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Bioplastics: Opportunities and Challenges

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THE THESIS submitted by:
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Bioplastics, a group of polymers that are either bio-based, biodegradable / compostable or both, represent a rapidly developing industry. Although until recently the term was unknown to the general public, currently bioplastics are often presented as one of the potential solutions in order to mitigate petroleum-based single use items and plastic waste pollution, and cases of 'greenwashing' emerge in the connection with these materials. The topic of bioplastics is very complex and opinions vary also among the scientists and experts from the bioplastics industry. However, despite their promising potential, it is clear that bioplastics do not provide any easy solutions.

In order to achieve the aims and answer the set research questions, the qualitative method of semi-structured interviews is chosen. The research explores opportunities and challenges of bioplastics from the point of view of stakeholders from the Czech Republic and several old EU Member States, who are involved in various sectors. The key focus of the thesis is on the interrelated areas, i.e. sources of bioplastics feedstock, bioplastics application and disposal of bioplastics waste since high concerns are related to the end-of-life of these materials.

Keywords: Bioplastics, Biopolymers, Challenges, Opportunities, The European Union, The Czech Republic, Innovation, Feedstock, Source, Disposal

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List of Abbreviations

ASTM	International-Standards Worldwide
Bio-PE	Bio-based polyethylene
Bio-PET	Bio-based Polyethylene terephthalate
CEN	The European Committee for Standardisation
CH4	Methane
CO2	Carbon dioxide
ECOS	Friends of the Earth Europe and the European Environmental Citizens' Organization for Standardisation
EU	The European Union
GHG	Greenhouse Gas
ISO	International Standards
LCA	Life Cycle Analysis
NGOs	Non-governmental organization
PA	Polyamides
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene terephthalate
PGA	3-Phosphoglyceric acid
PHA	Polyhydroxyalkanoates
PHB	Polyhydroxybutyrate

P3HB	Poly-3-hydroxybutyrate
PHBV	Poly(3-hydroxybutyric acid-co-3-hydroxyvaleric acid)
PLA	Polylactid acid
PLLA	Poly (L-lactide)
PP	Polypropylene
PS	Polystyrene
PVC	polyvinylchloride
PU	Polyurethane
PUR	Polyurethanes
UNEP	United Nations Environment Programme
US	The United States

1 Introduction

Plastic waste is changing the so-called 'blue planet' into a 'plastic planet'. As it stands, more than 300 million tons[1] of plastic across the world is manufactured every year and this number is increasing (Thakur *et al.* 2018). If the current trend of the rising amount of produced plastics continues, by 2050 around 20 per cent of the whole oil consumption could be used for plastics production, which would account for 15 per cent of greenhouse gas emissions. There are also estimates that plastics will outweigh the amount of fish in the oceans by then (European Commission 2018).

It is estimated that up to 12 million metric tonnes of plastic makes its way into the ocean each year. Single-use plastic items represent 50 per cent of marine litter (European Commission 2018). Furthermore, levels of carbon dioxide in the atmosphere still grow mainly due to use of fossil resources.

The unflattering data contributed to the acknowledgement of the issue of plastic waste from the side of international organizations, politicians, producers and customers. Above all, packaging and food industry together with retailers are encouraged by the current trend to behave more sustainably. Customer demands lead manufactures and retailers to seek more sustainable alternatives to their existing processes and approaches. The media also play an important role as even mainstream media such as The Guardian give more space to the issue of ocean pollution and contribute to the attacks on conventional plastics. According to a survey of the European Commission (2018), 87 per cent of European citizens worry about the environmental impacts caused by plastics. Hence, as Farmer (2013) claims, companies present sustainable objectives such as to become zero landfill manufacture or to produce lighter bottles with less material than previous.

[1] As recorded, in 2015 the amount of manufactured plastics achieved 322 million tons (Thakur *et al.* 2018).

New trends also encourage a growing industry for alternative materials - bioplastics. Nevertheless, cost reduction plays a role as well as prices for certain bioplastics are plunging to that of fossil-based plastics. Moreover, companies calculate with the limited sources of oil and potential increasing prices of this unrenewable fossil fuel.

Bio-based and biodegradable products are often presented as one of the potential solutions in order to mitigate petroleum-based single and limited use items. However, has mankind really found a way from the plastic crisis? What is the opposite side of these materials? In order to find out what this side is and explore it in detail is one of the main aims of the thesis. Although I deal with the topic in depth, the main purpose of the thesis is not to develop a theory. As the title suggests, the key focus of the thesis is on bioplastics and biopolymers and not on conventional plastics, i.e. fossil-based and non-biodegradable polymers with additives, although I mention these materials quite frequently in the connection with bioplastics. The core if my interest lay mainly on sources of polymers involved in the group of bioplastics, relating application and disposal of bioplastics waste since high concerns are related to the end of bioplastics life and closely related sources of bioplastics and their application.

In terms of geographical orientation, I mainly deal with an approach towards bioplastics in the Czech Republic due to several reasons like lack of language barrier, familiarity with the local environment, experience from the area of environmental protection and related easy access to various experts. In order to assess the bioplastics situation in the Czech Republic, as well as in general on the European market, the research is aimed also on the 'old EU Member States'. The reason behind is the assumption that these countries are knowledge-based economies that invest into innovations and their public is more concerned about environmental issues, such as plastic waste pollution. Nevertheless, the thesis does not have the capacity to cover the whole bioplastics and biopolymers market and related research with particular policies in each EU 15 country. Instead, I focus on the EU authorities' approach towards bioplastics because EU policy measures have an impact on all the Member States.

In the text, I mostly use the word 'bioplastics' although it may be considered confusing and misleading. By this term, I mean all Old and New Economy [2] bio-based and/or biodegradable materials including fossil-based polymers. By 'biopolymer', I mean natural polymer although some authors, such as Michael Niaounakis, use biopolymer as a synonym to bioplastics, i.e. bio-based or fossil-based bioplastics, which an increasing number of scientists and bioplastics experts consider inaccurate. I also use the word conventional plastics for fossil-based and non-biodegradable plastics that form a majority of plastics on the market, albeit the terminology is rejected by particular chemists.

In the chapter 'Literature Review', my intention is to sufficiently explain what bioplastics is, their source, application, disposal and related policy from the side of the Czech and EU authorities in order to enable the reader to understand properly the analytical part of the thesis. Despite the evident necessity to include exact terminology while referring to the polymers, I attempt not to overwhelm the reader with too many special terms especially from chemistry and microbiology of the use of which would not contribute significantly to the aims and objectives of the thesis. For instance, on purpose I do not mention the list of all current polymers included in the large group of bioplastics, enzymes and microbes used for biodegradation of bio-based bioplastics.

The analytical part of the thesis is named 'Discussion' and divided into several chapters in accordance with categories created within the content analysis. In this chapter, interviewees' answers are presented and complemented mainly with several studies' findings.

[2] Including traditional polymers from biomass manufactured since the middle of the 19th century, as well as new coming types of polymers.

The chapter ‘Recommendation’ presents a list of policy recommendation related to the area of bioplastics, i.e. including recommendations on the treatment of conventional plastics. Based on my own research experience, the subchapter deals with a guidance for the future researchers on the topic of bioplastics.

1.1 Aims, Objectives and Methods of the Research

The aim of the research is to provide policy recommendations in terms of production, use and treatment of bioplastics. The main question of the research is as follows: *Do bioplastics pose a suitable material to mitigate petroleum-based plastics?*

Furthermore, the research investigates four subquestions:

1. What are the opportunities and challenges of the current varieties of bioplastics and biopolymers?
2. What is the most suitable application of bioplastics and biopolymers?
3. How do particular EU Member States and the Czech Republic deal with bioplastics?
4. Why do bioplastics in general do not enter the waste collection and treatment systems, including mechanical recycling and energy recovery?

The objective of the research is to understand the complex and rapidly developing field of bioplastics and provide deep analysis of the current varieties of bioplastics; and Czech Republic and particular EU Member States’ approaches to these materials.

2 Literature review

2.1 Plastics

Plastics are polymers with various unique characteristics such as low density, high durability or due to which they have found useful applications in all areas of our life (Thakur *et al.* 2018). Polymers might be from biomass or petrochemicals. Several polymers can be produced from both renewable or fossil resources (Niaounakis 2015). The term biopolymer is being used for polymeric materials that are formed in nature by living organisms. Examples of biopolymers include cellulose, chitin, starch, rubber or lignin (Kabasci 2018).

"The first mention of a raw material for plastics production" comes from the year 1530. At that time a milk protein casein was used. At the end of the 18^{th} and the beginning of the 19^{th} century, natural rubber was modified in order to be used for various applications (Kabasci 2014, 4). However, the mid-nineteenth century, when the first plastics were made from biomass, is considered to be the origin of the bioplastics industry (Cooper 2017b). In 1868, the first thermoplastic material was made from celluloid with the aim to replace ivory (Kabasci 2014). Nevertheless, the development of the new material with very unique characteristics was soon overtaken by the petrochemical industry which dominates the plastics production until today (Cooper 2017b; IfBB – Institute for Bioplastics and Biocomposites 2018).

Plastics are divided into two groups based on how they respond to heat. Thermoplastics, or thermo-softening plastics, account for nearly 80 per cent of manmade polymers (Chidambarampadmavathya *el al.* 2017; Smil 2014). "Thermoplastics are either linear or branched molecules that lack any chemical bonds" (Smil 2014, 62). Thus, they can be easily remoulded into different shapes. The dominant thermoplastics are polyethylene (PE), Polyethylene terephthalate (PET), polypropylene (PP) and polyvinylchloride (PVC). Polystyrene (PS), polycarbonate (PC) and nylon are also included in the group of thermoplastics. The rest of polymers are formed by thermosets, or thermos-setting plastics, which cannot be modified because they have bonds among molecules. An example of thermosets is polyurethane (PU) (Chidambarampadmavathya *el al.* 2017; Smil 2014).

