Biobased plastics:
A sustainable alternative towards a circular economy?
Research paper

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i. Abstract

Plastic food packaging includes numerous benefits *e.g.*, low costs and flexibility in manufacturing, chemical resilience and a varied range of physical properties. This does not incentivise the industry to look for alternatives. However, plastics are posing a threat to the environment and human wellbeing. These drawbacks led the European Commission to establish the "EU action plan for the circular economy". One of the objectives is to ensure that all plastic packaging is recyclable and/or reusable by 2030. Biobased plastics are deemed to be a potential solution in the journey towards circularity in Europe. On the other hand, critical remarks have been made as well. Thus, the question rises whether biobased plastics are indeed a sustainable alternative to replace fossil-based plastics in a circular economy. Additionally, it is unclear what the overall effect of implementing biobased plastics on a large scale will be. This reveals a research gap, since no literature describes this phenomenon. It requires a holistic approach to define the impact of biobased plastics on a circular economy. Therefore, this research will apply the Triple Bottom Line concept as the research lens. A qualitative approach, comprising a literature review and semi-structured interviews was applied. It became evident that no clear conclusion can be drawn on whether biobased plastics are a sustainable alternative to achieve a circular economy.

ii. List of abbreviations

CE: Circular economy
CEN: European Standardisation Organisation
CH_4: Methane
EMF: Ellen MacArthur Foundation
GHG: Greenhouse gas
GMO: Genetic modified organisms
CO_2: Carbon dioxide
H_2O: Water
HD-PE: High density polyethylene
LCA: Life Cycle Assessment
LD-PE: Low density polyethylene
MCI: Material Circularity Indicator
O_2: Oxygen
PET: Polyethylene terephthalate
PLA: Poly lactic acid
PP: Polypropylene
TBL: Triple Bottom Line
UV: Ultraviolet

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1. Introduction and problem statement

Due to their versatility and unique properties, plastics are pivotal in our modern daily life and are applied widespread applications and industries, such as the food packaging industry. In Europe, 19.6 million tonnes of plastic are used as food packaging, which is 40% of the total demand. (Schweitzer et al., 2018) Benefits of plastic food packaging most importantly include the prolonged shelve life and quality of fresh produce ,which reduces food waste, and its contribution to consumer health and safety by protecting the products. Other advantages are for example low costs and flexibility in manufacturing, chemical resilience and a varied range of physical properties. These benefits amongst others, maintain the use of plastics in the food packaging industry. (Andrady and Neal, 2009) In contrast to these benefits, however, plastic food packaging has its drawbacks as well. In Europe, only 40% of the total amount of plastic food packaging waste is recycled. The remaining amount ends up in landfill and marine litter or is incinerated for energy recovery. These two end-of-life options both release toxins, poisonous components, greenhouse gases and microplastics (plastics smaller than 5 mm) during the breakdown and fragmentation of these plastics. This not only poses a threat to human wellbeing, but in particularly on the environment as well (European Commission, 2018[a]). This predominately "take-make-waste"-approach to waste management also caters to significant economic losses in the system. (European commission, 2015)

In 2015 the European Commission established the "*EU action plan for the circular economy*" In this plan, the drawbacks mentioned above where identified as the drivers to initiate a transition towards a circular economy in Europe. In 2017 the European Commission prepared a strategy, with the objective to ensure that all plastic packaging is either recyclable or reusable by 2030. (European Commission, 2018[b]) This trajectory forces companies and other stakeholders in the plastic packaging industry to innovate and find alternatives for the status quo, where fossil-based plastics are predominately used (Degnan, 2015). On 4 March 2019 released the '*Final Circular Economy package*'. Ten key documents in this package report on the implementation of the '*Circular Economy Action Plan*' from various perspectives. (European Commission, 2019) Four of these documents explicitly mention the importance of biobased plastics in a circular economy. However, none of these documents clarify the impact of the actions the EU will take to meet their circular goals. This is acknowledged by Crippa et al. (2019), who on behalf of the European Commission, wrote the document '*A circular economy for plastics*'. They state various knowledge gaps and barriers in implementing bioplastics and conclude that there is no specific EU-wide systemic approach to deploy biobased plastics. The association European Bioplastics, who represents the interests of around 70 companies in the European bioplastics value chain, took a clear stance on the '*Circular Economy Action Plan*'. They believe biobased plastics will create numerous opportunities stimulating circularity and agree upon their relevance therein. However, they opt for a homogenous approach in this transition in order to monitor impacts better, which is in line with the statement of Crippa and co-workers, as this is currently lacking in their opinion as well. (European Bioplastics, 2015)

A minute fraction (0.07%) of the total amount of plastic packaging in Europe is biobased and most of this fraction is used as food packaging. (European Bioplastics and Nova Institute, 2018) Since biobased plastics are derived from renewable biomass sources, are tackling the issue and usage of depleting fossil resources and mitigate environmental disadvantages, (Hottle et al., 2013) they are deemed to be a suitable solution in the journey towards circularity in Europe. On the other hand, critical remarks have been made regarding biobased plastics as well. There is a potential that its growing demand will create competition for food resources, which will result in the increase of food prices. (Lagaron and Lopez-Rubio, 2011). Another assumption made is that biobased plastics, will not contribute to solving the issue regarding landfill and marine litter, as they are not necessarily biodegradable and need specific conditions to degrade. (Adhikari et al., 2016) The lack of a sufficient waste management infrastructure of biobased plastics, is called out to be a drawback as well. (Iles and Martin, 2013).

Thus, at the moment it is not clear what the overall effect of implementing biobased plastics on a large scale will be on the transition towards circularity in Europe, as a unified view is lacking. This reveals a clear research gap, as there is no literature describing this phenomenon. Therefore, this research will mainly focus on the impacts of biobased plastics on a circular economy.

The research question is therefore: *To what extent are biobased plastics a sustainable alternative to achieve a circular economy in the European plastic food packaging industry?*

In order to answer the research question, five different sub-questions are formulated:

1. *What are occurring trends in the European food packaging industry?*
2. *What are the pros and cons of biobased plastics vs. conventional plastics in the food packaging industry?*
3. *What is the social impact of deploying biobased plastics for circularity in Europe?*
4. *What is the environmental impact of deploying biobased plastics for circularity in Europe?*
5. *What is the economic impact of deploying biobased plastics for circularity in Europe?*

The remainder of this report is divided in six sections. The next section (2) consists of the contextual background, which elaborates on the background of the concepts of circular economy and biobased plastics and consists of a literature review on these topics. Section 3 describes the theoretical background to place the concepts in theoretic context. The methodology is described in section 4. Section 5 describes the findings from the collected primary data, which is then followed by the discussion and conclusion in, respectively, section 6 and 7.

2. Contextual background

This section is divided into two parts. In the first part relevant definitions and background information regarding biobased plastics and circular economy will be explained and summed up. The second part of this section will give a critical review on both concepts and will explain how they relate to the plastic food packaging industry.

2.1 Definitions and background information

2.1.1 What are biobased plastics?

To understand the fundamentals of biobased plastics, several pieces of literature will be regarded. Chapter 11 of the textbook '*Food and Beverage Packaging Technology*', written by Song et al., (2011) is dedicated to bioplastics and serves as an overall guide through this entire research. The same applies for chapter 6 in the '*Kirk-Othmer Encyclopedia of Chemical Technology*'. This chapter written by Lackner (2015), provides a fundamental overview on bioplastics similar to the literature of Song. In addition to this, it extensively discusses the chemical composition of these plastics as well. The article of Vert and colleagues (2014) provides definitions of relevant terminology and articles written by European Bioplastics, support the foundation of this study as well.

Since fossil-based plastics, derived from non-renewable resources, are considered to be problematic nowadays, the interest of 'bioplastics' increased. (Chen, 2014) However, the term 'bioplastics' is ambiguous and often misused. 'Bioplastics', 'biodegradable' and 'biobased plastics' are often used interchangeably, which is not entirely correct. (Vert et al., 2014) Another cause of this ambiguous use is the rise of technologies enabling conventional plastics to be derived from renewable resources as well (Chen, 2014).

Bioplastics are not one specific material but include a variety of substances with a variation of properties and applications. They can be defined in three general groups, which are depicted in figure 1. All bioplastics are either (partly) biobased, biodegradable or both (European Bioplastics, 2017).

