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ENVIRONMENTAL & ECONOMIC IMPLICATIONS OF BIOBASED PACKAGING

Sustainable Packaging Research Group

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Contents

Introduction

The main function of food packaging is to protect the product after harvest and extend shelf life for sale and consumption through chemical, biological or physical protection. In other words, these three functions can be summarized as protection, information to the customers and standardization for the producers and sellers (Santulli and Mastrolonardo 2021).

Current estimates suggest 37 per cent of packaging products are made from rigid and flexible plastics, which makes plastic the most used food packaging material (Rexam 2011). Global plastic waste generated in 2015 had packaging contributing about 50%. This figure has remained high with food packaging estimated to be more than a third of the world total packaging market (Ncube, Ude et al. 2021).

Despite the clear benefits plastic packaging brings in terms of reducing food losses and improving food security, plastic food packaging is produced and used in a manner that has substantial and increasing environmental and social costs. Plastic packaging that is produced from fossil-based or virgin sources is responsible for 10 per cent of global oil production (Ncube, Ude et al. 2021). In conjunction with plastic that is incinerated the production of plastics generates large greenhouse gas (GHG) emissions Zheng and Suh (2019) even before the well-established end of life issues when plastic packaging becomes waste.

The end of life for plastic often leads to marine plastic debris that has significant effects on oceanic wildlife and habitat and causes negative impacts on marine ecosystems. Recent studies estimate that 31 per cent of plastic in marine environments originate from food and beverage packaging (Jambeck, Geyer et al. 2015). Plastic pollution of the global marine environment is a major pervasive and long lived problem. It is estimated every year 8 million tonnes of plastic enter the ocean. This is equivalent to the contents of one garbage truck being emptied into the ocean every minute. The current trend suggests this quantity is expected to double by 2030 and quadruple by 2050 (Jambeck, Geyer et al. 2015). If this trend continues it will lead to more plastic by mass in the ocean than marine life by 2050. As a high proportion of waste plastic originating from plastic food and beverage packaging, considering the impact of food and beverage packaging on the marine environment is a key issue for the packaging industry and the environment (Moore, Gregorio et al. 2001). A recent study has suggested half of all ocean plastic waste originates as food packaging (Morales-Caselles, Viejo et al. 2021).

Bioplastic Food Packaging

An alternative to fossil fuel sources for plastic packaging is bio-based food packaging made out of biomass residues. Replacing fossil fuel sources for plastic production with biomass residues has two core advantages (Yuvaraj, Iyyappan et al. 2021):

- it breaks the link between food packaging and fossil fuel utilisation and can include composting disposal to generate soil conditioners to increase the organic material in soils
- Utilising agricultural by-products has environmental and economic benefits both directly and indirectly. Directly, using residues reduces the demand for ‘virgin’ or

primary biomass resources. Indirectly, using residues may result in higher revenues for the biomass generators, such as farmer and forest owners

Despite the considerable potential benefits of bioplastic food packaging, there are significant challenges and barriers to increase the uptake of bio-packaging including (Gerassimidou, Martin et al. 2021):

- Production costs of bio-based food packaging are currently substantially higher than fossil fuel based packaging.
- Lack of policies to support agricultural by-product biomass packaging can often mean regulations for bio-based materials with respect to food products are inappropriate and highly restrictive which can constrain new materials being developed and entering the market.
- Inappropriate or lack of composting facilities and systems prevent many of the benefits of bio-based and compostable food packaging from eventuating.

Primary and Secondary Biomass

There are two types of biomass, primary and secondary. Secondary biomass feedstock differ from primary biomass feedstock, as it is a by-product of the primary biomass feedstock, so secondary biomass feedstock is not grown specifically for the purpose of packaging as opposed to primary biomass feedstock. By-product streams from food, feed, fibre, wood, and materials processing plants are the main source of secondary biomass. Processing involves some form of physical or chemical treatment of the primary biomass and production of by-products. Secondary biomass is the focus of this paper (Santulli and Mastrolonardo 2021).

Social and Environmental Issues

Carbon neutral products

Bio-based products can be carbon neutral because as trees or plants grow they absorb carbon dioxide, and when they biodegrade they transform their carbon content back into the carbon dioxide sequestered previously during their development and growth. Due to this carbon cycle, there is no net loss or gain of carbon dioxide in the environment or atmosphere over the short period of time in which the material will be used (Marsh and Bugusu 2007).