The vast majority of current plastics are petrochemical-based made from unrenewable fossil resources offering a wide range of applications. At present, they can be found in all sectors. Approximately half of all plastics manufactured in the world are used for disposal applications, mainly packaging[3], which consumes around a third of plastics, then agricultural purposes like mulching films, and other consumer items (Briassoulis and Innocenti 2017; Cooper 2013a). The annual production of petroleum-based plastics exceeded 300 million tons in 2015 which is a dramatic increase in comparison to 1950 when only 1.5 million tonnes of plastics was produced each year (Chidambarampadmavathya *el al.* 2017; Mehdi Emadian *et al.* 2017).

China is the world's leader in the production of plastics as the country delivers approximately one third of all manufactured plastics, followed by the EU and North America. However, the average consumption per capita is the highest in the US and in the EU (Smil 2014). On average, the per capita rate of plastic material consumption is 139 kg per year for the Nafta region and 136 kg for Western Europe (Plastics Insight 2016). Each EU citizen creates on average 31 kg of plastic waste (Armstrong 2018).

2.2 The problem of petroleum-based plastic

Petroleum-based plastics are polymers synthesized chemically via polymerization from petroleum products containing long chains of monomers" (Chidambarampadmavathya *el al.* 2017, 555).

[3] It applies to 37 per cent in Europe (Cooper 2013a).

Without any doubt, fossil-based plastic is an important material in our economies. It has unique properties and its production is cheap. These facts contribute to its wide spread across the world. Within several decades plastic has become part of the daily lives of millions of people around the world including developing countries and the production of plastics is expected to grow exponentially. However, the material has significant environmental and health implications. According to scientists such as Vaclav Smil (2014), PVC is considered the most environmentally damaging and the most toxic of all plastic. "PVC production and incineration emit dioxins, and phthalates, plasticizers used to soften PVC are suspected carcinogens that enter the environment during the use and disposal of the polymer" (Smil 2014, 65).

In the EU, only approximately 30 per cent of the plastic waste is collected for recycling, which means that according to estimates, "95 per cent of the value of plastic packaging material, i.e. between EUR 70 and 105 billion annually, is lost to the economy after a very short first-use cycle" (European Commission 2017b, 6). The rest of plastics ends up in landfills or in incineration plants. Several members of the European Union have already banned landfilling, but around 50 per cent of plastic wastes is still disposed in landfills (Emadian *et al.* 2016).

Due to the negative impact of plastics in general on the environment, the UNEP (2014) estimates that the overall natural capital cost of plastics use in the consumer goods sector is US$74 billion each year. The calculation of this amount was made based on the financial impacts of marine pollution or air pollution resulting from burning plastic. Moreover, over 30 per cent of the natural capital costs of plastic account for greenhouse gas emissions caused by raw material extraction and processing. Nevertheless, the marine pollution resulting from plastic waste, which found its way into the ocean, is the largest downstream cost estimated at US$13 billion.

About two per cent of all plastic produced, around 8 million tonnes, leaks into the ocean each year, and only approximately one per cent of all the amount is found on the surface of the ocean. Eighty per cent of the ocean plastic waste enters the ocean via rivers, 20 per cent comes from ships (report One World). Plastic waste polluting the oceans originates from littering related to poor or no waste management, poorly managed landfills, tourist activities fisheries (UNEP 2014) and also road runoff (Lindeque 2017).

Plastic litter which ends up in the oceans each year is only one of the most visible signs of the current challenge plastic poses today, however impacts of plastic waste present in other ecosystems should not be overlooked either. As presented by Pennie Lindeque (2017), recent research suggest that we should be more concerned about microscopic plastic than rubbish visible to the human eye. So-called microplastics are particulates and fibres <5 mm in diameter and they originate from two sources. The first is the manufacture of microplastics which are used mainly in cosmetics. The second source is the degradation of larger plastic items. According to Smil (2014), in spite of the durability of plastic, each plastic product loses its shape sooner or later depending on the type of material. PVC can remain integral for two to three decades or longer in ideal conditions. After its lifespan, the product is fragmented into small pieces and gradually breaks down into microplastic. These tiny pieces have been identified in marine and freshwater ecosystems across the world. Microplastics potentially affect the health of humans and animals, while complete degradation may take decades or even centuries.

2.3 Bioplastics

The term ‘bioplastics’ is somewhat confusing since it is used for several different types of material (Cooper 2013b). The prefix ‘bio-’ in bioplastics sometimes does not mean the bio-based origin of the material but is used to indicate the 'bio'-functionality of the material, i.e. either biodegradability or biocompatibility (Kabasci 2014).

Bioplastics are a group of polymers that are either bio-based, biodegradable/compostable or both (European Bioplastics 2017). Bio-based material contains organic[4] carbon from renewable resources, which means that it can be renewed within one to two years like plants, microorganisms, marine or forestry materials and even animals (Niaounakis 2015; Cooper 2013b; Narayan 2017). In contrast, fossil resources need millions of years for renewal (Cooper 2013b). Biodegradation[5] refers to biochemical processes during which bacteria, fungi or algae break the material and convert the polymer into substances that are water, carbon dioxide and biomass (Gilbert and Ricci 2015; Harding *et al.* 2017). In comparison, "terms like 'oxo', 'hydro' 'chemo', 'photo' degradable describe abiotic (nonbiological process) mechanisms of degradation" (Narayan 2017, 24).

Bioplastics might be divided into two main categories, biodegradable and nonbiodegradable polymers (in different words biodegradable and durable) or bio-based and fossil-based. Cooper (2013b) and European Bioplastics (2017) divide the bioplastics family into four groups (see the Figure 1 below).

[4] Organic material "contains carbon-based compound(s) in which the carbon is attached to other carbon atom(s), hydrogen, oxygen, or other elements in a chain, ring, or three dimensional structures – IUPAC nomenclatures" (Narayan 2017, 30).

[5] Biodegradability and biodegradation are frequently used as synonyms, although "biodegradability refers to a potentiality (i.e. the ability to be degraded by biological agents) while biodegradation refers to a process, which occurs under certain conditions, in a given time, with measurable results. The inherent biodegradability of a plastic is inferred by studying an actual biodegradation process under specific laboratory conditions, and the conclusion that the plastic is biodegradable (i.e. it can be biodegraded) in a specific environment can be drawn from the test results" (Briassoulis *et al.* 2017, 141)

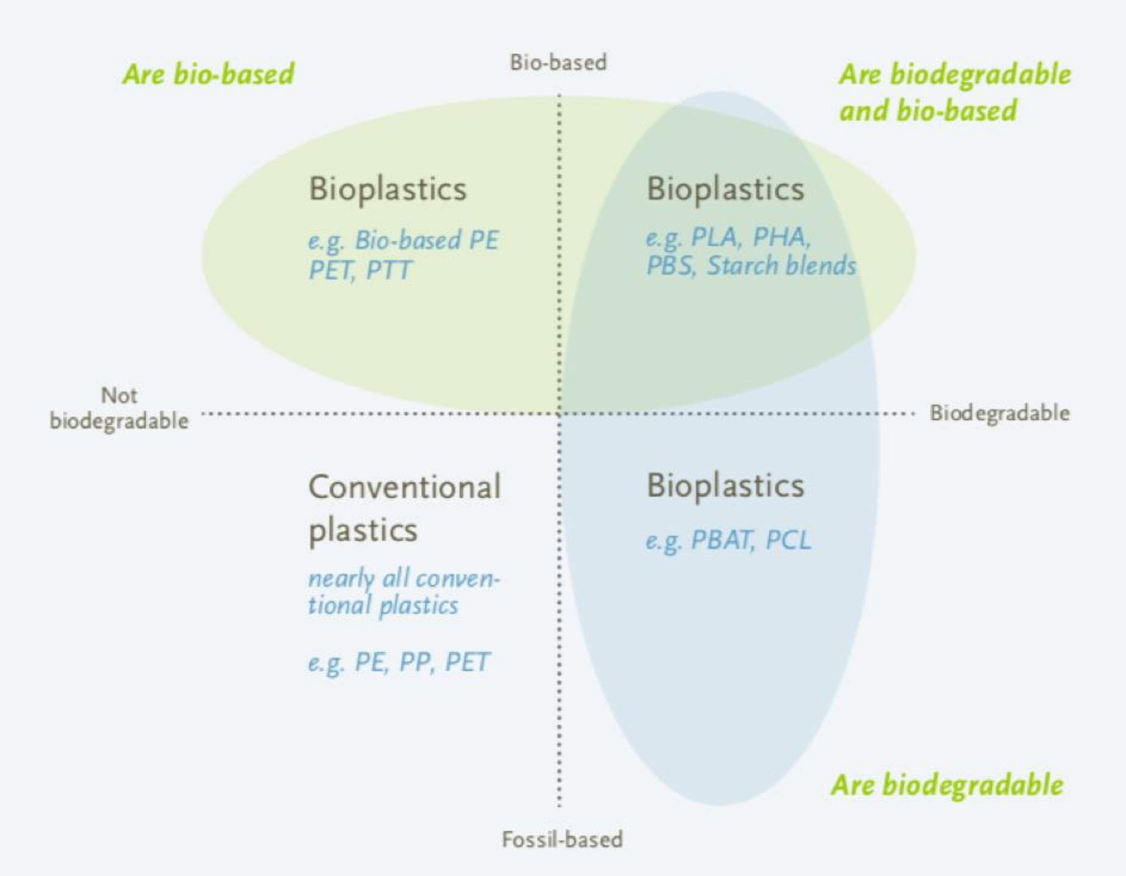

Figure 1: Material coordinate system of bioplastics (EUBP 2017)

As presented in the figure, the fourth group of polymers are conventional fossil-based and non-biodegradable polymers. Although conventional plastics are not in the focus of this thesis, they are regularly mentioned in connection with bioplastics.

The current bioplastics, that needed approximately 15 years to become more visible and noticeable for the general public, could be considered a revival to already known materials, although until present only several Old Economy biopolymers and bioplastics have been utilised. Examples are cellulose, cellophane and rubber-based materials. New economy bioplastics include new polymers as well as polymers which were developed several decades ago as presented in the Figure 2, such as PLA which was synthesized in 1913 for the first time or polyhydroxyalkanoates that were isolated and described in 1925 (Kabasci 2014; IfBB – Institute for Bioplastics and Biocomposites 2018).