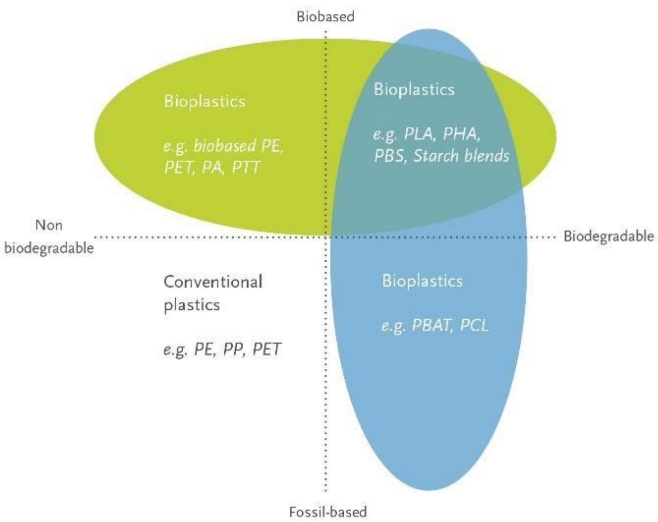

Figure 1: Overview of types of plastic based on resource and biodegradability

This research will focus on biobased plastics, both non-biodegradable as biodegradable. When referring to plastics derived from fossil-based material, term ‘conventional plastic’ will be used.

2.1.2 Biodegradable versus compostable

Biodegradable is the process of chemical breakdown of a material, into naturally occurring substances (water, carbon dioxide, methane or biomass), by the enzymatic action of living organisms such as fungi, algae or bacteria, without causing harm to its ecological environment. Biobased plastics are not necessarily biodegradable as biodegradation is not linked to the resource of the material, but to its chemical composition. (Focht, 2014). Biodegradation includes the cleavage of hydrolytically sensitive bonds, which causes the plastic to break down. These liable bonds consisting of functional groups such as esters and amides, break down in the presence of water and suitable reaction conditions. Hydrolytically sensitive bonds are present in all biodegradable biobased plastics (Gómez and Michel, 2013).

Biodegradation can occur in either aerobic or anaerobic conditions. Aerobic biodegradation takes places in the presence of oxygen (O_2) and releases carbon dioxide (CO_2). With absence of oxygen anaerobic biodegradation occurs and methane (CH_4) is released instead of CO_2. Both alternatives form water (H_2O) (Leja and Lewandowicz, 2010).

The mechanism of biodegradation involves two general steps. During the first step the polymer undergoes chemical (e.g. UV-irradiation, pH), thermal or mechanical degradation. This phase enhances the rate of biodegradation as it increases the reaction surface of the polymer exposed to microorganisms. The second step solely consists of the microorganisms attacking and digesting the polymer. These organisms release enzymes that react with the liable bonds mentioned earlier on. Both steps occur simultaneously. The process is finished when all the carbon is converted into CO_2. The reaction pathways are depicted in figure 2 (Künkel et al., 2016).

Aerobic biodegradation:

$$\text{Polymer} + O_2 \rightarrow CO_2 + H_2O + \text{biomass} + \text{residue(s)} \qquad (1)$$

Anaerobic biodegradation:

$$\text{Polymer} \rightarrow CO_2 + CH_4 + H_2O + \text{biomass} + \text{residue(s)} \qquad (2)$$

Figure 2: Reaction pathway aerobic biodegradation (1) and anaerobic biodegradation (2)

Compostable biobased plastics contain the same molecular characteristics as biodegradable plastics and the processes are similar. However, the terms ‘biodegradable’ and ‘compostable’ are not the same. Biodegradation is a natural process. In contrast to composting, which is a human driven and controlled process and needs to be finalized within the timeframe of 6 to 12 weeks (Avella et al., 2001). Specific conditions are applied to properly maintain this process. First of all, aerobic conditions are essential in this process, as aerobe organisms (organism that survive in oxygenated environment) initiate and continue the process of composting. Oxygen levels should stay above 18% throughout the mixture, thus continued ventilation or rotating is necessary. Since microbial activity is temperature dependent, this is a factor that needs to be maintained as well. Microbial activity is at its optimum between 30°C and 55°C, depending on the species. Within the optimum range, microbes consume oxygen most efficiently which optimizes the composting process. The optimum pH-level for composting is between 5.5 and 8, again depending on the species utilized. The content of moisture should be monitored closely too but depends rather on the particle size of the material. All these factors should be fine-tuned to one another in order to sustain the composting process. (Bertoldi et al., 1982) These conditions are needed for both industrial composting as home composting.

In order for biobased plastic food packaging to be classified as compostable, it has to meet the EN 13432 standard set by the European Standardisation Organisation (CEN). If a material meets this standard, it can be labelled with several logos, which are depicted in figure 3, verifying its certification. These labels aid to better waste management and for recognition of compostable materials by consumers. (European Bioplastics, 2019)

Figure 3: Compostable certification logos. From left to right: "The seedling", "DIN-Geprüft Industrial Compostable", "OK compostable"

2.1.3 Biobased plastics vs conventional plastics in the European food packaging industry

As elaborated on in section 1, plastic food packaging serves to protect the product in order to maintain its quality. The vast majority (99,9%) of this material is made from conventional plastics. Although 30 different plastics are used as food packaging (Lau and Wong 2000), the most common types are low-density and high-density polyethylene (shorted by LD-PE and HD-PE respectively), polyethylene terephthalate (PET) and polypropylene (PP) (Marsh and Bugusu, 2007). These plastics all have a biobased nonbiodegradable counterpart, with identical molecular structures. Figure 4 shows their monomer, which is the building block of the plastic.

These plastics have different characteristics when looked at performance. therefore, it is important to take the gas and water barrier properties and the product to be packed into account, when choosing the material. In general, these properties are sufficient enough, in order for the packaging to serve its purpose (Lange and Wyser, 2003) In contrast to this, biodegradable materials do not fulfil these requirements. Poly lactic acid (PLA), depicted in figure 4, and cellulose are the most common biodegradable materials used as food packaging. In its pure form, these materials are brittle, not heat resistant, and have low gas and water barrier properties. Therefore, chemical additives are often processed into this polymer when applied as food packaging, in order for it to correspond to the expectations of the market. This affects the sustainability of the material. (Rhim et al., 2009)

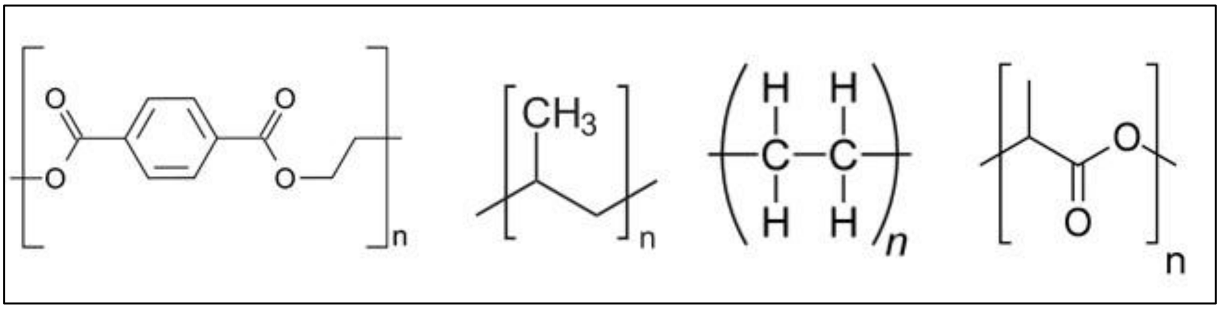

Figure 4: Several monomers, from left to right: polyethylene terephthalate, polypropylene, polyethylene, lactic acid

2.1.4 Circular economy

The article, '*Towards the Circular Economy: Economic and business rationale for accelerated transition*' by the Ellen MacArthur Foundation (EMF) (2013), elaborates on the essentials needed in a circular economy and describes its potential throughout Europe.