This short term carbon cycle contrasts with materials made from fossil-based sources where the carbon is obtained from underground geological formations deposited millions of years previously. Subsequent biodegradation of these materials releases carbon dioxide into the environment that would not have been released otherwise. While the short-term, additional carbon released by bio-based materials does not add to the overall short term levels of CO_2 in the atmosphere, the geological carbon, released by fossil-based materials does add to an overall net increase in greenhouse gasses (Marsh and Bugusu 2007).

Food Security

A significant environmental issue related to bio-packaging is the use of agricultural land for growing biomass for industrial purposes with a resultant decrease in land available for food production. This can lead to decreased food security and a resultant increase in food prices.

However, this phenomenon is only applicable to primary biomass, as opposed to secondary biomass, as these sources do not displace food production, but rather use the by-products of agricultural production. Crops being grown for purposes other than food such as fuel, e.g. corn, has been the sources of considerable controversy and criticism, with these crops displacing crops intended for human consumption (U.S. Department of Energy 2016).

Air Pollution and other Environmental Issues

Crop and forestry by-products are frequently burnt for land clearing and pest control as this is often considered a cheap and easy method to dispose of the leftover crop residues after harvesting. In addition to releasing carbon dioxide, burning these residues emits other gases including sulphur dioxide (SO_2), oxides of nitrogen (NOx), carbon monoxide (CO), black carbon (BC), organic carbon (OC), methane (CH_4), volatile organic compounds (VOC), ozone (O3), and aerosols, which affect the global atmospheric chemistry and climate (Pan, Crowley et al. 2011, Satyendra, Singh et al. 2013). Consequently the use of agricultural by-product materials would prevent this pollution into the atmosphere. However, the utilisation of secondary biomass residues does raise some environmental issues, for example, transport distances of biomass residues may result in increased GHG emissions from transport. Despite such considerations, the overall environmental impact is likely to be reduced, for example if transport was powered by renewable energy and that residues would otherwise contribute to waste that need to be disposed or burnt, it would be beneficial if this waste streams is considered as a feedstock, rather than a waste stream (Santulli and Mastrolonardo 2021).

End-of-life scenarios

While making use of a waste material in the form of biomass has considerable advantages in terms of preventing extraction of fossil fuels and the associated greenhouse gases, the end-of-life scenario is also a critical stage with regards to the environmental impact and capturing any value. A significant advantage of bio-based materials over their virgin sourced equivalents is their potential to offer a wider range of end-of-life options. Theoretically there are two end of life options for bio-based packaging materials: recycling and composting (Yates and Barlow 2013).

Recycling and Composting

There are two main types of recycling, mechanical and chemical, while composting forms a separate category.

Recycling

Mechanical recycling involves processes that circulate plastics via mechanical processes (grinding, washing, separating, drying, re-granulating, compounding), without significantly changing the chemical structure of the material. Conversely chemical recycling involves processes that that break down plastics into their chemical components, which are then used to produce a new material (Davis and Song 2006).

In general, the more intact a material can stay while being circulated in the economy, the more desirable it is from a circular economy perspective as more embedded energy and labour is preserved. For example, as a rule of thumb, retaining the shape of the packaging (e.g. through reuse) is more desirable than grinding up the packaging (e.g. through mechanical recycling) which, in turn, is more desirable than breaking the packaging down into basic chemical components (Barlow and Morgan 2013).

Most of the common materials used in packaging (i.e. steel, aluminium, glass, paper, paperboard, plastics and wood) can be efficiently recovered by mechanical recycling; however, if packaging materials are mixed or contaminated with foods or other organic substances, physical recycling of these materials becomes essentially impossible and consequently not economically viable. In addition, some studies suggest consumers are less likely to place packaging materials contaminated with food remnants into a recycling bin. Should consumers place the material into a comingled bin, it is time intensive and costly to separate the food scraps from the packaging materials, leading to recycling of food packaging materials nearly always being uneconomic (Kale, Kijchavengkul et al. 2007).

Composting

Compostable, in the context of plastic, has a precisely defined term. It means that an item can break down into carbon dioxide, water, and biomass within a specific time frame and under specific, controlled conditions. 'Industrially compostable' and 'home compostable' are subsets of the term, which have internationally recognised standards. Home composting involves milder conditions (temperatures and pressures) in which the plastic still breaks down into biomass, CO_2 and water (Kale, Kijchavengkul et al. 2007).