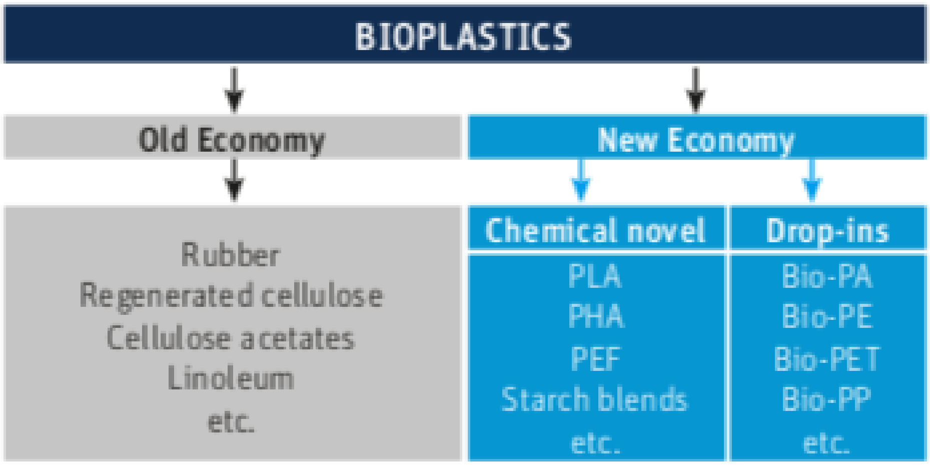

Figure 2: Bio-based polymers (IfBB – Institute for Bioplastics and Biocomposites 2018)

Bioplastics represent an economically innovative sector that grows annually between 20 and 100 per cent (European Bioplastics 2016). At present, materials of Old and New Economy bioplastics account for about 6 per cent of the global plastics market out of New Economy bioplastics represent only around 1 per cent of the global plastics market (IfBB – Institute for Bioplastics and Biocomposites 2018).

Besides the three main groups of bioplastics on the current market, there are also oxo-degradable, or so called oxo-plastics. These materials are fossil-based plastic with organic additives forming 1-2 per cent (Mynarova 2018). “These additives are designed to promote the oxidation of the material to the point where it embrittles and fragments” (Hann *et al.* 2016, i).

Although these materials are not included in the bioplastics family by main stakeholders such as European Bioplastics, the European Union or front bioplastics producers, they are still among bioplastics for many manufactures who present them as biodegradable.

Nevertheless, “the fundamental biological data showing the percentage of carbon utilized or assimilated by the microorganisms, as measured by the evolved carbon dioxide CO_2

(aerobic) or CO_2 + CH_4 (methane) (anaerobic), are not provided. Some of the data show 10-20 per cent biodegradation which then levels off with little or no biodegradation" (Narayan 2017, 29). Weight loss, microbial colonization and other changes do not prove the biodegradability (Narayan 2017).

In November 2014, the European Parliament proposed a ban of oxo-plastics within the EU. This measure was blocked, but "an amendment to the Packaging and Packaging Waste Directive, adopted in May 2015, commits the Commission to examine the impact of the use of oxo-degradable plastic on the environment" (Hann *et al.* 2016).

The study issued by the European Union reviewed these materials in detail. The study's authors Hann et al. (2016) produced evidence that oxo-degradable plastics are not suitable for any type of composting including industrial composting or anaerobic digestion. The materials do not meet the current standard of compostable packaging ISO 13432 due to the reason that oxo-degradable plastics can biodegrade under special conditions, but there are doubts if in practice biodegradation occurs fully and within "reasonable time periods".

Oxo-degradable plastics tend to be more problematic materials than conventional plastics. There are concerns that the proclamations on biodegradability can lead to littering on a larger scale. These materials might be more fragmentable in the marine environment and thus increase the impact on wildlife in the form of microplastics. Furthermore, oxo-degradable plastics decomposition in landfills is considered worse than conventional plastics from a carbon emissions point of view (Hann *et al.* 2016).

2.3.1 Bio-based and Non-biodegradable polymers

In this group there are fully or partly bio-based non-biodegradable polymers, which have an identical composition as conventional fossil-based plastics. Examples of these materials are bio-based polyethylene (bio-PE), polyethylene terephthalate (bio-PET) or as bio-based technical performance polymers, e.g. polyamides (PA), and bio-based polyurethanes (PUR) (European Bioplastics 2017).

2.3.2 Bio-based and Biodegradable / Compostable polymers

The second group is probably the most frequently debated type of bioplastics. It is formed by polymers that are bio-based and biodegradable / compostable such as increasingly popular polylactic acid (PLA), polyhydroxyalkanoates (PHA), polybutylene succinate (PBS) or starch blends (European Bioplastics 2017).

Words ‘biodegradable’ or ‘compostable’ are often used interchangeably, although each term has a different meaning referring about the product properties. This fact causes confusions among consumers and often among experts as well.

“A biodegradable plastic is a plastic that can be broken down into its constituent monomers and metabolised through the action of naturally occurring micro-organisms, such as bacteria and fungi, over a period of time”. On the contrary, “a compostable plastic is one that is capable of undergoing biological decomposition in a compost site as part of an available programme, such that the plastic is not visually distinguishable and breaks down to carbon dioxide, water, inorganic compounds, and biomass, at a rate consistent with known compostable material (e.g. cellulose) and leaves no toxic residue” (Gilbert and Ricci 2015, 7).

The two most promising bioplastics are polylactic acid (PLA) and poly-hydroxyalkanoate (PHA). “PLA is a type of aliphatic thermos-softening polyester”. “Commercially available PLA at present is mostly poly (L-lactide) PLLA” (Niaounakis 2015, 8). PLA has poor insufficient mechanical and physical properties. Therefore, manufacturers let PLA blending in order to fulfil the needs of the practical application.

The most common production of PLA is primarily by the ionic polymerization of lactide. Polymerization takes place at the temperature between 140 °C and 180 °C. PLA can also be obtained from lactic acid by polycondensation (Niaounakis 2015).

"Polyhydroxyalkanoates (PHA) is a family of naturally-occurring biopolyesters" (Amulya *et al.* 2016, 4618). Those currently commercially available include PHB, PHBV and PHBH" (Cooper 2017b, 123). "The PHA production is four to nine times more expensive than conventional plastics due to mainly its high production cost" (Amulya *et al.* 2016, 4618). But, "PHAs have very similar material properties to conventional plastics" (Chidambarampadmavathya 2017, 557)

2.3.3 Fossil-based and Biodegradable Polymers

It a single category in which polymers are partially or fully fossil-based (European Bioplastics 2017). Partially bio-based polymers, where one monomer may be from biomass and another is fossil-based, are for example polybutylene adipate terephthalate (PBAT) or castor oil-based polyamides (Cooper 2017b).

2.4 Sources of Bioplastics

As suggested in the subchapter above, the large bioplastics family consists of various materials that can be derived from biomass or petrochemicals. However, in this chapter only sources of bio-based bioplastics are be reviewed.

The choice of feedstock can influence the overall sustainability of a bio-based product. Agricultural cultivation often uses significant amounts of water, fertilisers, herbicides, and pesticides (InnProBio 2016).

At present, the majority of bio-based bioplastics is produced from the so-called first-generation feedstock, which includes "edible biomass such as sugar, starch, and plant oils, and nonedible sources such as natural rubber, one of the first used biopolymers" (Niaounakis 2015, 42). First generation feedstock poses "the most efficient feedstock for the production of bioplastics as it requires the least amount of land to grow and produce the highest yields" (Hydal corporation 2018).

Starch-based bioplastics are currently the most common bioplastics produced on an industrial scale (Harding *et al.* 2017). "The most important industrial starch sources are crops such as corn[6], wheat or potato. In starch-based bioplastics, starch is fully utilised with a yield very close to 100 per cent, whereas in starch-derived bioplastics […] the yield is generally less than 45 per cent" (Bastioli *et al.* 2014, 9-10).

Critics of bioplastics claim that the business might contribute to the global food crisis by taking over large areas of land previously used to grow crops for human consumption. The corresponding use of land of all bioplastics is approximately 15.7 million hectares, which is equivalent to 0.3 per cent of the whole land or around 1 per cent of the arable land (IfBB – Institute for Bioplastics and Biocomposites 2018).

Despite the small percentage of the land utilised by the bioplastics industry, many manufactures turn to the second and third generation feedstock. The definition of the second generation says that it "refers to feedstock not suitable for food or feed. It can be either non-food crops (e.g. cellulose) or waste materials from first generation feedstock (e.g. waste vegetable oil)". The term third generation feedstock "currently relates to biomass from algae, which – having a higher growth yield than 1st and 2nd generation feedstock – were given their own category" (Hydal corporation 2018).

2.5 Application of Bioplastics

At present, bioplastics occur in all market sectors, especially in service packaging, food services, agriculture, automotive industry, textiles/fibres, medical/pharmaceutical sector, cosmetics and many others (Niaounakis 2013).

[6] "In the United States, 39.4 per cent of the corn production in 2010 was used as livestock feed, 10.5 per cent was processed into food, seed and industrial products […], and the 34.9 per cent was converted to ethanol. The remaining 15.2 per cent was exported" (Bastioli *et al.* 2014, 9).