The EMF defines a circular economy (CE) as "a framework for an economy that is restorative and regenerative by design". In a circular economy material cycles are closed in order to retain the value as much as possible. In natural ecosystems there is no waste, as all residual streams are used as resource. (Ellen MacArthur Foundation, 2017) Circular economy is often simply referred to as 'circularity' and is a more sustainable alternative, to the traditional linear economy. In a linear model, one adopts the 'take-make-waste' approach where resources are extracted from nature, then applied in products and are subsequently disposed, without retrieving the utilized resources again. They generally end up as landfill or are incinerated. In contrast, the circular economy applies the 'reduce, reuse and recycle'-approach and uses concepts from living systems. In this way resources are utilized to the fullest extent, mimicking the continuous cycles within natural ecosystems. (Ellen Macarthur Foundation, 2013) According to Ghiselline and co-workers (2015), CE has to be seen as a new business model, with the potential to enhance sustainable development if all stakeholders in the system collaborate, as they influence one another. To achieve sustainable development, environmental, economic and social aspects are required to be balanced and considered equally.

Figure 5 shows a diagram, created by The Ellen MacArthur Foundation, visualizing how the biological and technical cycles come together in one system in the circular economy.

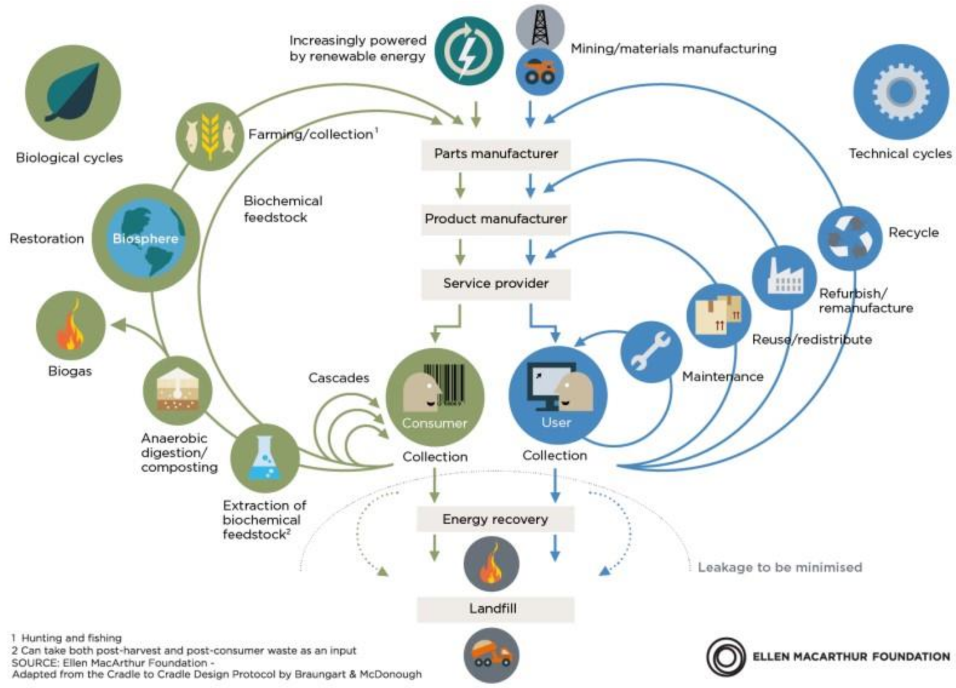

Figure 5: Circular economy systems diagram

In 2015, the EMF were the first to establish circularity indicators to aid in the assessment of circularity. (Ellen MacArthur Foundation, 2015) Based on this, they developed the Material Circularity Indicator (MCI) index, which focusses on the restoration of material flows. The indicators in this method are based on four principles:

1. using feedstock from reused or recycled sources
2. reusing components or recycling materials after the use of the product
3. keeping products in use longer (e.g., by reuse/redistribution)
4. making more intensive use of products (e.g. via service or performance models)

Since there is no legal standardization developed for the circular economy, many entities refer to this index in relation to circularity assessments.

2.2 Literature review

The concept of sustainable biobased plastics is widely studied. In general, the literature highlights the potential of biobased plastics in the transition towards sustainability from various perspectives. This literature review will not be a summary of all research on this topic, but a sampling of relevant research for this research project.

2.2.1 Environmental impact of deploying biobased plastics

Biobased materials are completely or partially derived from biomass e.g. sugarcane, corn, wood or and other renewable resources (Vert et al., 2014). This leads to a few environmental advantages and disadvantages over conventional plastics.

An advantage of the use of biobased plastics is the reduction of CO_2-emission. CO_2 is sequestered from the air by growing plants. The carbon footprint of the production process depends on whether the CO_2 is permanently sequestered in the synthesized plastic. If biobased plastics are recycled mechanically, the CO_2 obtained from the air stays sequestered permanently. This is always the case for non-biodegradable biobased plastics. When biodegradable biobased plastics degrade into CO_2 and H_2O, the sequestration is consequently reversed. (Chen, 2014) The critical remark has to be made, that when the demand of biobased plastics will rise, more land will be needed to grow these. This can possibly increase the deforestation rate of rainforests, cancelling out the reduction of carbon emissions, as rainforests are effective in sequestration of CO2. Moreover, fossil-based energy is primarily used in the production process of biobased plastics, which also adds to carbon emissions. (Mülhaupt, 2013)

Next to this, it is assumed that biodegradable plastics have the potential to reduce permanent plastic litter. However, the rate of biodegradation is varying in different surroundings and depends on the chemical make-up of the polymer (see section 2.1.1.2). Often it does not degrade at all. This make the statement on reducing permanent litter debatable. (UNEP, 2015) Moreover, additives are often incorporated into these plastics, which end up in the environment as well, after degradation of the polymer. These additives might be harmful, posing a threat to the environmental too. (Hamer, 2003)

One disadvantage found in literature is that the feedstock for biobased plastics, often is derived from industrial agricultural production. This leads to several consequences. First, genetic modified organisms (GMOs) are used quite often. GMOs are organisms with an engineered genetic make-up, in order to express characteristics in favour of human consumption. The risks of exposing these organisms to human and nature are unclear, thus leading to controversy surrounding the use of GMOs (Oliver, 2014). Second, fertilizer use will be increased. The fast majority of feedstock for biobased plastics comes from corn. Corn is known to be one of the most fertilizer demanding crop to grow. When the demand of biobased plastics will increase, the demand for corn will subsequently increase as well, leading to the use of more fertilizers. This in its turn, leads to nitrogen- and phosphorus pollution, jeopardizing biodiversity and pose increase health risks to humans (Groom, 2008). The third consequence goes hand in hand with increased fertilizer use, as this will lead to greater emissions of greenhouse gasses (GHG) other than CO2, leading to more environmental stress. (Álvarez-chávez et al., 2012) Despite of biobased plastics replacing fossil-based products, they still pose potential risks to the environment.

2.2.2 Economic impact of deploying biobased plastics

Since biobased plastics and conventional plastics are derived from different feedstocks, the economic impact of these materials is not the same. One barrier often mentioned, is the higher production costs of biobased plastics compared to conventional plastics. At the moment, oil prices are relatively low, and this results in difficulties establishing competitive prices for biobased plastics. (European bioplastics, 2016) Even though chemical companies developed techniques to efficiently extract building blocks for plastics production out of organic feedstock resulting in lower production costs, the market of biobased plastics is still relatively small. Therefore, companies need to develop new business models and discover new market opportunities, which cancels out the cost-efficient extraction techniques as R&D expenditure is high. (Iles and Martin, 2013) However, oil prices are increasing over the last decade. If this trend continues, the inability to competitive pricing for biobased plastics will no longer be a barrier (Imre and Pukánszky, 2015).