Conversely, 'biodegradable' does not have a clear definition. It indicates that a material is able to be broken down into carbon dioxide, water, and biomass by the natural action of microorganisms — but the term by itself does not define how quickly this process will occur, or a specific set of conditions that are required. Consequently the poorly defined term biodegradable is not useful with respect to plastic end of life (Degli-Innocenti 2021).

According to the EN13432 standard, plastic packaging can only be called compostable if it is demonstrated that:

- The packaging material and its relevant organic components are naturally biodegradable
- Disintegration of the packaging material takes place in a composting process for organic waste
- The packaging material has no negative effect on the composting process
- The packaging material does not negatively influence the quality of the compost

In most of the certification cases, industrial composting means that materials will compost in an industrial plant, usually in the temperature range of 50-60°C, while home composting means that materials will compost under a much lower temperatures, in a compost facility at home. As most countries approximately 50 per cent of municipal solid waste is organic (garden and food waste and non-recyclable paper products), having composting facilities with appropriate infrastructure has the potential to halve the quantity of biomass disposed in landfill, which also lead to methane emissions (World Bank 2012).

Biomass Substitutes for food packaging

There are two main categories of bio-based alternatives for fossil-based materials suitable for food packaging can be made: fibre-based and bio-plastic materials each with its own specific characteristics.

Bio-based plastics

According to the Food Packaging Forum (2014), bio plastics emit less emissions coming from raw material extraction, and in most cases during the production process. Bio-based plastics, also referred to as bio-plastics, as plastics that are bio based, biodegradable or both. Three types of bio-plastics are defined (European Bioplastics 2015):

- Bio-based or partially bio-based on non-biodegradable plastics such as bio-based Polyethylene (PE), Polypropylene (PP) or Polyethylene terephthalate (PET)
- Plastics that are both bio-based and biodegradable, such as Polylactic Acid (PLA), and Polyhydroxyalkanoates (PHA) or Polybutylene Succinate (PBS)
- Plastics that are based on fossil resources and are biodegradable, such as Polybutylene adipate terephthalate (PBAT) (Pan, Farmahini-Farahani et al. 2016)

Fibre-based materials

Fibre-based materials belong to the second category of materials suitable for bio-based packaging. Paper and board are the most commonly used fibre-based packaging materials. More than 95 per cent of paper and board is made from wood, and the remaining sources are mainly agricultural residues, such as straw (of wheat, rye, barley, and rice), sugar cane bagasse, cotton, flax, bamboo, corn husks etc. (He, Chowdhury et al. 2019)

Structural Barriers for Bio-based food packaging products

While bio-based food packaging has the potential to improve environmental outcomes in theory by acting as a substitute fossil-based materials applied in food packaging there are considerable structural and institutional barriers to wide scale adoption of these materials. These include but are not limited to (Raźniewska 2022):

- Lack of supporting policies
- Inappropriate waste management facilities

Lack of Supporting Policies

Many countries that have policies to support a bio-economy sector focus on bio-energy, as opposed to bio-based products (Moshood, Nawanir et al. 2021). This is true for Australian with many state and federal polices to support waste to energy projects. An OECD report on bio plastics found out that lack of policy support places bio-plastics at a disadvantage in the competition for biomass (OECD 2013), in addition to other constraints for bio-based products. A lack of policy support for bio-based food packaging is shown by:

- None or poorly developed standards on bio-based packaging and food contact approval. Given the stricter standards placed on packaging with food contact, this places biomass plastics at an even greater disadvantage

- Confusing and misleading labels on bio-based and compostable food packaging
- Limited and incomplete information on biomass utilisation

Poor standards on bio-based materials and food contact

Bio-based packaging products need to compete with the currently cheaper fossil-based food packaging products. At present there are few standards for bio-based materials and food contact. A consequence of this is that safe bio-based materials are not allowed in food packaging, which is a significant barrier to the uptake of bio-based food packaging solutions (Ivonkovic, Zeljko et al. 2017).

Confusing labels on bio-based food packaging

To facilitate a more rapid transition to bio-based materials in the food-packaging sector, policies to improve the awareness of the benefits of bio-based materials compared to fossil-based materials are required. There are many different 'eco-labels' used globally, and definitions and procedures to identify goods as 'bio-based', 'renewable', reduced GHG impact' or 'compostable', which is confusing for both producers and consumers (Guillard, Gaucel et al. 2018).