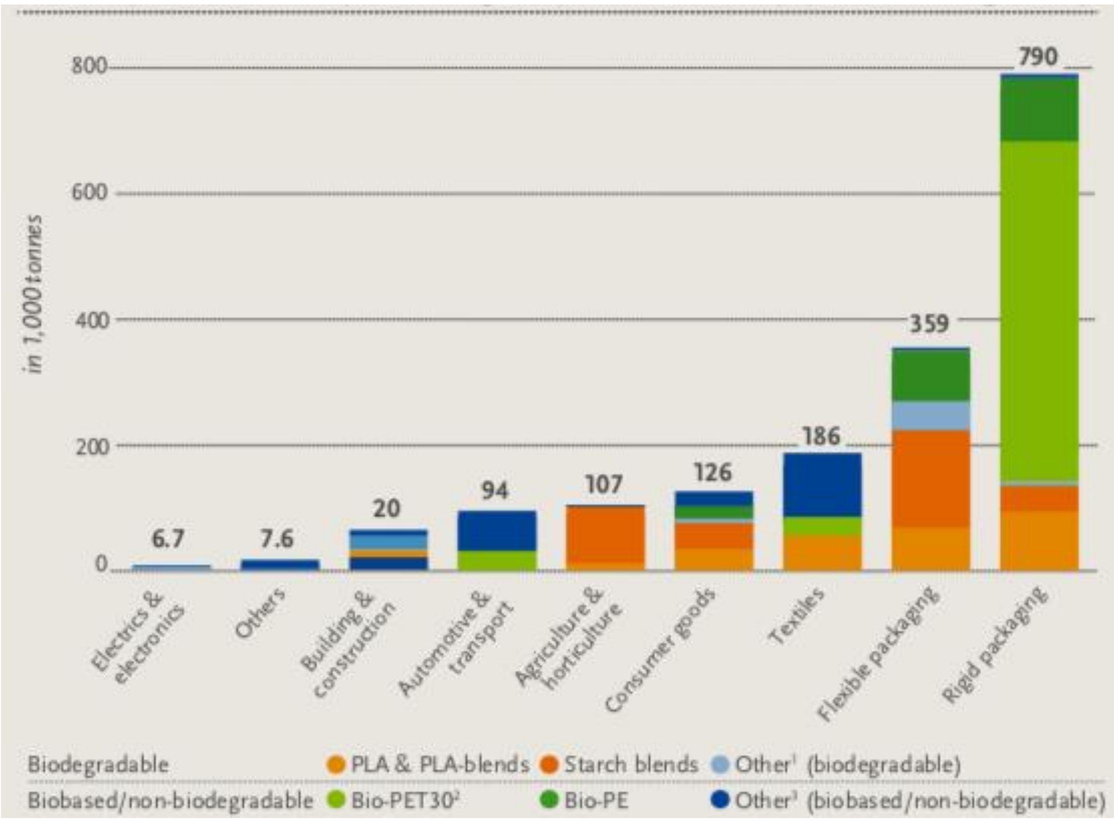

Figure 3: Global production of bioplastics 2014 (by market segment) (EUBP 2015)

Bioplastics found their place especially in service and food packaging such as compostable bags usually intended for kitchen waste, packaging for fresh food, single use items including boxes used in restaurants, cups or disposable tableware. On the market, there are also bioplastics bottles (Niaounakis 2013).

Biodegradable biopolymers have potential utilization in agriculture where they could replace the current fossil-based materials like mulch films[7], fruit and vegetable coverings, sheets, rods or various clips. Plastic used for agriculture purposes constantly increase especially on the fast growing and at the same less developed markets of Asia and South America[8] due to

[7] "Mulching is a worldwide agricultural practice consisting in covering the soil with a natural or synthetic material in order to provide suitable conditions for plant growth, to conserve moisture, to prevent weed and nutrient leaching, and to provide a barrier to soil pathogens" (Santagata *et al.* 2017, 106).

[8] In Europe, which is considered a mature market, the use of plastic materials in agriculture stays stable (Guerrini *et al.* 2017).

pressure on intensification of agriculture production. Around 45 per cent of these materials is intended for silage packaging, dominated by polyethylene (PE) films (Guerrini *et al.* 2017). These artificial materials contribute to richer harvests of farmers but their disposal is problematic (Niaounakis 2013; Naryan 2017; Guerrini *et al.* 2017). It is estimated that only approximately 50 per cent of all plastic waste utilized in agriculture is properly recuperated and disposed. Plastic films used for covering silage are difficult to recycle as they are usually contaminated by soil, silage and other organic materials. Moreover, plastic waste left in the fields contribute to the release of harmful substances[9] (Guerrini *et al.* 2017).

The main application of biodegradable plastic films in agriculture is mulching which has a potential to substitute polyethylene (PE) films (Martín-Closas *et al.* 2017). In agriculture approximately 1 million tons of plastic mulch films is used around the world each year. However, demand for biodegradable films increase because of the strict regulation for using fossil-based plastics (Santagata *et al.* 2017).

Utilization of biodegradable mulching for the production of a wide range of crops has been already widely documented. Studies demonstrate that both biodegradable and PE mulches enhance crop development and support yield increase similarly, although slight differences occur by plant type. Nevertheless, the adoption of the alternative bio-based and biodegradable material is limited mainly due to the higher price compared to PE and farmers' insufficient knowledge (Martín-Closas *et al.* 2017). Current biodegradable mulching films are mostly starch-based. Films produced from other polymers like PLA or PHAs are also take their place on the market. PLA is considered a relatively inexpensive polymer and can be manufactured in large quantities. PHAs pose a promising polymer (Santagata *et al.* 2017). Nevertheless, it is necessary to take into the account the fact that 'biodegradability' is often a misused and misleading term. (Niaounakis 2013; Naryan 2017).

[9] "12 per cent of dioxin and furan emissions come from the agriculture sector" (Guerrini *et al.* 2017, 38)

2.6 Policy Towards Bioplastics

2.6.1 The EU and Czech Republic directives

In the European Union, currently there is no united policy on bioplastics, as well as in the Czech Republic which follows the EU measures. The European Union actively supports the research and development of bioplastics. According to the report ‘Bioplastics: Sustainable Materials for Building a Strong and Circular European Bioeconomy’ (2017, 2), “Bioplastics are becoming a crucial component in the drive to create a fully sustainable and circular bio-economy. The EU has been actively supporting the development of these materials through ambitious and collaborative research that aims for a greater uptake that will help transform Europe’s plastics’ industry over the coming years”.

However, recently the European Commission and the Parliament approved the directives on waste, on the landfill of waste, on packaging and packaging waste. The directives aim to improve waste management in the EU within the principle of circular economy. The documents refer to the necessity of the reduction of landfilling, the importance of improving the efficiency of resources and other areas (European Union 2018). Furthermore, the European Union is working on the proposal of the home-scale composting standardisation which is lacked at present (Trylc 2018).

2.6.2 Certification

Certification of bioplastics is a complex area with several certification systems. ISO, ASTM and CEN belong to “the main laboratory standard test methods for testing biodegradation” (Briassoulis *et al.* 2017, 142) of bioplastics in soil. The main focus is on biodegradability, compostability, and content of renewable biomass. Other systems are related to environmental safety or to ability of biodegradation in water and soil (Niaounakis 2013).

The level of biodegradation reached by a bioplastic product under soil conditions is tested by means of laboratory methods. Standard specifications are defined based on studied specific laboratory conditions. Nevertheless, behaviour of biodegradable bioplastics when exposed to real soil of different types can deviate from the laboratory results. “The standard testing procedures are designed to determine the inherent biodegradation characteristics under an optimal controlled biodegradation process that may not be representative of the biodegradation of the specific bio-based materials/products under specific soil conditions but they ensure repeatability” (Briassoulis *et al.* 2017, 142).

Although the bioplastics industry is keen on developing an international certification and logo system that would be valid everywhere around the world, at present there are no European or international specifications regarding biodegradation in soil. Plus there are several certification systems for compostability (Niaounakis 2013; Briassoulis *et al.* 2017), including the European “EN 13432 standard ‘Packaging – Requirements for packaging recoverable through composting and biodegradation – Test scheme and evaluation criteria for the final acceptance of packaging’ specifies requirements and procedures to determine the compostability and anaerobic treatability of packaging and packaging materials” (European Bioplastics 2015, 2).

The standard EN 13432 is meant for biodegradable bioplastics treated in industrial composting facilities. Regarding standardisation for home-composters, there are at least two certification schemes (Gilbert and Ricci 2015).

In order to meet the requirements of biodegradability under industrial composting circumstances, a bioplastic has to satisfy the essential requirements of complete microbial utilization as measured by the evolved CO2 within composting or in soil environment (Narayan 2017).

The standard EN 13432 defines the minimum requirement the package has to meet to be allowed for procession in an industrial composting. EN standard ensures that the following features are tested in a laboratory: Disintegration – the material has to lose its visibility in the final compost after three months within which it is composted together with biomass (European Bioplastics 2015). […] "The mass of the test material residues has to amount to less than 10 per cent of the original mass". Biodegradability – the capability of the material to be converted into CO2 under microbial activity. According to the standard "at least 90 per cent biodegradation must be reached in less than 6 months". The third characteristics is the absence of all negatives affecting the composting process and the last one refers to the amount of heavy metals. (European Bioplastics 2015, 2-3).

Bioplastics certified based on EN 13432 can be recognised by the logo in figure 4.

compostable

Figure 4: The label for compostable packaging certified according to EN 13432 (European Bioplastics 2015)

2.7 Bioplastics waste treatment

Bioplastics as other materials have also their life cycle. Hence, many different treatment methods might be applied to bioplastics waste including mechanical and chemical recycling, energy recovery i.e. incineration or composting and anaerobic digestion. Landfilling is considered unsuitable method of disposal as in case of conventional plastics. However, landfilling is still a better life-end-life option than incorrect recycling efforts.

2.7.1 Mechanical and Chemical Recycling

Recycling bioplastics might seem odd as a significant part of bioplastics is biodegradable, however, in case of bioplastics it has a high importance to speak about recycling. According to European Bioplastics (2016), the major share of bio-based polymers is suitable for existing mechanical streams.

The mechanical recycling is the most common type of plastic waste recycling. It means "to reuse the plastic solid waste to form the product with same inherent characteristics" (Thakur et al 2018, 33), as presented in the figure 5.