Plastics are characterized as thermoplastics, when they become mouldable when subjected to heat. Because all plastics used as food packaging are thermoplastics, it is easy to mechanically recycle them. (Da Róz et al., 2011) However, one has to note that is essential to keep biodegradable and non-biodegradable plastics separate during processing in a recycling facility. According to Hopewell and co-workers (2009), biodegradable plastics have the ability to obstruct proper waste management when they are entering a waste facility without proper systems to process them. Their chemical makeup is different when compared to conventional plastics, and they thus have different characteristics under certain conditions. Heating is the essential step in recycling of food packaging. Biodegradable plastics are less heat resistant compared to non-biodegradable plastics and decompose in the process. This pollutes the conventional recycle stream (Ren, 2003). Insufficient consumer education also aids to this, as it increases the changes of biodegradable plastics to mix with conventional plastics. (Hopewell et al., 2009). This problem does not go for non-biodegradable biobased plastics. They are molecularly the same as conventional plastics and can therefore be integrated in its existing recycling infrastructure without any issues. (Álvarez-chávez et al., 2012)

Because the volumes of biodegradable plastics in general is relatively low, it is not profitable for waste management facilities to build composting units. This often leads to incineration of biodegradable plastics, which is economically an unfavourable option. (Ren, 2003)

2.2.3 Social impact of deploying biobased plastics

One main concern is that growing crops solely for the production of biobased plastics, leads to competition with the crop production for human consumption. As seen in the biofuels industry, farmers switched from producing cheap food to producing higher value crops more suitable for the biofuel industry. It is expected that this will happen, if the demand for biobased increases. Food prices will rise, resulting in decreased accessibility to food. (Mülhaupt, 2013)

As mentioned in the previous section, lack of consumer education supports the pollution of conventional recycle streams; social causes can be imputed to this. Consumer behaviour is influenced by their knowledge, which can lead to undesirable behaviour when knowledge is lacking. (Ren, 2003) It is also mentioned that marketing tools, mislead consumers by persuading them with incorrect information in order for them to buy the company's product. Especially information about biodegradability often is incorrect. (Harding et al., 2017) Implementing more biobased plastics, can cause more health risk due to increased use of fertilizer, as explained in section 2.2.1.

2.2.4 Biobased plastics for circularity

Now the environmental, economic and social impacts found in literature are found, these impacts will be linked to the circular economy. Table 1 shows an overview of the identified barriers and opportunities of implementing biobased plastics.

Table 1: Overview of identified barriers and opportunities of implementing biobased plastics found in literature

Environmental	Drivers	• Reduction of carbon emission • Potential to reduce permanent plastic litter
	Barriers	• In case of higher demand, fertilizer use will increase • In case of higher demand, GHG emissions will increase • In case of higher demand, more arable land will be used • Feedstock often derived from industrial agricultural production
Economic	Drivers	• Existing infrastructure for non-biodegradable biobased plastics
	Barriers	• Higher production price compared to conventional plastic production • Biodegradable plastics potentially obstruct proper waste management • Low volumes of biodegradable plastics
Social	Drivers	• -
	Barriers	• In case of higher demand, competition with crop production • In case of higher demand, food price will rise • In case of higher demand, increasing fertilizer use will increase health risks

On the first glance, one could argue that biobased plastics do not sustainability (see section 3) contribute to CE. Reduced carbon- emissions and footprints, are in line with the philosophy of circularity. The ability of non-biodegradable biobased plastic to integrate with existing infrastructure, complements the potential for a circular economy as well. Nevertheless, the barriers in all dimensions outdo the drivers, as they do not incorporate the principles of circularity.

3. Theoretical background

3.1 Triple Bottom Line

The term Triple Bottom Line (TBL) was coined by John Elkington (1994) and gained momentum by the late 1990s. The first bottom line is "people", which measures social variables. The second bottom line is "planet", and this takes environmental variables into account. "Profit" serves as the last bottom line and addresses economic variable. If the three P's within a system or organization are balanced and aligned equally, it can be seen as sustainable. Because the research question focusses on sustainability, the TBL is a justified framework to apply in this research. The framework is depicted in figure 6.

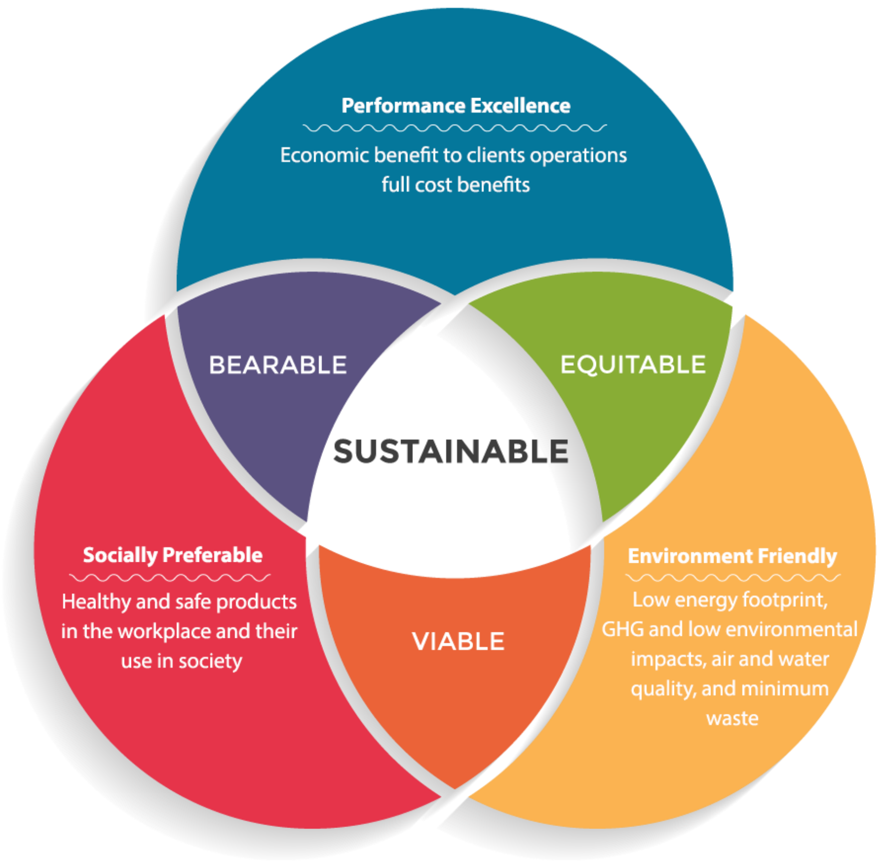

Figure 6: Triple Bottom Line framework

3.2 Conceptual framework

The conceptual framework is based on the five stages that are assessed in a Life Cycle Assessment. In this framework the choice has been made, to alter these into extraction, synthesis, manufacturing, consumption and end of life, which represent the five stages of the biobased plastics life cycle. These stages will be assessed by using the TBL framework as the research lens.

A schematic overview of the conceptual framework can be found in figure 7.

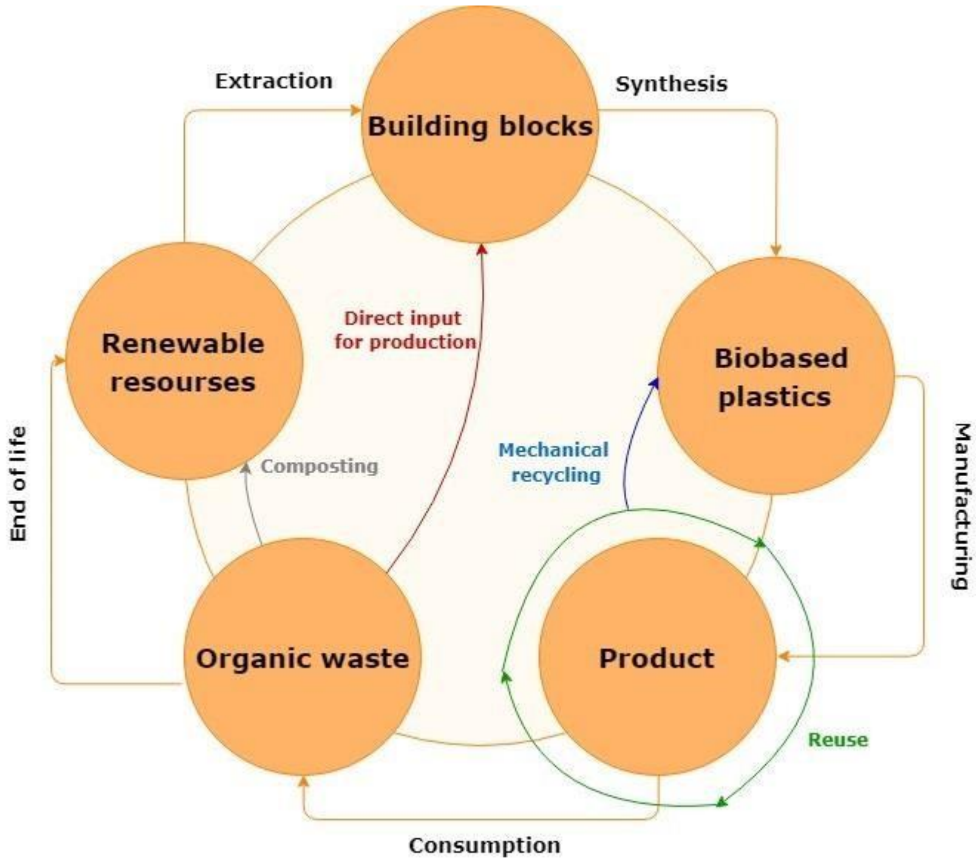

Figure 7 : Conceptual framework

4. Methodology

This section will describe the methods applied to collect and analyse the data and aims to justify these methods.