Limited information on sustainable biomass utilisation

Access to relevant technical information on the use of agricultural by-products and their role in biomass packaging for policymakers, consumers and investor's is a significant challenge. A report by UNEP revealed that decision-makers and end-users of biomass waste streams usually lack information for selecting appropriate biomass waste conversion technologies (UNEP 2009). These reports highlight the limited knowledge base on consumption and production of bio-based materials. This is exacerbated by commercial in confidence issues on companies' production systems where they are not usually willing to release feedstock sources and costs (Birania, Kumar et al. 2022).

Inappropriate Waste Management Systems for bio-based packaging materials

To realise the benefits of the flexible end-of-life scenarios of bio-based and compostable food packaging, appropriate waste collection and composting systems must be in place. Better use of compostable materials will help to divert organic waste from landfills and incineration to organic recycling (Torrijos, Dopico et al. 2021). However, in most countries, no separate collection system for bio waste exists, though this is beginning to change. For example, numerous local governments in Australia are now providing a food organics and garden organics waste bin (FOGO) (Blue Environment 2020). In addition, most developing countries lack an industrial compost facility, or a landfill with energy recovering mechanisms. If such facilities exist, the capacity of composting facilities for bio-based products is often very low. Most of the existing composting facilities are not adapted to processing compostable packaging, due to limited capacity at the level of pre-processing. The unused global potential is estimated at about 100,000 million tonnes of bio waste annually, as a valuable bio-based resource and secondary raw material, in the EU only (EuropaBio 2015).

Costs and Benefits

While the qualitative costs and benefits of transitioning to bio-based packaging have been explored in the literature to some degree, fewer studies have attempted to quantify these costs and benefits

Social and Environmental Costs

Some studies that have attempted to quantify costs of fossil fuel based plastics have examined the costs due to the greenhouse gas emissions from plastic production of fossil-based plastics accounts for 10 per cent of the oil production. Across its lifecycle, plastic is responsible for generating 1.8 billion tonnes of GHG emissions a year (Zheng and Suh 2019). It is estimated the cost of GHG emissions from across the plastic lifecycle amounts to more than US$171 billion (DeWit, Burns et al. 2021)

A factor that is often not considered in establishing the environmental impact of plastics produced from of biomass residues in comparison with fossil fuel based in life cycle assessments is the respective destinations for biomass residues. While some LCA studies include biomass residues however, they do not allocate any environmental costs for the production of biomass residues. This is usually justified by the fact that waste materials would otherwise been unused (Santulli and Mastrolonardo 2021). However, other LCAs base allocation factors on the economic value of the biomass residues, compared to the main product with different allocation approaches can lead to very different LCA outcomes. In addition, most LCAs do not include the possibility of materials ending up as litter, and associated environmental impacts (WEF 2016).

As discussed previously, some studies indicate that 31 per cent of all plastic packaging ends up in the marine environment, implying that there is a significant chance for packaging material to end up as unmanaged waste in the environment (Jambeck, Geyer et al. 2015). Given this is the case, it would suggest most LCA outcomes do not fully capture a material's environmental impact at the end its life. Most importantly, such LCA conclusions do not describe the environmental advantages of a compostable material compared with a non-compostable material, when unmanaged in the land or marine environment (Santulli and Mastrolonardo 2021).

Financial Costs

In addition to the environmental costs and benefits associated with biomass plastics, numerous additional financial costs present barriers to their uptake, these include additional costs associated with utilising biomasses compared to fossil fuel sources, the cost of research and development and the additional costs imbued through a lack of economies of scale when compared to established fossil fuel based production systems.

Cost of Utilising Biomass Residues

As biomass is inherently produced in a dispersed area and often for only some periods of the year, this presents production challenges that traditional plastic production does not have. These include storage and transport issues unique to biomass residues (van Dam, Elbersen et al. 2014). Setting up a financially viable bio-based production chain from biomass residues to final bio based product is consequently different to traditional plastic production, can be more complicated and costly to establish than traditional plastic manufacturing (Awasthi, Sarsaiya et al. 2020).

Cost for Research and Development

Technological development leading to efficiencies in biotechnologies and biomass conversion will inevitably lead to cost savings in bio-based packaging. More specifically, biomass residues are usually more heterogeneous than virgin fossil fuel sourced feedstock. Consequently, innovations are needed to adapt and develop bioconversion technologies to new types of feedstock, or develop new technologies. Investment in production and R&D in the bio-based packaging sector requires a supportive policy framework, which provides a basis for continuing use, re-use and recycling of these materials (EuropaBio 2015). Until recently there has been a relatively low investment in research and development for technological innovation in relevant to bio-based materials derived from biomass residues applied in food packaging (Klein, Humpenöder et al. 2014), however there is evidence of an increasing trend in research and development in this field. Case studies on food and bio-packaging chains should identify the trade-offs between various value and supply chain participants, in order to improve the data on costs of food loss and waste, and quantify bio-packaging benefits (Birania, Kumar et al. 2022).