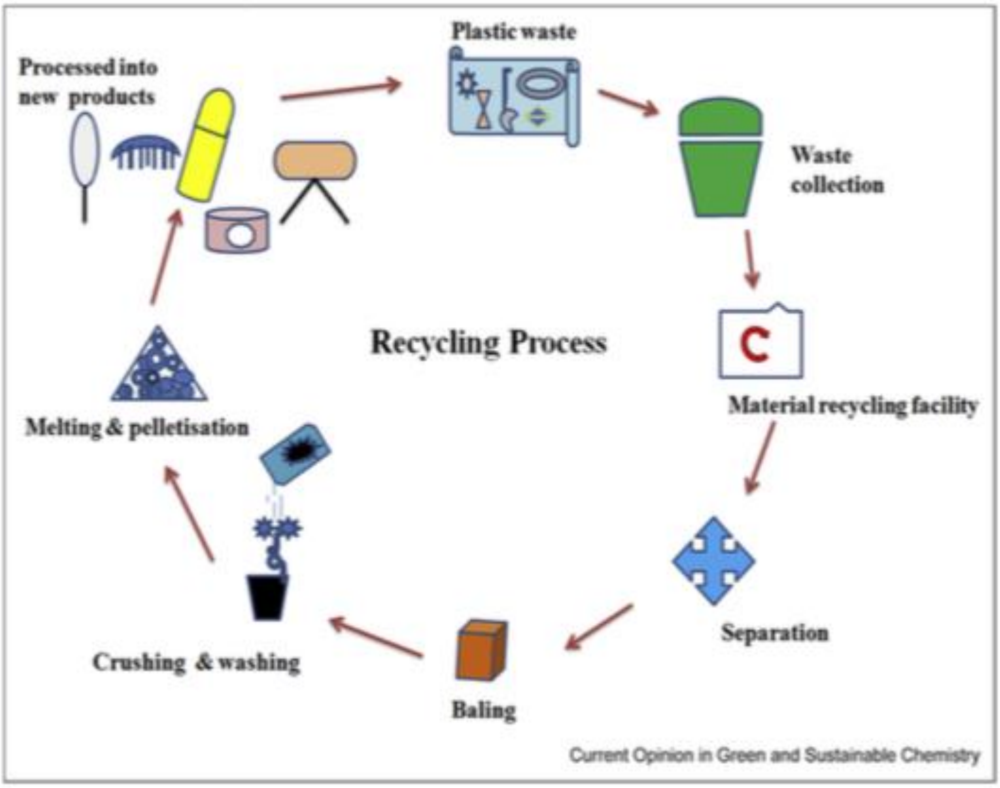

Figure 5: Schematic representation for recycling of plastic solid waste (Thakur et al. 2018, 33)

Nevertheless, biodegradable bioplastics may contaminate the existing recycling waste stream. Representatives from the recycling industry have raised the concern that if biodegradable items get mixed with recyclable plastics, the final plastic product would be compromised. Conventional plastics are not distinguishable from biodegradable bioplastics. Furthermore, both types of plastics have similar weights and densities, which complicates manual separation. New technologies on the basis of infrared spectroscopy allow plastic waste to be automatically separated, but these systems are more expensive and technologically challenging (Sokele and Pilipovic 2017).

Chemical recycling means that "plastic waste is converted into fuels and chemical feedstocks by using various treatment such as pyrolysis and hydrothermal. By using chemical recycling […] polyesters and polyamides can be turned back into respective monomers" (Thakur *et al.* 2018, 34).

2.7.2 Biological processes

"Biopolymer biodegradation can take place either aerobically[10] or anaerobically[11]. An example of aerobic biodegradation is composting, of which there are two types, home and industrial" (Niaounakis 2013, 109).

Composting represents a type of waste disposal process that is based on the biodegradation of biomass through microbial activity. Microorganisms grow on the organic material and break it down into carbon dioxide, water and compost. Home composting occurs at ambient temperatures (35°C). Industrial composting occurs under the temperatures ranging between 50°C and 60°C but not higher than 70°C. In industrial composing facilities, there is also 100 per cent relative humidity, and decomposition period might be several weeks or even several months, depends on the organic matter (Niaounakis 2013; European Bioplastics 2015).

[10] Occurring in the presence of oxygen.
[11] Occurring in the absence of free oxygen.

Composting is considered a preferable method of end-of-life circle for biodegradable bioplastics waste while industrial composting requires a developed infrastructure and the system of biowaste collection (Niaounakis 2013). In industrial composting facilities, PLA biodegrade on average from 4 to 6 weeks, like paper (Chidambarampadmavathya 2017).

Industrial composting facilities are already well established in several European countries, such as Germany, Austria, Italy or the Netherlands, where the separate collection of biowaste is on the high level. Nevertheless, in general the capacity of industrial composting facilities is limited in the EU. Most of plants are non-industrial composting facilities unable to undergo packaging compostable process (European Bioplastics 2015; Rujnic-Sokele and Pilipovic 2017).

"Anaerobic decomposition occurs naturally in swamps, waterlogged soils and rice fields, deep bodies of water, and in the digestive systems of termites and large animals, […] where it results in the formation of gases (e.g. carbon dioxide, methane and nitrous oxide), water and digestate. Anaerobic processes might also be achieved artificially in a covered pond or a biogas plant. Based on different temperature under which biodegradation takes place, anaerobic decomposition is divided into thermophilic (50-60°C) and mesophilic (≥35°C). For example, PLA degrades only under thermophilic conditions" (Niaounakis 2013, 114).

Biodegradation of bioplastics has to be distinguished from decomposition which takes place naturally. A plastic product when left in the open environment breaks down because of photochemical degradation and microbial activity but does not fully degrade. In case of bio-based biodegradable bioplastics, their degradation in soil can be also a slow process and take up to several years (Rujnic-Sokele and Pilipovic 2017; Niaounakis 2013).

2.7.3 (Bio)degradation in water

"Hydrolitic degradation is the process by which moisture penetrates a disposable material and hydrolyzes, for example, ester bonds, thereby breaking down polymers in the material" (Niaounakis 2013, 135).

Potential biodegradation of bioplastics in water has been a discussed topic considering the accumulation of plastics in the oceans where it seriously affects the wildlife. At present, only PHAs - biodegradable and thermoplastic polymers can degrade in fresh and marine water, soil, sludge, and compost. But in case of other polymers, biodegradation is influenced by the real temperature of water. PLA and its blends degrade very slowly, up to a year (Mynarova 2018).

Sewage water is more suitable environment. "Any biopolymer that meets the compostability criteria can in principle degrade in a sewage environment. Sewage is a favourable medium for biodegradation of certain types of biopolymers since it is rich of microbes and high levels of nitrogen and phosphorus" (Niaounakis 2013, 138).

2.7.4 Incineration and landfilling

Authors vary in opinions on energy recovery by incineration as an end-of-life disposal option of bioplastics. Niaounakis (2013) does not find incineration of bioplastics a preferable way of disposal. According to him, incineration causes release of dioxins and other pollutants and contributes to global warming. Moreover, biopolymers are a high-moisture items which can limit efficiency of the incinerator.

Nevertheless, for instance incineration of PLA and PGA does not contribute to pollution formation and they release the same amount of carbon dioxide as generated during production. The incineration of PLA does not increase carbon dioxide emissions. Furthermore, the incineration of PLA releases no nitrogen gases (Niaounakis 2013).

According to Rujnic-Sokele and Pilipovic (2017), incineration is a suitable option for all bioplastics. The authors consider the combustion of bioplatics beneficial for renewable energy production.

Landfilling requires lots of space and pollutes the environment. According to European Bioplastics (2008) landfilling should be avoided as it leads to a loss of useful material and energy. Hence, this method is not considered preferable (Thakur *et al.* 2018). Biodegradable bioplastics might degrade spontaneously in landfills, but the period required for decomposition is too long. Depolymerization of PLA and PGA occurs on average from 6 months to 2 years (Niaounakis 2013).

3 Methodology

3.1 Semi-Structured Interviews as a Method of Qualitative Research

In order to comprehend the issue of bioplastics and achieve the aims and objectives of the research, I opted for a qualitative method of semi-structured interviews. Although bioplastics are a product of chemical engineering, their further development relies on many political and socioeconomical factors and thus the human dimension plays a crucial role. As Jane Ritchie points out, although "cause and effect in social inquiry can only be speculative", qualitative methods still play a key role "in identifying the important influences and in generating explanatory hypothesis" (2003, 28). Furthermore, as noted by Strauss and Corbin (1998), the set research questions dictate the method. Thus, the qualitative study was chosen as more beneficial one.

"By the qualitative research it is meant any type of research that produces findings not arrived at by statistical procedures or other means of qualification" (Strauss and Corbin 1998, 10-11). With the help of this naturalistic, interpretative approach I aim to understand the meaning people attach to their social phenomena such as actions, decisions, beliefs, values etc. Until the late twentieth century qualitative methods were used more in a research related to developing social theory than in more applied research (Snape and Spencer 2003), such as my work on bioplastics. However, alongside with qualitative methods have since taken a respected position within research methods alongside with quantitative methods.

All methods of qualitative data collection have some degree of structure. However, a researcher can choose between highly structured and less-structured methods. Highly structured methods of asking questions require an interviewer to carefully follow the procedure of data collection is laid down. For example, interviewees are asked the same questions in the same order. On the other hand, less-structured methods include the naturalistic or unstructured interview reminding of a natural every-day conversation of two people (Wilson 1996). Based on the initial assessment of the techniques I decided to apply semi-structured interviews with key stakeholders and content analysis. I did not consider quantitative random sample questionnaire an adequate tool for my research because of the complexity of the topic. In the field of bioplastics and related waste treatment, the number of experts with the potential to answer research questions is limited.

Interviews were divided into six categories representing various stakeholders from the Czech Republic and particular EU Member States with different involvements in the field of bioplastics:

1. Research
2. Business – Bioplastics and plastics production
3. Business – Waste Management
4. Public sector
5. Non-profit organizations
6. Bioplastics users

Out of each category, on average of seven potential interviewees were contacted. The only exceptions were 'Public sector' and 'Bioplastics users'. The respondents were given open-ended questions, the purpose of which was to understand the experts' knowledge, experience and "the meaning they made of that experience" (Seidman 1998, 3). I chose this type of open-ended questions because they "do not constraint the respondent's beliefs or opinions to predetermined categories as fully standardised methods of data collection must do" (Wilson 1996, 101). Nevertheless, as other methods, open-ended questions have their downside as well. Wilson (1996) claims that an extraction of the relevant material from potentially long responses can be challenging for a researcher. One problem is that post coding of the material increases the time and cost of the interviewing process. Furthermore, open-ended questions open the space for the interviewer's biases.

