditions, 20% of the respondents believe that bioplastics do not degrade completely but instead only into small pieces, 7% of the respondents answered that they fully degrade despite the conditions they are in and 4% believe that bioplastics do not biodegrade. This is, once more, a misconception from the part of most of the respondents since bioplastics do not need necessarily to completely biodegrade to be considered so. There were also 11% of the respondents that answered that they did not know about the degradability of the bioplastic. This again shows the level of confusion about novel alternative packaging materials that might influence the purchase and waste management choices of consumers even if they want to take the most environmentally friendly approaches in their product packaging choices.

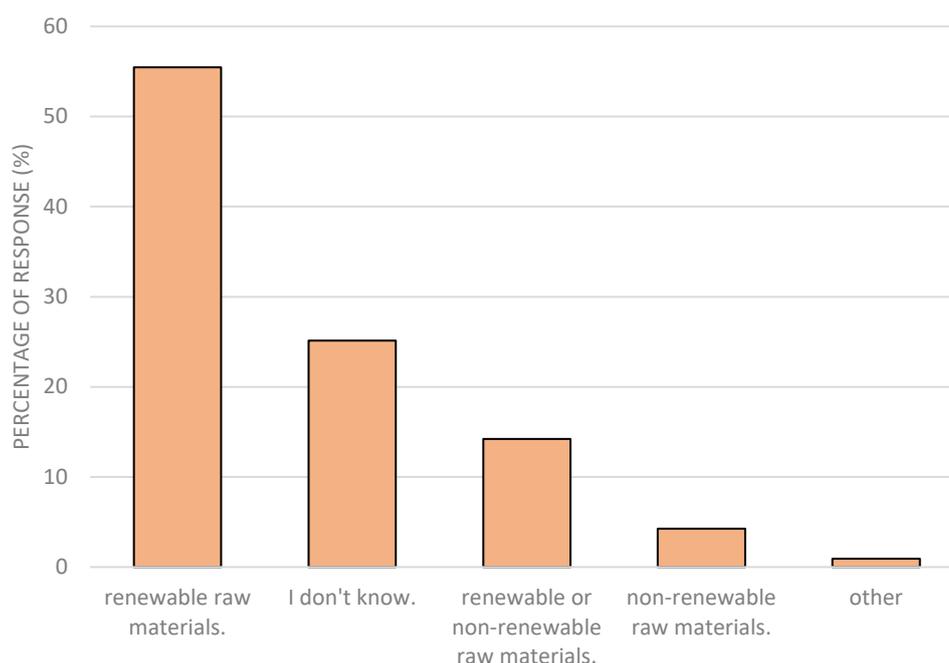


Figure 4. Percentage of responses to completion of phrase “I believe that a package made of bioplastic is made of a material coming from ...”. N = 215.