Lack of economies-of-scale

The current fossil fuel based plastic packaging industries have well established and efficient supply chains that are profitable and rely on low-priced fossil feedstocks. Plastic production companies are vertically integrated to coal, oil, and natural gas extraction and production and have economic ties to the extraction of these fossil resources (Wong 2010, Vermeulen, Niemann et al. 2016). In contrary to fossil-based materials, most bio-based plastic production firms and processes lack economies-of-scale which bring the cost advantages due to size, output, or scale in operation, with cost per unit of output generally decreasing with increasing scale as fixed costs are spread out over more units of output (van Dam, Elbersen et al. 2014).

Further Research

Given the lack of data regarding plastic packaging costs in the Australian market, an initial study to determine the baseline packaging costs is fundamental in order to establish what cost benchmarks biomass plastic is requirement to meet. Such a study should incorporate national data as well as local case studies to gain a full understanding of the costs involved.

It is clear there is limited understanding of the full environmental and economic benefits and costs of food packaging. In order to address this it is necessary to establish evidence on how better application of bio-based food packaging reduces food loss in an environmentally friendly manner.

Additional comprehensive and rigorous studies examining the environmental, economic and social costs and benefits of a packaging material are also required. Such evaluations would include assessment of biomass residues as a feedstock and inclusion of litter as an end-of-life possibility. There is also a need to overcome the technical barriers to bio-based food packaging derived from biomass residues and facilitate the benefits of compostable food packaging materials. Further research is required to determine the state of composting facilities in Australia and how they are fit for purpose including monetary flows of such facilities and systems. Ensuring composting is included in the waste system is particularly relevant for bio-based food packaging, as most materials contaminated with organic residues cannot be recycled, and can only be landfilled or incinerated. Both scenarios are less environmental, and most often also less economically favourable.

Conclusion

Food packaging serves a very important function in society to protect the product after harvest and extend shelf life for sale and consumption. However, much of this packaging is made from plastic which is the largest individual application of plastic (Ncube, Ude et al. 2021).

Despite the many benefits plastic packaging offers it is currently produced in a manner that generates substantial environmental and social costs with plastic packaging from fossil fuel based sources accounting for 6 per cent of global oil production with additional greenhouse gas (GHG) emissions from end of life issues when plastic packaging becomes waste Zheng and Suh (2019).

An alternative to fossil fuel sources for plastic packaging is bio-based food packaging made out of biomass residues. Replacing fossil fuel sources for plastic production with biomass residues has two core advantages: breaking the link between food packaging and fossil fuels, and utilising agricultural by-products to reduce demand for plastic from fossil fuel based sources. Despite the potential benefits there are some barriers including high production costs of bioplastic food packaging, lack of supporting policies and standards as well as a lack of composting facilities.

Plastic from secondary biomass sources (i.e. by-products) addresses several social and environmental issues including reducing greenhouse gas emissions while not affecting food security by displacing food crops. While there are some environmental issues with respect to possible increased transport emissions these are expected to be outweighed by other environmental benefits. As well as displacing fossil fuel sources the potential end of life benefits from recycling or composting increase the environmental and social benefits.

While the benefits of plastic from secondary biomass have been established, there are significant number of barriers for them to be widely adopted. These include a lack of supporting policies including poor standards for biomass plastics and food, confusing labels and a lack of information. Inappropriate waste management systems and facilities also limit the alternative end of life options and the associated benefits from composting.

Some attempts have been made to quantify the costs and benefits of transitioning to biomass plastics included economic benefits from reduced greenhouse gas emissions and lower levels of plastic waste in marine environments, however, these studies are high level and subject to uncertainty. Some studies have undertaken a life cycle assessment approach to establish these igures but these do not fully capture all the costs and benefits as they do not include different end of life options.

The financial costs associated with a transition to biomass plastics are significant and include higher costs of utilising Biomass sources, costs for Research and Development as well as a lack of economics of scale

These are significant issues and ones that require further research starting with establishing a baseline for fossil fuel packaging costs to determine what cost benchmarks biomass plastics must achieve. In addition, further research is required to establish the full environmental and economic costs and benefits of different end of life outcome and what waste systems can achieve through the inclusion of composting infrastructure.

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