Approximately a half of the participants were interviewed within "face-to-face interviews in a free format" (Wilson 1996, 94). The rest of the interviewees received questions via email and/or answered them within a skype call. The participants received questions targeting the following areas:

1. The stakeholder's general knowledge, opinion and attitude to bioplastics
2. The stakeholder's knowledge and opinion of bioplastics impact on mitigation of fossil-based plastics
3. The stakeholder's opinion of the sources of bioplastics and their application
4. The stakeholder's knowledge and opinion of proper bioplastics waste treatment
5. The stakeholder's attitude to policy measures related to the bioplastics industry

3.1.1 Technique of interviewing

Interviewing research is considered a suitable method to gain deeper insight into an area which is unclear and blurred and where experts' opinions and attitudes often differ. The issue of bioplastics is one of them. As Seidman (1998, 4) points out, "interviewing provides access to the context of people's behavior and thereby provides a way for researchers to understand the meaning of that behaviour". In the context of the thesis topic, this means that interviewing allows us to put behavior of experts dealing with bioplastics or related fields in context in order to understand their concrete actions performed at their work places, i.e. in research, the public sector, business or in NGOs.

The method of inquiry might be a suitable tool for an investigation of an organization or a company because of the experience of individuals making up the institution or carrying out the process. Furthermore, interviewing is regarded as an efficient way how to gain a better overview of a topic (Seidman 1998).

Based on my experience, I find interviewing as a time demanding technique which required satisfactory communication and organization skills. Initially I had to search and select potential interviewees and establish access to contacts via websites of the institutions in which experts resided, or via my friends and contacts from the former work places. One of the useful options to gain contacts on potential participants of a research is attendance at a conference or other similar events where there is a high concentration of experts on the particular topic. In general, interviewees are more willing to get involved in a research if they already have a relationship with the interviewer, gained ideally during a networking. I attended the 11th international Conference on Bio-based Materials which took place in Cologne from 15th to 16th of May where I got to know several experts who later either participated in my research or recommended me more suitable colleagues willing to answer my questions.

According to Seidman (1998), easier access to contacts does not ensure an easier interview. In this case, easier access meant more complicated interviews. I partly agree with the author as some of the experts I got the easiest access with did not participate in my research in the end due to the lack of time or their slightly different research focus.

This initial phrase was followed by writing emails asking my contacts for an interview and making phone calls. In my opinion, the way the first contact is made might influence the interviewing process and decide about its future success. Hence, I took my communication with potential participants seriously. An important part was scheduling of my interviews in order to comply with interviewees' requests in terms of their availability and to avoid interview overlaps. I also wanted to show my flexibility and adapt to respondents' schedule, which prolonged the interview period that overall lasted for more than one month. Already at the beginning I expected rejection since I find it a natural part of each interviewing. However, the majority of experts contacted replied to my emails and showed willingness to get involved in the research, although a few of the potential interviewees did not participate mainly due to the lack of time.

In order to avoid misunderstandings, Tom Wengraf indicates that prior to an interview it is important to carry out a consultation with the interviewees "as agreed with the interviewees subject to any conditions they impose on all or parts of their spoken material either in general or up to a particular date" (2001, 186). Hence, at the beginning of each interview I asked the participant if the conversation can be recorded and if their names can be quoted. Only four participants of the research refused the interview to be tape-recorded and were reluctant to being named in the thesis.

The next phrase of interviewing is well described by Strauss and Corbin, "Analyses begins with the first interview and observation, which leads to the next interview or observation, followed by more analyses, more interviews […] and so on" (1998, 42). After I completed all scheduled interviews I began analysing records/answers via email based on the recommendations of Irving Seidman (1998) who favours to avoid any in-depth analysis of the interviews until all planned interviews are gathered in order to minimise imposition of meaning from one respondent's interview to another. He also advises researchers to transform spoken words into a text by transcribing interviews. I found transcribing interviews an essential activity enabling further proper analyses, although the transcripts were not intended to be published. I consider the analytical part as labour intensive as the preparational phrase of the whole interviewing process.

Even if not all interviews are transcribed, a vast amount of text is generated. The first suggested step is reducing the data allowing me to analyse and code the material. It is important to know well what I wanted to find out and identify my interests (Seidman 1998). According to Strauss and Corbin (1998), there is no need to study in depth available literature beforehand since it is legitimate not to know the salient problems and theoretical concepts prior the investigation. Nevertheless, in my opinion it is essential to gain basic knowledge about the topic even before contacting potential interviewees in order to show a certain level of expertise and to be able to formulate research questions.

When analysing interviews, it is expected that a researcher has already a broader knowledge of the topic than at the beginning of the research. Hence, scholars, such as Tom Wengraf (2001), recommend to involve a further follow-up-session on the phone (or email) into an interview plan in order to clear up questions that arise during content analysis. In case of several respondents I followed the author's recommendations and asked for follow-up phone calls with additional questions about topics that emerged during the analyses.

3.2 Data Analysis and Coding

When I finalized all my interviews, I continued with the analytical phrase as described in the chapter above, with the help of "coding" which is in brief a procedure to interpret and organize the data.

This qualitative research technique is also marked as "content analysis" (Hsieh and Shannon 2005). Thus I use these terms as synonyms. As Strauss and Corbin (1998) note, this process usually consists of conceptualizing and reducing data, elaborating categories in accordance with their properties and relating through the statements. "The goal of content analysis is 'to provide knowledge and understanding of the phenomenon under study'" (Hsieh and Shannon 2005, 1278).

Coding refers to a word or a short phrase which symbolizes and summarizes a piece of qualitative data (Saldana 2015). Open coding is a dynamic and fluid process during which "data are broken down into discrete parts, closely examined, and compared for similarities and differences" (Strauss and Corbin 1998, 102). Based on suggestions of Strauss and Corbin (1998) I grouped everything similar or related in meaning into "categories" that refer to titles of my chapters in the discussion part of the thesis. Grouping concepts into categories enabled me to reduce the number of units. “Categories are concepts, derived from data, that stand for phenomena […] which are important analytic ideas that emerge from our data” (Strauss and Corbin 1998, 114). It is necessary to take into the account that not every phrase or idea is meant to be conceptualised. For the analyses, both objectivity and subjectivity are relevant for making discoveries (Strauss and Corbin 1998).

Open coding might be done by line-by-line analysis, which is a detailed examination of each phrase or even word. The researcher might also “code by analysing a whole sentence or paragraph” with the intention to find the key idea (Strauss and Corbin 1998, 120), which was my attitude to content analysis. Fracturing data during open coding is followed by axial coding which the purpose of which is to connect categories to their subcategories “to form more precise and complete explanations about phenomena” (Strauss and Corbin 1998, 124). Based on the suggestion of Hsieh and Shannon (2005), I identified and analysed data that primarily could not be coded later to determine if they were about to represent a new category or subcategory.

3.3 Limitations of the research

The research faced several limitations and challenges. Initially I planned to involve Life Cycle Analyses (LCA) as one of my research methods. But at the beginning of the research, I decided to leave it out because I realised that the accessibility of the latest outcomes of LCA of bioplastics was limited. I also could not claim that this this method to was my own because I would have used other researchers’ work. Thus, LCA and studies’ outcomes are presented in the ‘Literature review’ and ‘Discussion’ part as other sources.

Considering interviews, as expected, a certain number of experts out of each category were not responsive despite multiple attempts to set an interview. Several respondents were communicative and willing to participate in the research but due to their limited time and/or the slightly different research focus they did not answer the questions sent. Several respondents showed willingness to get involved in the research but they never replied back after the questions were sent to them. Overall four interviewees did not agree to tape recording. On the one hand, their requirement was understandable. On the other hand, this fact made the interview less smooth and complicated further analyses of the respondents' deep technical and business knowledge.

Another limiting factor was the length of the interviews. Each interview lasted for around one hour. Conversations with scientists from research institutions and with other experts with the deepest knowledge and experience lasted on average for one hour and 15 minutes. Due to this fact, in case of several interviewees I was unable to cover all my research questions.

Although the number of participants is in general considered sufficient for this type of research, and I regard the information gained from interviews as highly beneficial and informative. Experts still pose a small percentage of all people dealing with the topic of bioplastics and biopolymers.

4 Discussion

4.1 Results of the interviews

The interviews were conducted between June 11 and 20 July 2018. Altogether 25 interviewees participated in the research out of 37 contacted experts: 16 came from the Czech Republic and 9 from four other countries: Belgium, Germany, Italy and the Netherlands. In the appendicies I provide the table summarizing the data collection, the date when the respondent was contacted for the first time while some of the interviewees were contacted several times, the date when questions were sent and the date of the interview.

The group 'Users' is assessed as a separate unit since users are the only group that received general non-technical questions. With the exception of Sarka Osickova from the farm Novy dvur, the majority of contacted people also showed lower interest in the research compared to other groups and provided very limited answers. The main questions directed to the bioplastics users were as follows:

- What led you or the company you represent to decide to start using bioplastics packaging?
- Do you or the company inform customers properly about the compostability of the package and its meaning?
- What polymer is the package made of?
- Do you or the company know the exact content of the material including all additives?
- What kind of certification does the package have?
- Are you or the company aware of the fact that biodegradable bioplastics might contaminate the non-biodegradable plastics recycling stream?

All participants, i.e. those who answered my questionnaire, agreed that outrage at current plastic waste pollution played a role in the decision to start using bioplastics. They all regarded the materials as ‘greener’ and more ‘environmentally friendlier’. Hence, praiseworthy thoughts stood behind the transition from conventional plastics into bioplastics. They also all agreed that the price of bioplastics packaging is higher compared to conventional recyclable plastics they were used to purchasing in the past.

Sarka Osickova was the only respondent who showed higher interest in the material used and its end-of-life. Her and her husband’s farm decided to start using biodegradable bioplastics ice cream cups for the same reasons as the others, plastics waste pollution and the information about exporting the collected plastics to China where the further application is often unclear. Although she tried to get to know about the material content as much as possible, she is unable to answer the question related to the type of polymer. Ms. Osickova initially considered the material to be compostable in the home compost. After finding out it was impossible, the farm begin looking for a composting facility. But no composting facility was willing to accept their biodegradable cups as in the country there is no guidance for composting facilities in terms of biodegradable bioplastics waste treatment. As Ms. And Mr. Osicka do not want to throw their biodegradable cups into communal waste, they stopped using them and are waiting for new information and developments in the field of bioplastics.

Overall, I perceive the involvement of the bioplastics users in my research beneficial, albeit or because it supported my hypothesis about the users’ low knowledge of the topic of bioplastics.