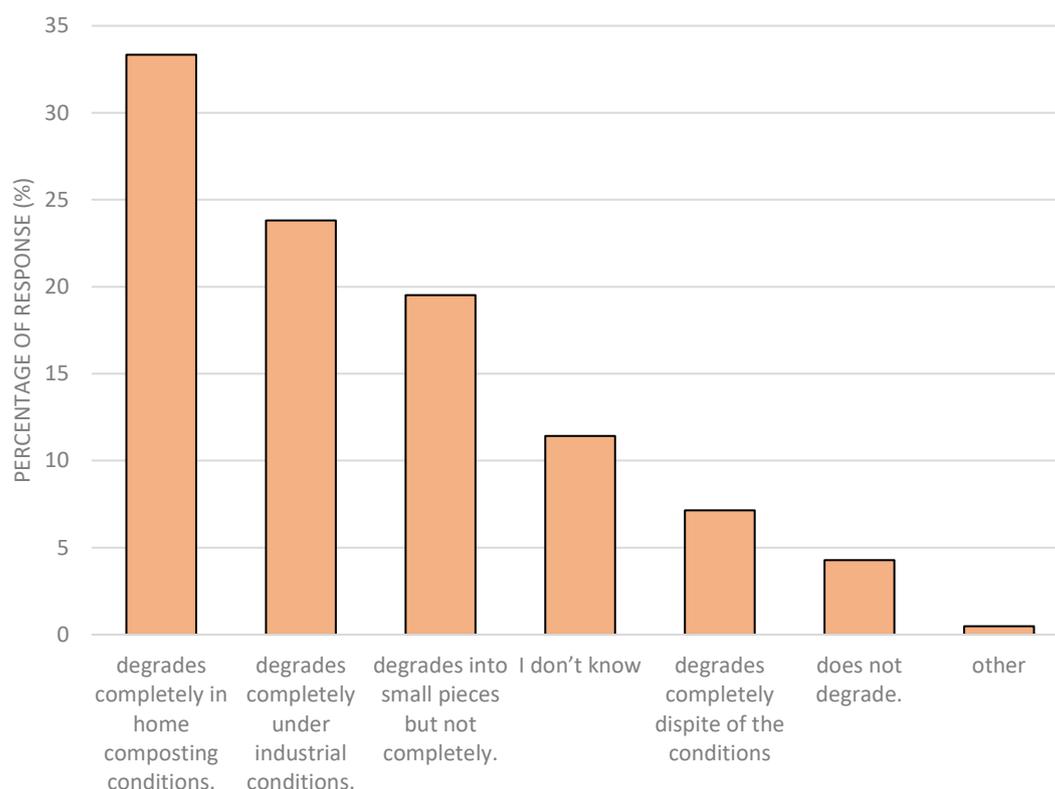


Figure 5. Percentage of responses to completion of phrase “I believe that a package made of bioplastic ...”. N = 215.

After interviews with the different stakeholders, especially retailers and packaging producers, it was clear that the characteristics of novel bioplastics to be used as environmentally friendly packaging materials need to be very different depending on the applicability intended for them. However, any significant change in the packaging industry needs to start with a specific packaging to further be adapted to fulfil other applications. The next question wanted to assess, from a consumer’s perspective, what would be the preferred applicability of the novel environmentally friendly packaging. It was asked what group of products, in the respondents’ opinions, they would immediately change the packaging of, if they could, for a more environmentally friendly packaging (Figure 6).

The fresh fruit and vegetable group was the preferred group for an immediate change, with 30% of the respondents choosing it. That urgency of replacing single-use plastic for a more environmentally friendly option seems to be clear across Europe, with increasingly more supermarkets changing the section of fresh fruits and vegetables into no-packaging zones [33]. There are, however, concerns about food waste, especially with fruits and vegetables that bruise easily, with a decrease in packaging [34]. On the other hand, there is still a significant number of fresh fruits and vegetables that do come with packaging with no reason other than commodity for the consumer [24]. Ideally, the single-use plastics in this section that is obsolete should be removed and, in case of impossibility, it should be replaced with recyclable or compostable alternatives.