4.1 Research design

To meet the research objective and to answer the research question about the sustainability of deploying biobased plastics to a circular economy in Europe, data was collected by conducting a literature study and by applying a qualitative research approach. Figure 8 schematically depicts the research design and explains in what order the secondary and primary data was collected and analysed.

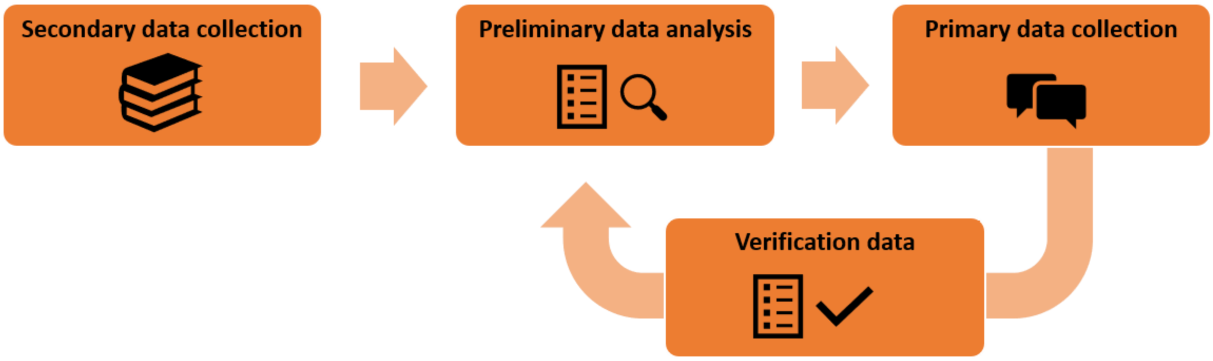

Figure 8: Research design

The first part of the research revolved around the collection of secondary data through desk research. This data regarded biobased plastics and the circular economy. Research concerning and combining these topics, was used if it described these concepts from either a general as a specific perspective. These perspectives included the three dimensions of the Triple Bottom Line. To prepare the data for further analysis, a preliminary data analysis was carried out and this was followed by the collection of primary data through semi-structured interviews and a focus group. This method will be discussed in more detail in section 4.2. The analysis of the obtained data will be discussed in section 4.5. The final step in this research design, was the verification of the primary data with the secondary data by triangulation.

4.2 Data collection method

The primary data was gathered via semi-structured interviews and a focus group, as mentioned earlier. The reasoning behind the use of this qualitative research method, was based on the complexity of the research topic. In order to answer the research question, it was required to understand motives and insights through a variety of perspectives provided by the various stakeholders involved.

The strength of qualitative research lies in its ability to provide complicated textual descriptions of how individuals experience a given issue and it can help to get a better understanding on how they experience the complex reality of a certain situation. This made it a suitable research method for this research project. Furthermore, when qualitative research methods are applied, it incorporates the motivation, beliefs, opinions, emotions and perception of interpersonal collaboration and conflict. (Grey, 2004; Mack et al., 2005).

Qualitative research includes many data gathering instruments such as questionnaires, observations, document analysis and interviews. In this research, interviews were done in the form of semi-structured interviews, as they have the advantage of being well suited for the exploration of beliefs, attitudes and motives. Moreover, the semi-structured nature of the interviews allowed the author to direct and steer the conversation and probe specific thoughts on the research topic (Gray, 2004). Another advantage of conducting semi-structured interviews, was the possibility to analyse the data schematically, which is a significant advantage as it increases the trustworthiness of the research.

4.3 Sampling strategy

The participants in this research were selected via non-probability techniques. These techniques draw samples that are not representative for a population and thus required findings to be judged and interpreted first before applying those to said population. Convenience and snowball sampling will be applied in this method. (Gray, 2014) The researcher applied the convenience strategy to approach potential participants, who were convenient to access and were part of the author's network. For the snowball strategy, the author asked participants to suggest another participant. The author also went to a congress regarding "innovating to tackle plastic waste and creating circularity", in order to engage with various experts.

Potential interviewees were approached via a LinkedIn-message and/or by email. A format was set up, so the approached individuals all received a message, that was equal in tone. If a positive response was received, a second message or mail was sent out to elaborate further on the topic and goal of this research. Once this was clear, appointments were made to conduct the semi-structured interviews.

A total of 58 organizations, companies and individuals were approached with the question to participate in an interview for this research. These entities could be categorized, into five groups: producers, brand owners and packagers, consumers, waste handlers (who all operate in the value chain of biobased plastics) and experts (who do not directly operate in the value chain of biobased plastics). This classification was based on the processes depicted in the conceptual framework (see figure 6). Next to this the author engaged with 12 experts during the congress. Apart from the consumer group, all other groups are considered to consist of experts in the field of biobased plastics and/or circularity. The only requirement for a potential participant, was that they had a stake in the biobased plastics value chain.

Table 2 shows the number of individuals who participated in an interview and the number of individuals who provided primary data during the congress per group.

Table 2: Number of participants

	Semi-structured interviews			Congress
	# approached	# responded	# interviewed	# conversations
Producers	21	6	3	1
Brand owners and packagers	11	7	1	0
Consumers	5	5	5[1]	0
Waste handlers	11	5	2	6
Experts	10	4	2	5
Total	58	27	**13[1]**	**12**

[1] Four individuals participated in focus group.

4.4 Interview guide

The interview guide was extracted from the five sub questions of this research. Because semi-structured interviews do not require a fixed set of interview questions, a guideline was created by formulating questions based on the collected secondary data and the preliminary analyses. The topics were as followed:

1. *Occurring trends in the European food packaging industry*
2. *Biobased plastics vs conventional plastics in the European food packaging industry*
3. *Environmental impact deploying biobased plastics*
4. *Economic impact deploying biobased plastics*
5. *Social impact of deploying biobased plastics*

The full interview guide can be found in appendix 1.

Even though, interviewees had a different set of knowledge and perceptions on the research topics, all the dimensions of the TBL framework were discussed to a certain extent during the interviews.

4.5 Data analysis

After conducting the interviews, they were fully transcribed and were coded in a way that allowed findings to be organized in a manageable and usable format. This was carried out in two steps.

Firstly, coding the interview was be done whilst transcribing. Relevant findings were marked and filtered according to the research topics. In this step, findings out of the secondary data were confirmed, contested or revised. Findings that were not present in the secondary data, are added in this step as well.

Secondly, the relevant data was organized in an extended matrix for which Microsoft Excel was used. This made the qualitative data as schematically as possible. The interview questions derived from the research questions, were placed on the Y-axis and the different interviews per category on the X-axis. Quotes of the interviewees were added to the matrix and linked to one of the research topics. By the utilization of this matrix, a clear overview of all the relevant findings was created. After coding the transcripts in the matrix, all the secondary findings were compared to the data found in the preliminary research.

5. Results

In this section the results of the semi-structured interviews and the focus group will be discussed. The results will be elaborated on per category. Every paragraph in this section starts with table presenting an overview of the results in its category, indicating the drivers and barriers of biobased plastics for sustainability.

5.1 Producers

The companies that employ the experts from this category, all produce biobased plastics. Two produce both bio-degradable and non-biodegradable plastics and the other only non-biodegradable. The individual from the congress is employed by a producer, specialised in design for circularity.