Regarding the rest of the participants, there are several topics where the interviewees found general agreement. They are the term ‘bioplastics’; the strict refusal of oxo-degradable plastics; focus on the general reduction of plastics regardless of whether conventional fossil-based or biodegradable bioplastics since it is necessary to take into account the fact that despite the prefix "bio", bioplastics are plastics that need to be treated and do not disappear on their own; focus on collection of recyclable plastics and their reuse or proper recycling; positive contribution of the PET bottles refund system.

In case of all other categories, there are slight differences or completely opposite opinions and attitudes to the issue of bioplastics. Diverse answers vary partly based on the sector in which the participant is involved. Nevertheless, the stereotypic hypothesis that there might be noticeable differences between sectors was not confirmed.

4.2 The Term "Bioplastics"

As briefly mentioned, in the literature the word 'bioplastics' is often regarded as confusing and misleading, although it is widely used by the significant majority of sources on the topic including the reports of the European Commission and European Bioplastics, the main bioplastics association.

As suggested above, all expert interviewees came to the agreement regarding the inaccuracy of the term bioplastics, regardless the sector they work in. Their argumentation shows similar features. Nevertheless, not all agree on the meaning of the term of 'biopolymer'.

According to the key NGOs, *Friends of the Earth Europe and the European Environmental Citizens' Organisation for Standardisation (ECOS)* (2017), the term 'bioplastics' creates confusion, as bio-based and biodegradable plastics are very different in terms of their usage and end-of-life processing. The representative of ECOS, Ioana Popescu agrees with the statement. According to her, in order to be accurate it should be more explicitly defined what bioplastics refers to. The term 'bioplastics' represent various things to different people. For example, bioplastics simply means 'organic plastic' for some people, while others know that various feedstocks are used for bioplastics production, and the rest deems that bioplastics refers to biodegradable substance. On the other hand, Ms. Popescu admitted that among experts the term is used widely in spoken language.

Meadhbh Bolger from other NGO, the organization *Friends of the Earth Europe*, agrees that bioplastics could mean a range of things and this fact causes a lot of confusions.

Stephan Kabasci, Head of Department of Bio-based Plastics, Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Germany, provides a detailed insight into the use of the most frequent terms 'bioplastics' and 'biopolymers', when:

> "'bioplastics' are either bio-based, or biodegradable, or both. Albeit this is a clear definition for bioplastics, there is, however, some inaccuracy in the definitions 'bio-based' and 'biodegradable'. […] The term 'Biopolymers' is being used for polymeric materials that are formed in nature. Cellulose, chitin, starch and proteins are the some of the most predominant examples. The bioplastic poly(lactic acid), being produced by chemical polymerization of natural lactic acid, would not be regarded as a biopolymer according to this definition".

Lenka Mynarova, CMO and the member of the Board of Nafigate corporation, adds that most authors also use the term biopolymer for fossil-based materials because indeed PBAT and some other polymers are biodegradable under certain circumstances.

Tomas Vanek, scientist from the Institute of Experimental Botany AS CR, notes that the term 'bioplastics' means essentially that the plastic is made of chemicals obtained from plants or other biological sources. It does not say anything about whether the material is biodegradable or not, as well as anything about whether it is environmentally friendly or not.

Tomas Vanek's words are supported by Ladislav Trylc, an expert from the Ministry of the Environment of the Czech Republic. He notes that in the media world, there is no agreement on what the bioplastics are. For someone, it is a PET bottle made of corn, but in case of the first group it is a conventional plastic made from renewable resources. The second group are substances based on oil or biomass, which should biodegrade over a certain period of time. Not all bioplastics meet those conditions (Trylc 2018).

Michael Carus, physicist, founder and managing director of the nova-institute, points out that the word biobased has nothing to do with final properties. Biodegradable polymer might be also fossil-based. Most biobased polymers are not biodegradable. Moreover, plastics are not equal to polymers.

Scientist Vratislav Duchacek from the Department of Polymers of the University of Chemistry and Technology, Prague notes that at the department there is an agreement on not to divide plastics into conventional and bioplastics. He points out that certain natural polymers, such as rubber, do not biodegrade and on the other hand, there are synthetic polymers that biodegrade well. Hence, in his opinion, the division into natural and synthetic polymers might be more accurate.

4.3 Sources of Bio-based Bioplastics

The respondents received questions on the source of bio-based bioplastics since this topic is in the centre of debates about bioplastics. Various authors such as Emadian *et al.* (2016, 527) touch the issue of the bioplastics input raw material. […] "although bioplastics are considered to be environmentally friendly materials, they also have some limitations such as high production cost […] which can be managed by utilizing the low cost of renewable resources such as agricultural wastes".

High production costs are closely related to the critiques of bioplastics in terms of their potential contribution to the global food crisis because they take over large agricultural areas that could be used to grow crops for human consumption. Respondents' opinions differ. Representatives of NGOs consider the critique to be more justified than representatives of the research or business sector although all respondents are disturbed by the current intensive agriculture.

According to Ioana Popescu, the first generation feedstock is space demanding, as well as the second generation feedstock which has a negative effect on ecosystems. Land is under intensive pressure due to intensive agriculture, but bioplastics feedstock production adds pressure.

Her colleague Meadhbh Bolger does not consider the land issue the main topic because, as she points out, only a small percentage of land serves for bioplastics crops growing. However, she immediately adds that this is still an industrial use of land and thus it brings the danger of excessive use of pesticides and herpicides in the fields.

Several other respondents also find growing crops for bioplastics industry purposes as inappropriate and unsustainable. They say that agricultural land should be primarily intended for food production. According to Jonathan Edmunds from the packaging and recycling company DS Smith, the demand for crops would be enormous if the bioplastics market share grows.

Nevertheless, according to the report of the IfBB – Institute for Bioplastics and Biocomposites (2018), despite the anticipated growing market share of bioplastics in the next few years, the need for land is expected to be kept at a low level. On average, since 2015 the market for New Economy bioplastics has been increasing by an annual 15 per cent but the need for land will not grow accordinly. Scientists assume that use of agriculture areas for bioplastics feedstock by 2021 will be as low as 0.04 per cent of the whole agricultural land.

Michael Carus does not find the discussion about the feedstock production appropriate. He notes that bioplastics do not compete with food production. He continues by saying that it is necessary to point out that it is proteins, not sugar, which are rare in the regions suffering from hunger. If mankind is not allowed to use biomass for any other purposes but food, people should not be allowed to purchase new cars, phones and other goods as long as a single person is starving in the world.

In addition, for example starch is used in paper production. Starch could be replaced by petrochemicals, but this step would contribute to the release of CO2 emissions contributing to the loss of large agricultural areas. Hence, first mankind has to decrease its carbon footprint (Carus 2018).

Expert on bioplastics from the Netherlands admits that there is a lack of a good debate on bioplastics sources. In his opinion, bioplastics production does not compete with crops growing for food. The productivity of farming has increased tremendously producing too much meat and dairy products. On the one hand people do barbecue each weekend but producers are blamed for using a small percentage of land, less than 0,1 % of the soil. Bioplastics industry should be able to debate about how to use the land in general.

4.3.1 First and Second vs Third Generation Feedstock

Opinions on the first and second vs third generation feedstock vary. For example, according to the authors Guerrini *et al.* (2017) bio-based plastics from agricultural feedstock might pose new production opportunities for farmers. The respondent Stephan Kabasci notes that there are basically economic reasons for using first generation feedstock, currently. Tomas Vanek also brings up the economic side of the bioplastics production since it is natural that producers use a source which is best available and cheap.

The company Novamont brings an innovative approach towards growing crops, which is not putting a burden on food production. The company uses waste land areas for the bioplastics feedstock. The waste land cannot be used for agricultural purposes since it is located next to highways, railways or the land is of very bad quality (Siebert 2018).

Regarding biowaste, i.e. the third generation feedstock, as a potential source of bioplastics, Stephan Kabasci provides a detailed comment. He notes that it:

> "[…] depends on the type of biowaste. If the waste consists of a broad mixture of constituents and contains a lot of valuable fertilizing elements (Nitrogen, Phosphor, Calcium etc.) like in mixed household kitchen and garden waste, composting and using

> the compost as a fertilizer is the preferred option. Materials that are rather 'pure' streams and do contain mostly the elements Carbon, Oxygen, and Hydrogen, like e. g. wood chips, pulp, straw etc., conversion to bioplastics (or other bio-based chemicals) might be favorable. However, even in this case the energy requirements for the processes definitely have to be taken into account. It needs huge efforts to produce sugars from lignocellulosic materials (or wastes) which are the standard raw materials for most biotechnological processes. Classical sugar sources like sugar cane, sugar beet or corn starch and their processing is much cheaper".

Tomas Vanek highlights that in some countries, maize does not grow much and all parts including green 'waste' parts are fed but in other countries, where maize is grown mainly for grain, green parts are considered waste. In those situations, green "waste" parts can be utilised as a bioplastics source and thus not contributing to the global food crisis.

The report issued by the European Commission speaks similarly. "PHA production using mixed microbial cultures which is the low-cost feedstock that is currently considered agro-food waste, has no market value, does not compete with food and is not affected by price volatility" (2017a, 8).

Hence, there is nothing wrong with using biowaste for material purposes, but economic calculation has to be taken into account and we should compare whether it is more convenient to produce bioplastics or biogas. Bioplastics manufacturing cannot be subsidised (Vanek 2018).

Critics of the subsidies claim that it disadvantages stakeholders who are not involved in the system. In this case, for example biogas power plants are subsidised in the EU. Thus, it leads to the question if this fact does not ruin the market wth biowaste by disadvantiging material production.

Ioana Popescu also says that biowaste might be utilized both for making bioplastics or fermented in a gas power plant and used as an energy source. Ladislav Trylc supports the idea of the bioplastics production from sources considered "waste" such as woodsrips or straw etc. Crops growing would not have to be burdened by pecticides and herpicides. In case of rape plant high amounts of pesticides and herpicides are used because oil is extracted from the plant. But Mr. Trylc doubts that third generation feedstock can satisfy subsequent demand. Partly, the third generation feedstock might be considered a marketing step, however, large investments can help to bring new polymers and move the whole industry forward.