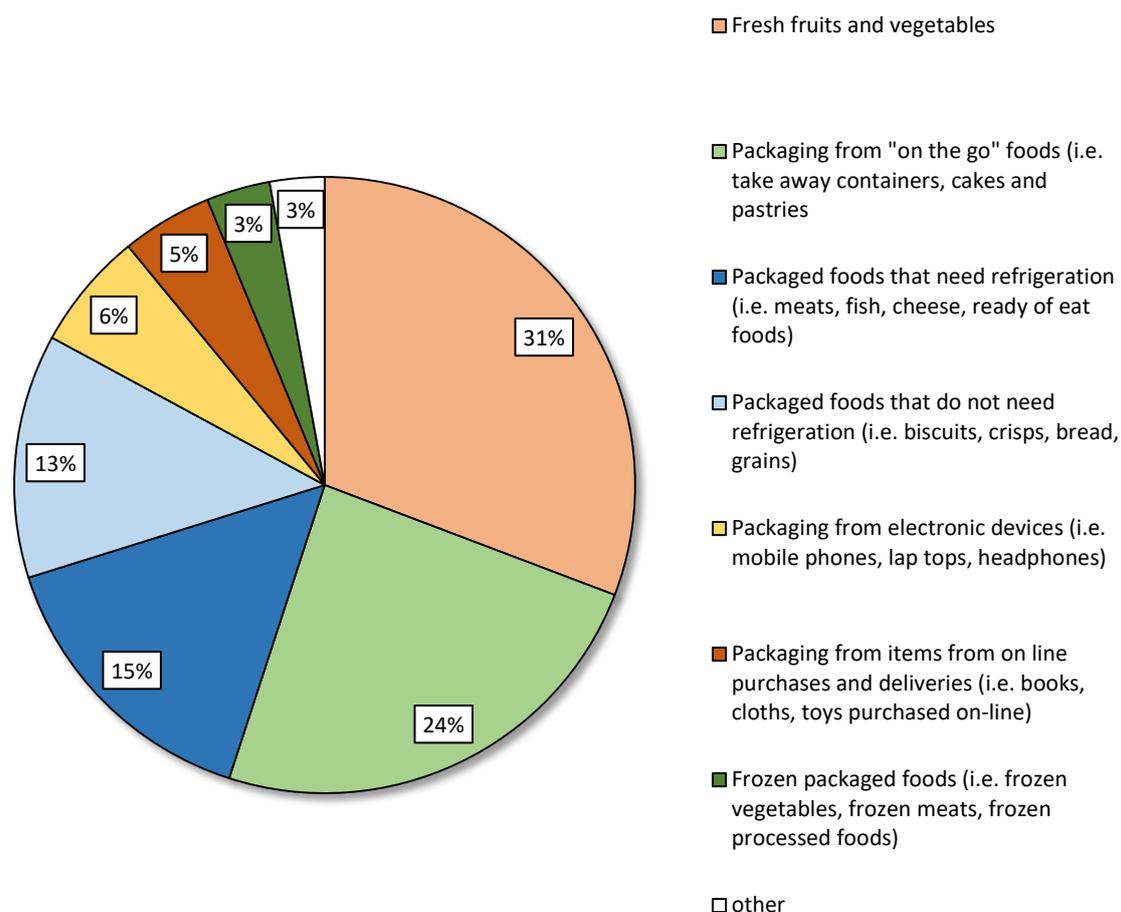


Figure 6. Percentage of responses to the completion of the phrase “If it was possible to change the packaging of one of the following groups of products immediately for a more environmentally friendly packaging, I think the top priority should be ...”. N = 215.

Packages for “on-the-go food” such as take away containers or cakes and pastry wraps were also seen as a priority for 24.2% of the respondents. We know from interviews with waste management companies, educators, environmental groups and consumers that, although there are compostable and recyclable alternatives to this group of products, which do not translate in a decrease of land field waste. The reason for that is the inaccessibility of waste separation bins when away from home, which makes those environmentally friendly alternatives for packaging for “on-the-go food” still end up in landfills. For that reason, there is a need to change policies that will incentivise towns to have more waste separation bins accessible to everyone to discard packaging on the go.

The next categories that are perceived as urgent to change were packaged foods that need refrigeration (such as meats, fish, cheese or ready to eat meals) and packaged foods that do not need refrigeration (such as biscuits, crisps, bread and grains). These groups were chosen as the most urgent to change for more environmentally friendly packaging by 15.2% and 12.8% of the respondents, respectively. Interestingly, frozen foods, often packaged in non-recyclable, non-compostable plastics, were only seen as a priority for 3.3% of the respondents.

With the increase of electronics accessibility (such as mobile phones, laptops or headphones) and the “over packaging” of many of them with non-recyclable, non-compostable plastic, 6.2% of the respondents chose this as the most urgent group of products that needed a change of packaging. In fact, studies have shown that the process of unpacking of electronics is considered satisfactory for many consumers and the marketing departments of many brands are using this moment to improve product satisfaction by making this process longer with the over-packaging their products [25]. For

the over-packaging of electronic materials to be reduced or replaced for better alternatives other than single-use plastic packaging, companies need to start realising the marketing value of making environmentally friendly choices.

The increase of online sales has led to an increase in the packaging of items that otherwise would not need to be packaged and excessive use of bubble wrap to protect them during transport and delivery. Items like clothes, books or toys from online purchases were considered a priority for 4.7% of the respondents.