Table 3: Overview of results in producer category

Environmental	Drivers	• Depleting fossil fuels • Reduction of carbon footprint
	Barriers	• -
Economic	Drivers	• Existing infrastructure for non-biodegradable biobased plastics
	Barriers	• Lower production price of conventional plastics • Biodegradable plastics cause pollution in other plastic recycling streams. • Inefficient production process biobased plastics • Technologies for production are underdeveloped • Government does not implement sufficient policy instruments
Social	Drivers	• Increased awareness on sustainability by consumer
	Barriers	• Consumer behaviour • Lack of knowledge by consumer

The interviewees believe that biobased plastics can become the main material used for plastic food packaging, because fossil fuels are depleting, and we need to look for other materials. Increasing sustainability awareness throughout the supply chain is also mentioned as a driver to implement biobased plastics. Especially when it comes to the consumers as they are more aware about sustainable options and are willing to pay extra for it. Barriers mentioned by all interviewees in this category are the lower price of conventional plastics compared to biobased plastics and that packaging companies are not willing to change their ways because of this. It is mentioned by two interviewees, that packaging companies are indeed aware of more sustainable options. However, they are reluctant to adopt these options because waste handlers are not positive about these plastics and since many technologies in this field are in their start-up phase, they are not cost-efficient yet. One interviewee continued by saying the development of biobased plastics, is still in its infancy and therefore it should not be compared with conventional plastics cost wise. Another interviewee said that one more reason for higher costs over biobased plastics compared to conventional plastics, is the inefficiency of the production of biobased plastics. According to the interviewee, almost 100% of products coming out of fossil-based plastics production has value. Where 50% of products in the production of biobased plastic is water, which has no value and costs money to handle properly. It is also mentioned by three interviewees, that the general consent towards biobased plastics is rather negative. They see this as a barrier too. More support from governmental bodies through policy instruments, is expected to increase the adoption of biobased plastics. Covering the higher costs of utilizing biobased plastics, by giving subsidies to sustainable practices is mentioned, next to increasing the tax on CO_2emmisons and obligate manufacturers and brand owners to label packaging.

Two interviewees implied that circularity should be about keeping atoms in your supply chain as much as possible. Both used money as a metaphor for atoms. “You want to retain money as long as possible, so should you do with your atoms in your supply chain.” Bio-PET, bio-PP and other plastics with the same molecular composition as conventional plastics, would contribute to a circular economy because the infrastructure is already existing, and they are sourced from renewable resources. The contribution of these plastics to the circular economy, according to both interviewees, is that they reduce the carbon footprint in the cycle. Biodegradable plastics will not contribute to circularity, in the opinion of all interviewees in this group. Firstly, they all name the issue of biodegradable plastics polluting recycle streams when it ends up in the wrong place, making the recycle stream useless and increases the costs for waste handles unnecessarily. One could argue that turning biodegradable plastics into compost and growing new plants from it, to make plastics out of those is circularity. The interviewees disagree upon this, because they feel like atoms and thus value, leaving the supply chain in this way. Emphasize is placed on considering the importance of the application for biodegradable materials. Secondly, three interviewees blame the behaviour of consumers for the plastic problem and think that implementing more biodegradable plastics will support this behaviour, seeing biodegradable plastics as an incentive for the consumer to dump it without thinking. Thirdly, lack of knowledge by the consumer is mentioned as a barrier for biodegradable materials. According to three interviewees, it is impossible for consumers to know what type of plastic they are dealing with and therefore, do not know how to dispose it. This inability of the consumer does not contribute to circularity, as it supports compostable plastics to end up in the wrong waste stream. It is also said that the consumer is misled by the term “plastic free” coined by brand owners using biodegradable plastics, which is also aiding to this issue.

When asked about potential competition with the food production, all interviews said that it is not an issue at the moment. Two interviewees explained that the amount of land used for biobased plastics, is almost neglectable and told that their production uses residual streams out of sugar production with low value, that else would be discarded. However, the critical remark was made mentioning that production indeed uses arable land and that this possible negative impact should be considered if the production of biobased plastics is growing.

5.2 Brand owners and packagers

One individual in this category was interviewed. This company who employs this interviewee, is next to brand owner also a franchiser of supermarket chains specialised in organic and sustainable products. They favour biodegradable plastics for packing their products and try to apply it as much as possible. Table 4 shows an overview of the results in this category.

Table 4: Overview of results in brand owners and packager category

Environmental	Drivers	• Reduction of carbon footprint
	Barriers	• -
Economic	Drivers	• -
	Barriers	• Lower production price of conventional plastics • Negative stance on biodegradable plastics by waste handlers, is based on economic standpoints • Brand owners invest in cheapest technologies
Social	Drivers	• Increased awareness on sustainability by consumer
	Barriers	• -

The interviewee identifies the increasing awareness by consumers of plastic pollution and the effects thereof and their efforts to use less plastic in general, as the main drivers for the acceptance of more biobased plastics. They feel that every stakeholder should take responsibility in issues caused by conventional plastic use, in order to initiate a change in behaviour. A barrier to adopt more biodegradable plastics, according to the interviewee, is that most brand owners and packaging companies focus on the recyclability of their product, as it is the cheapest to invest in. So, there is not an incentive for companies to invest in newer technologies. The interviewee also mentions that LCA's of biobased plastics are unreliable, because inaccurate data is used. This leads to a biased negative stance towards biobased plastics.

The interviewee states that biodegradable plastics, and poly lactic acid in particular, contribute to a circular economy. "It is possible to recycle PLA both technically as mechanically. And if that might not be possible, we compost it and then it can be used as a feedstock for new plant material. That is circular!" The interviewee does not see any barriers for biodegradable materials in a circular economy. According to the interviewee, waste handlers are misinformed and use sophisms based on economic standpoints. "It is true that compostable plastics, pollute the stream of conventional plastics. However, it is not fair to blame compostable plastics for all these issues. At the moment 26 kinds of plastics are used as food packaging material and only three of them are properly recyclable. The real problem is the fact that we have so many different plastics in our society". The interviewee tells that it is not allowed for food packaging to be 100% made out of recycled material, due to food safety laws and regulations. So, it is always necessary to use virgin materials for food packaging. "…conventional plastics therefore have no place in a circular food packaging economy."

The reduction of the carbon footprint, when using biobased plastics in general, is mentioned as an environmental benefit. No environmental disadvantages are mentioned. An economic disadvantage mentioned is the cost of producing biobased plastics compared to conventional plastics.

5.3 Consumers

The individuals in this category, have no detailed knowledge on biobased plastics, circularity and sustainability. Yet, all consider the environment to be important and say that they have the intention to contribute to this in a positive way as much as possible. They all try to use less plastic and try to choose for more sustainable packing options. Table 5 shows an overview of the results in this category.

Table 5: Overview of results in consumer category

Environmental	Drivers	• -
	Barriers	• -
Economic	Drivers	• -
	Barriers	• Not willing to pay extra for sustainable packaging
Social	Drivers	• -
	Barriers	• Negative emotions when facing insufficient facilities to dispose waste correctly • Lack of knowledge • Insufficient facilities to dispose waste correctly

Despite their good intentions, the interviewed consumers are all not willing to pay extra for items that are packed in sustainable packaging materials. They feel like the producers and brand owners, should consider other ways to cover the costs of the usage of more expensive packaging material. Next to this, they complain about insufficient facilities to properly dispose their waste. Which leads them to getting discouraged and not feeling supported in their good intentions. They propose that the municipality, who is responsible for the waste management, to act on this. "Often, I cannot dispose my waste the way I want it, as waste bins are often full. I have already walked 10 minutes to get there, so I am not going to look for the next recycle station." One of the interviewees said. The other interviewees mentioned similar situations and according to them, it is a cause of litter. To address this problem, biodegradable plastics would be a solution in this problem because "it is a self-solving problem", as it composes by itself in nature according to the interviewees. Also, they would like to encounter more commercials made by the government, about plastic recycling and waste management. As they get demotivated to recycle, due to these insufficient facilities and thus do not have an incentive to educate themselves actively.

They all said it is the responsibility of the government and municipalities to educate people on the matter of waste disposal. In the focus group, one individual mentioned that they dispose plastic and metal cans in one bin. This erupted in a discussion about which material belongs in which bin. In the end, they agreed that the situation is different per region and that the government and municipality should take responsibility in educating citizens on this matter.