It was also noticed that, particularly in this question, 2.8% of respondents felt the need to expressing their interest in all types of packages to change to more environmentally friendly packaging. In the choice of answer "Other", respondents gave answers such as "why not change them all?", "all of these groups of products should stop immediately to use single-use plastic for packaging", "I see an exaggeration of packaging in all these groups of products, so all of them should change", among other answers expressing the same idea of refusing to choose one and instead expressing their belief for the need of all of them changing to more environmentally friendly packaging of the products.

After analysing all responses in terms of gender and age group, it was possible to conclude that there were no significant differences between male and female respondents or between age groups for any of the questions.

4. Conclusions

Both strategies for understanding the acceptability of a potential novel bioplastic as an environmental material for the packaging industry in Ireland yielded corroborating conclusions.

Both interviews and surveys showed that the majority of stakeholders and consumers are open to, and agree with, the need to change the Irish packaging industry to a more environmentally friendly industry and the population shows an awareness of the consequences to the environment if the change does not happen. Moreover, there is still confusion associated with legislation and directives linked with single-use plastics, compostability and bioplastics, and confusion on how is the best way to do the abandon single-use plastics in the packaging industry, as well as how to discard packaging waste in the appropriate bin. A bit of distrust in the waste management system from the part of consumers was noticed in the survey and explained in the one-on-one interviews as being directly related to lack of understanding of the system.

The more effective group to lead the change in terms of habits of consumption and societal pressure are teenagers (between 12 and 18 years old), and the types of products that would be more realistic to start with would be specialty products with high profit margins. Companies are open to buying more expensive environmentally friendly products because they believe that this change will give them a marketing advantage and it will allow them to avoid non-compliance fees associated with new directives in use of single-use plastics.

It was also possible to conclude that there is still more work to be done in environmentally friendly materials such as bioplastics that will comply with the packaging necessities of many products, as well as the necessities of package processing and waste management industries. Some of the characteristics identified as fundamental for the acceptability to these industries are the thickness of the bioplastics, with thin films being preferred to hard plastics, time of degradability being no more than 8 weeks, and the possibility of being integrated into currently used packaging processes and machinery.

Another major finding in both the survey and interviews that explains low rates of packaging separations by consumers is the lack of access to waste separation bins in public places. For the 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.

Finally, the groups of products that are perceived as more urgently needing a change in packaging to a more environmentally friendly alternative are food, in particular vegetables, followed by "on-the-go" food packaging.

Overall, it is possible to identify specific problems and solutions for an impactful introduction of novel bioplastic materials to be used in the packaging industry in Ireland. However, further work needs to be done not only in the development of novel bioplastics but also in the design and branding of products using bioplastics to communicate to consumers effectively the plastic waste management strategy. Building on the work of European bioplastics, TUV Austria and others [28], novel bioplastics and their design and labelling should be standardized and incorporated into relevant legislation to ensure their success as packaging materials.

Author Contributions: Conceptualization, A.C.N., M.M.M. and B.P.C.; Methodology, A.C.N., M.M.M. and B.P.C.; Validation, A.C.N., M.M.M. and B.P.C.; Formal Analysis, A.C.N.; Investigation, A.C.N., M.M.M. and B.P.C.; Resources, A.C.N., M.M.M. and B.P.C.; Data Curation, A.C.N., M.M.M., C.E. and B.P.C.; Writing—Original Draft Preparation, A.C.N.; Writing—Review & Editing, A.C.N., M.M.M. and B.P.C.; Visualization, A.C.N., M.M.M., C.E. and B.P.C.; Supervision, A.C.N., M.M.M. and B.P.C.; Project Administration, A.C.N., M.M.M. and B.P.C.; Funding Acquisition, A.C.N., M.M.M. and B.P.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Science Foundation of Ireland Future Innovator Prize—Concept Phase grant number 18/FIP/3537 and the MDPI reviewer vouchers were used to cover the APC.

Conflicts of Interest: The authors declare no conflict of interest.

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