During the interviews, the author showed 10 plastic items and asked all individuals in what bin they should dispose it. All had 2 to 4 items correct and would dispose compostable plastics in the conventional plastic bin. "But plastic is plastic right? So, it should go in the plastic bin." They all stated to be confused and again expressed the need for more governmental interference.

5.4 Waste handlers

One interview conducted in the waste handler group, was with an association who represents several waste management- and recycle companies. The other interview was conducted with a recycling company specialised in polymers and plastics. The six individuals spoken to at the congress, all are involved in waste management in several municipalities throughout Europe. Table 6 shows an overview of the results in this category.

Table 6: Overview of results in waste handler category

Environmental	Drivers	• Depleting fossil fuels
	Barriers	• -
Economic	Drivers	• Existing infrastructure for non-biodegradable plastics
	Barriers	• Lower production price of conventional plastics • Biodegradable plastics cause pollution in other plastic recycling streams. • Unprofitable to invest in composting facilities due to low volumes of biodegradable plastics • Technologies for detection of biodegradable plastics in waste streams are underdeveloped • Government does not implement sufficient policy instruments
Social	Drivers	• -
	Barriers	• Lack of knowledge by consumer

Depleting fossil resources are considered to be the main driver towards implementing more biobased plastics in general. However, strong scepticism is expressed regarding biodegradable plastics. According to all participants, the volumes for biodegradable plastics are very low at the moment, and therefore it is not profitable to invest in composting facilities. One reason which creates a barrier for implementing biobased plastics in general, are the lower price of production of conventional plastics, giving brand owners no incentives to move to biobased plastics. Governments can use several policy instruments to overcome this hurdle but are not actively doing so according to the participants.

Non-biodegradable plastics are not a contribution nor an obstruction to the circular economy. "They are molecularly the same, only the source is different. That can be considered a benefit." Compostable plastics do not contribute to the circular economy according to all individuals in this group, as they heavily pollute the recycle streams of conventional plastics. This makes these streams useless and turns them into waste, resulting in financial losses for recycling companies. They say technologies are not well developed yet to detect compostable plastics effectively in waste streams, causing them to end up in the wrong stream. Another issue facilitating this, is that the consumer does not know how to dispose their plastic waste properly. Which increases the likelihood of compostable plastics entering conventional waste streams even more. They believe that it is the responsibility of municipalities to educate citizens on this, as they are responsible for proper waste management in their city. Another issue adding up to this, is that the consumer often does not know what type of plastic they are handling, because there are just too many types on the market.

5.5 Experts

The interviewees in this group are consultants, researchers and European policy makers. Two of them participated in an interview and five were approached during the congress. Table 7 shows an overview of the results in this category.

Table 7: Overview of results in expert category

Environmental	Drivers	• -
	Barriers	• -
Economic	Drivers	• Existing infrastructure for non-biodegradable plastics • Biodegradable plastics close the carbon loop
	Barriers	• Lower production price of conventional plastics • Biodegradable plastics cause pollution in other plastic recycling streams. • Negative stance on biodegradable plastics by waste handlers, is based on economic standpoints
Social	Drivers	• -
	Barriers	• Lack of knowledge by consumer

They all agree that the higher price of biobased plastics in general, is related with low oil prices and with brand owners putting a premium price on food packaged in sustainable materials, such as biobased plastics. Creating a barrier for these materials to be implemented in the mainstream food packaging industry. LCAs performed with bias and inaccurate data, is also mentioned as a barrier, resulting in brands owners and packaging companies not applying these plastics, as it would be easier to them to stay with conventional plastics due to the already existing infrastructure.

All of them believe that all biobased plastics contribute to the circular economy in the plastic packaging industry. Non-biodegradable plastics because there already is a solid infrastructure for these plastics to process. And biodegradable plastics because they close the carbon loop. However, they put emphasis on keeping biodegradable plastics out of recycle streams of conventional plastics, as they disturb the recycling process of the latter. This does not aid to circularity, according to them. Two participants mentioned, that the negative stance of waste handlers towards compostable plastics, is caused by economic reasons, as they do not have an incentive to build composting facilities in their establishments.

They agree on the statement that the consumer is oblivious to what type of plastic they are consuming, but do not agree on who is responsible to educate them on this. Three think it is the responsibility of municipalities to support their citizens in this and four think this should be done by brand owners and packaging companies.

5.6 Summary

Table 8 shows an overview of the results in all categories

Table 8: Overview of results in all categories

		Producers	Brand owners and packagers	Consumers	Waste handlers	Experts
Environmental	Drivers	• Depleting fossil fuels • Reduction of carbon footprint • Reduction of carbon emission	• Reduction of carbon footprint • Reduction of carbon emission	• -	• Depleting fossil fuels • Reduction of carbon emission	• Reduction of carbon emission
	Barriers	• -	• -	• -	• -	• -
Economic	Drivers	• Existing infrastructure for non-biodegradable biobased plastics • Biodegradable plastics close the carbon loop	• -	• -	• Existing infrastructure for non-biodegradable plastics	• Existing infrastructure for nonbiodegradable plastics • Biodegradable plastics close the carbon loop
	Barriers	• Lower production price of conventional plastics • Biodegradable plastics cause pollution in other plastic recycling streams. • Relative low oil prices • Inefficient production process biobased plastics • Technologies for production are underdeveloped	• Lower production price of conventional plastics • Negative stance on biodegradable plastics by waste handlers, is based on economic standpoints • Brand owners invest in cheapest technologies	• Not willing to pay extra for sustainable packaging	• Lower production price of conventional plastics • Biodegradable plastics cause pollution in other plastic recycling streams. • Relative low oil prices • Unprofitable to invest in composting facilities due to low volumes of biodegradable plastics • Technologies for detection of biodegradable plastics in waste streams are underdeveloped	• Lower production price of conventional plastics • Biodegradable plastics cause pollution in other plastic recycling streams. • Relative low oil prices • Negative stance on biodegradable plastics by waste handlers, is based on economic standpoints
Social	Drivers	• Increased awareness on sustainability by consumer	• Increased awareness on sustainability by consumer	• Intention to apply sustainable practices	• -	• -
	Barriers	• Consumer behaviour • Lack of knowledge by consumer	• -	• Negative emotions when facing insufficient facilities to dispose waste correctly • Lack of knowledge • Insufficient facilities to dispose waste correctly	• Lack of knowledge by consumer	• Lack of knowledge by consumer

6. Discussion

In this section the results will be critically reflected on, dividing them according to the dimensions of the Triple Bottom Line framework. This will be linked to the circular economy, before continuing to discuss encountered limitations during this research.

6.1 Environmental impacts of biobased plastics

In section 2.2.1, environmental drivers and barriers found in literature where elaborated on. The reduction of CO_2 emissions, the reduction of carbon footprint and the depletion of fossil fuels, were identified as environmental drivers for implementing biobased plastics. These drivers were also derived from the primary data. By applying triangulation, one could conclude these factors, are indeed drivers for implanting biobased plastics.

However, the literature was critical and argued causes which undermined the credibility of these proposed drivers. The interviewees did not provide criticism, as none of them mentioned environmental barriers to implementing biobased plastics. A reason for this could be lack of knowledge from certain interviewees, as not all are active in the production of biobased plastics and therefore are possibly not aware of certain processes and trade-offs, which could potentially cause environmental harm. Next to this, the interviewees all have a stake in the biobased plastics industry, therefore they might have a biased and less critical standpoint on the environmental aspects of these plastics.

As the environmental barriers are only mentioned in literature, it is difficult to draw a nuanced conclusion on this element. Based on the literature, one could argue that the impact of deploying biobased plastics, is not benefiting the environment when compared to conventional plastics. However, no literature has been found which quantifies these differences and where trade-offs are compared. Therefore, no conclusion can be made on the environmental barriers of deploying biobased plastics.

6.2 Economic impacts of biobased plastics

Section 2.2.2 described economic drivers and barriers of implementing biobased plastics. High production costs compared to production cost of conventional plastics, is a barrier found both in literature and in the interviews. Interviewees in the producer group, mentioned that the production process of biobased plastics is inefficient and that this is the cause for higher production costs. They specifically referred to the conversion of Bioethanol to Ethylene, which is the chemical building block of PE. Additional literature justified this statement. This conversion is an endothermic reaction, which entails that it is temperature depended. An optimal temperature needs to be maintained; else the conversion yields other compounds instead of Ethylene. External temperature control (by e.g. heaters, coolers) during a chemical reaction, costs extra energy in the process affecting the overall efficiency of the reaction unfavourable (Schulze et al., 2017). In addition to this, water is formed next to ethylene during this reaction with a 1:1 ratio, meaning that the yield of this reaction only is 50% (under optimal conditions), as water in this case is a by-product and does not have any value. Moderate yield affects the overall efficiency of this reaction negatively as well. (Mohsenzadeh et al., 2017) So it is reasonable to believe that the inefficient production process, is a cause for the higher costs. Low oil prices were also mentioned as a cause for biobased plastics to be expensive, but there is no direct correlation between oil prices and the efficiency of producing biobased plastics. Nonetheless, oil prices do have an effect on the demand of biobased plastics and that could influence the price of the latter. As long as oil prices remain relatively low, there is no strong incentive for companies to invest in biobased plastics and developing improved production techniques, which was stated in several interviews.

Biodegradable plastics obstructing recycling of conventional plastics and being unprofitable to process in the end-of-life, were both identified a barrier according to the primary and secondary data. It is inevitable to conclude that this is indeed a fact. These barriers are the explanation of the negative stance of waste handlers towards biodegradable plastics. The interviewed brand owner and some other interviewees stated that waste handlers are biased due to economic reasons and are miseducated on biodegradable plastics. The interviewed waste handlers acknowledged that they are indeed biased due to economic factors. However, they were able to showcase their knowledge on biodegradable plastics, by elaborating extensively on them. The brand owner failed to do so, undermining its statement and exhibited bias itself in favour of biodegradable plastics as they produce it themselves. Nevertheless, the negative bias of waste handlers amplifies the overall negative stance on biodegradable plastics, which is pointed out by several interviewees, leading to little incentive to integrate higher volumes of biodegradable plastics into the system, which in its turn leads to underdeveloped technologies in the end-of-life phase of biodegradable plastics. This maintains each other and leads to a vicious circle for biodegradable plastics. Therefore, it is important to apply biodegradable plastics in applications where biodegradability truly adds value. Food packaging is not one of those applications.

6.3 Social impacts of biobased plastics

Based on the literature no social drivers on implementing biobased plastics where identified. However, the interviewee acknowledged increased awareness of sustainability throughout the supply chain and especially amongst consumers as a driver. This can possibly result in a higher demand of sustainable alternatives and eventually a paradigm shift towards more sustainability in general. However, this needs to be reviewed before a conclusion can be made as there is no literature supporting this statement.

Lack of knowledge by the consumer, seems to be indirectly and directly linked to all barriers found in this research and is considered to be a significant problem. This became evident looking at both the literature reviews, as results of the interviews. Because the consumer does not know what type of plastic they are consuming, they consequently do not know how to dispose correctly, which creates issues when it comes to biodegradable plastics. This caters to the negative stance of waste handlers towards these plastics, mentioned in the previous section. The potential for biodegradable plastics to reduce permanent plastic litter as environmental driver, is brought into discredit due to lack of knowledge by the consumer. They were convinced that it does not harm the environment when these materials end up as litter and saw it as a solution to waste bins often being full. During the focus group and interview, they came to a realisation that they indeed lack knowledge and consider it the responsibility of municipalities to do something about this. This, however, is the source of blame shifting throughout the supply chain. The municipality does not feel responsible for the problem with biodegradable plastics and say that brand owners should bring less plastics on the market. In its turn, brand owners point the finger to waste handlers, saying that they should invest in composting facilities. Waste handlers do not take the blame and shift it back to brand owners, also stating that they put too many plastics on the market. It is clear that nobody in the supply chain is taking responsibility and this leads to various unsustainable practices and no solutions.

Competition with food production and increased health risk, where found to be barriers for implementing biobased plastics in the literature. But these where not mentioned by the interviewees or were invalidated by data produced by companies having a stake in this industry. As with the environmental factor, biased standpoints could have played a role here.

6.4 Discussion of biobased plastics for circularity

As explained in section 3, environmental, economic and social factors need to be balanced in order to achieve sustainability. The reduction of carbon footprint and the depletion of fossil fuels were identified as environmental drivers. However, critical literature was lacking and therefore, no nuanced and founded statements can be made on the environmental impacts of deploying biobased plastics. The same applies to economic and social factors, as barriers were primarily elaborated on. Based on this, one could argue that implementing biobased plastics is not sustainable.

Kirchherr et al. (2017), identified 114 circular economy definitions in literature. As explained in section 2.1.4, the 'reduce, reuse and recycle'-approach is applied in CE. They conclude that several authors leave out one of these elements or use linear models to elaborate on circularity. They also state that many authors, do not consider CE to be seen as a system and that they use misconceptions in their literature. Spierling et al. (2018) also state that the heterogenous definitions used for circularity. Based on the interviews, this phenomenon became evident as well. Interviewees gave different examples of circularity and argued that some of the examples given by others, are not circular. This was very clear when biodegradable plastics were discussed. The brand owner and several other interviewees claimed that it is circular to compost biodegradable plastics and use the residue as a feedstock for new plant material[1]. They argue that in this process, the use of carbon is reduced, the plastic is recycled by composting and is then reused as feedstock for new plants, within one value chain. The 'reduce, reuse and recycle'-philosophy is applied here. One argument against this was that circularity also can apply to intangible factors, such as energy consumption. When broken down into CO_2 and H_2O during composting, the energy used to produce the plastic left the value chain. As it is not reused for the production of new plastics in the value chain. Many more arguments could be made supporting both sides in this

[1] This statement is incorrect, as composting of biodegradable plastics results CO_2 and H_2O, which do not have any additional value to compost (Spierling et al, 2018). However, this is not mentioned in text, as the statement serves for the sake of illustration.

disagreement. Nevertheless, this example clearly illustrates that the used definitions for circularity are based on conceptions and different point of views.

6.5 Limitations

Several limitations were encountered during this research, which will be elaborated on in this section.

- The conclusion to be drawn will not be representative for the entire industry, due to a relatively little number of participants in the semi-structured interviews. First of all, the participants primarily operated in the Netherlands (15) and gave insights especially on the Dutch situation of biobased plastics and circularity. Participants operating in Germany (1), Spain (5), Denmark (1), Croatia (2) and the United Kingdom (1) participated as well but did not gave insights specific to their regions. So, it is not possible to make a distinction between several European regions.
- Because the number of participants was little, bias and prejudice heavily influenced the results. All interviewed experts have a stake in the biobased plastics industry, which might influence their opinion on the subject. Participants regularly stated to have a bias in one way or another. This was in particularly seen during the interview with the brand owner, which affects the validity of the data obtained from this interviewee negatively. Especially since this participant was the only one in its category.
- Participants sometimes gave socially accepted answers, which was noticed when contradicting statements were made or when participants admitted in doing so. This was evident in the consumer group, where all participants stated to recognize the importance of sustainability and told they were willing to contribute positively to this. As the interview progressed however, their positive attitude towards sustainable practices started to decline.

7. Conclusion

Based on the results and discussion, no clear conclusion can be drawn on whether biobased plastics are a sustainable alternative to achieve a circular economy in the European food industry.

As the data found on environmental, economic and social factors are not presenting a definitive answer, no concluding statements can be made on the sustainability of this concept. The current situation is rather negative described in literature. Nevertheless, biobased plastics are still in their infancy leaving room for growth, improvement and maximizes it potential to become a sustainable alternative for conventional plastics.

In order to answer the question of the impact of deploying biobased plastics for a circular economy, distinction between biodegradable biobased plastics and non-biodegradable biobased plastics need to be made, as they are processed differently during the end-of-life phase. However, to answer this question one has to consider the definition of circular economy. As there is no clear definition, any answer to this question is debatable.

Further research needs to be conducted on the concept of circularity, to clearly define a definition. This will harmonize the biobased plastics industry, as there is a clear division between biodegradable and non-biodegradable plastics at the moment. Another recommendation is researching the trustworthiness of LCAs. It was often mentioned that outdated and unreliable data is used to perform LCAs. Though performing LCAs need to be done according to certain standards, inaccurate data still seems to pose an issue.

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