Lenka Mynarova disagrees. She claims that if biodegradable polymers are manufactured from used oil, there is no difficulty in getting the feedstock anywhere in the world. Furthermore, in Europe there are also imported sources of used oil due to the policy on biofuels. Oil is three times more yielding than sugar or starch. Hence, this feedstock is viable without subsidies.

On the other hand, the currently frequently mentioned algae as an example of the third generation feedstock is extremely water and energy consuming (Popescu 2018). Together with cellulose these feedstocks are not viable sources (Mynarova 2018).

A new source of polymers might be waste water. Stephan Kabasci notes that here is a lot of interesting research regarding the production of PLA from waste streams. PHA production from wastewater has already been driven to first pilot plant tests. Stephan Kabasci is not sure that whether these materials can be used for any challenging products or not – due to the variability of the source materials that might lead to changes in PHA quality from batch to batch. Nonetheless, especially for some single-use items which are in discussion presently (straws, ice cream spoons, other take-away cutlery etc.) such plastic materials would be an interesting option because of the extraordinary good degradation behavior of PHAs.

4.4 Application of Bioplastics

Currently, the subject of the debate is the question what type of bioplastics is widely suitable and in what sector. The majority of biodegradable bioplastics does not have resolved their end-of-life circle, or more precisely most of countries' infrastructure is not ready to let bioplastics to enter the waste collection and treatment systems. The limitations in terms of higher price and lower mechanical properties also play a role in decision making of potential users.

Lenka Mynarova points out that if the product does not have resolved its end-of-life circle, it should not be present on the market. According to Michael Carus, biodegradation makes sense only in a few applications, i.e. in cases when the material cannot be collected and recycled. If the collection and recycling is enabled, then biodegradation is not needed. Ioana Popescu supports this idea. It is most important is to know for what purposes the package is designed, which tells us what properties it should have. If the product should be long-lasting and durable, biodegradability does not belong to the suitable characteristics of the material. Furthermore, in case of single use items, biodegradability is not always desired due to several reasons. On the other hand, if the biodegradability of the product is beneficial, then it should be biodegradable.

The vast majority of the respondents points out the necessity to avoid contamination of the conventional plastics recycling stream. Milan Havel from the NGO Arnika and Ivo Kropacek from the organisation Hnuti Duha aptly summarise these concerns. NGOs and recycling business are concerned about the expansion of PLA and other biodegradable bioplastics. They assume that it is difficult for consumers to distinguish between conventional plastics and bioplastics with respect to their identical appearance. Biodegradable materials might endanger plastics recycling as soon as they are mixed in containers intended for recyclable plastics. I admit that not only NGOs and recycling companies are concerned about potential contamination. Various representatives of the packaging and bioplastics industry share theses worries as well.

Furthermore, several interviewees note that the existence of biodegradable bioplastics may increase the tendency for littering. Bioplastics may cause the risk of sending the wrong message. Tomas Vanek brings up the concern that biodegradable bioplastics might have a negative impact on the initial efforts of developing countries to improve their waste management system if the users begin to believe that the substance is biodegradable, i.e. from their point of view compostable in the open environment.

4.4.1 Application in Food and Packaging Industry

Packaging industry and connected food business have been developing rapidly in the recent years due to the requirements of customers who generate a pressure on the companies in terms of higher sustainability

According to a 2012 survey of 250 senior executives, 44 per cent find sustainability critical to their business, “78 per cent think that it is vital to their future growth, 62 % say their sustainable investments are motivated by customer expectations for sustainable products and services and 60 per cent by the opportunity to drive growth” (Cooper 2013b, 110).

Companies apply their ‘sustainable investments’ to bioplastics as well. Recently, plastic biodegradable straws, cups and other single use items have emerged on the European market. In my point of view, this is an example of the wrong usage of bioplastics. In general, straws and cups belong to one of the most problematic single use items contributing to plastic waste pollution, mainly in coastal regions where they enter the oceans due to littering and the weak local waste management system. The potential replacement of conventional plastic straws and cups with biodegradable fossil or bio-based materials does not offer a solution to the problem of pollution because the materials biodegrade under special circumstances. In contrast, proclaimed biodegradation can even increase the current issue of plastic waste pollution since consumers influenced by marketing slogans could become more indifferent to littering.

Especially biodegradable straws do not bring any positive value, as this item is generally overused and can be easily replaced by straws processed from iron for repeatable usage or straw material without further synthetization. In my opinion, for instance tea bags might be biodegradable which would enable their composting.

Several respondents are strictly against the utilization of bioplastics in food and packaging industry where it could get mistaken by an ordinary consumer. Ivo Kropacek notes that it is impossible to explain to customers the difference between conventional plastics and biodegradable bioplastics and what waste bin the material belongs to.

On the other hand, for example Ioana Popescu claims that biodegradable bioplastics might be used for food packaging. It is only necessary to put labelling on the package such as ‘put me into the compost’. She explains that if an explicit text is located on the package, customers cannot get confused. Nevertheless, widespread introduction of these packages cannot occur without efficient collection of biowaste.

The expert on bioplastics from the Netherlands provides a similar opinion that biodegradable bioplastics might be used in packaging intended for contact with food, such as food packages in shops or packages for leftovers from restaurants. In his opinion, currently it is harder to separate these packages because they cannot be composted due to the presence of plastics, and they cannot be directly recycled due to the presence of food. If the package was biodegradable, it could be composted together with food and provide a good end life solution.

Nevertheless, this measure could be functional only under the prerequisite that packages intended for food would be biodegradable all at once. At present, the majority of plastics for food can be easily separated and recycled because biological contamination is minimal. In case of packages for leftovers from restaurant, paper material might be more useful because of its lower production cost and satisfaction of the requirement of compostability.

The expert on bioplastics from the Netherlands adds that beverages should not be put into biodegradable bottles. They should be collected, reused or recycled instead. In the Netherlands, there is a good experience with the system of PET bottles deposits. Stefanie Siebert or Michael Carus from Germany also praise the PET bottles refund system and admit that biodegradable bottles are not a good idea.

But, despite the name ‘deposit refund system on PET bottles’, the majority of the collected PET bottles in the particular countries are not reused but crashed and recycled. Thus, the system does not minimise the use of single-use PET bottles. However, the real deposit refund system allowing to reuse bottles repeatedly has many advantages compared to recycling, landfilling and energy recovery.

Using this system allows avoiding tons of packaging waste. The deposit refund system uses around 30 per cent less water than recycling as cleaning containers uses less water than producing them (Anty n.d.).

4.4.2 Application in Agriculture

The utilization of biodegradable bioplastics in agriculture has become a hot topic on which experts have slightly different opinions. The most preferred products that might be manufactured from biodegradable bioplastics are mulch and other types of covering films, cups and clips. As Briassoulis et al. claim that “biodegradable plastics can be used in products that are intentionally used in soil contact, e.g. agricultural mulching films, and in products where soil is the inevitable final location” (2017, 141). Compared to conventional plastics, biodegradable bioplastics can be left in the soil to degrade naturally and save farmer’s resources as there is no need to manually remove, transport and recycle the product (Niaounakis 2013; Naryan 2017).

In the past the mulching technique was performed by using natural mulches like straw, leaves, fibres or compost which are currently used by many organic farmers. Neverthless, plastic (conventional or bioplastics) mulching films can satisfy particular requirements such as prevent the rise of water containg salts or help suppress weed growing. Moreover, artificial mulching films can guarantee the stable mechanical and physical characteristics needed for the whole crop cycle (Santagata *et al.* 2017).

Hence, biodegradable mulches appear to have a potential since they might combine properties of conventional mulch films with biodegradability. However, current biodegradable films are naturally more expensive than conventional PE films. As Martín-Closas et al. (2017) argue, it happens partly because of the weaknesses in the economic evaluation. Recycling is performed outside the agricultural sector and because of that farmers take no responsibility in the waste treatment. If the costs of recycling were involved in the price of films, PE and biodegradable mulch prices would be balanced.

On the other hand, the collection of recyclable waste is covered from taxes in order to motivate citizens to recycle. Furthermore, for example mulching films can hardly be suitable for recycling since they are usually stained with soil.

Briassoulis and Innocenti challenge the view of Martín-Closas et al. According to them, "recycling is not considered as a cost-efficient and/or technially feasible solution" […]. The alternative for these materials is the costly option of energy recovery" (2017, 140).

A certain number of interviewees mentioned agricultural purposes as an option for bioplastics application. For example, Stefanie Siebert notes that biodegradable plastics could be suitable in agriculture where common plastics often contaminate the soil. Tomas Vanek finds potential usage of biodegradable bioplastics in mulch or cover films. Michael Carus sees the potential usage of bio-based and biodegradable polymers in films protecting young trees, that are currently from PE.

Nevertheless, all the research participants as well as various authors such as Briassoulis et al. also point out that the soil quality is a major interest since soil is "the precious resource for food and fiber production" (2017, 141). For bio-based materials which degrade in soil, the rate of degradation can vary considerably, depending not only on the molecular structure of the material, but also on availability, which varies widely and influences microbial acitivity. Materials that are not soil-biodegrable may result in contamination of the soil.

Jonathan Edmunds (2018) identifies himself with the utilization of biodegradable bioplastics for the agricultural purposes but he doubts to what extent the material degrades in the soil. Hence, he finds the replacement of mulching films and cups as risky.

Ladislav Trylc sees the capacity only in certain uses such as various films. But he considers the massive replacement problematic. Bioplastics contain additives supporting their mechanical and other characteristics, which can increase the risk of soil contamination. In order to prove the harmlessness of a product, earthworms or salad seeds are used for testing. The material must not force earthworms to leave the compost or soil and inhibit the germination of the salad.

The expert from Italy on separate collection opposes the utilization of biodegradable bioplastics in agriculture. He does not consider the soil a final degradant. At present, standardisation for open degradation is lacking. Thus, it could be risky to let material biodegrade in the field. However, he is open to the future potential use of bioplastics in the agriculture sector.

Ivo Kropacek emphasizes that in case of various cups utilized in the agriculture sector, paper appears to be a better solution. It would biodegrade anyway without a danger to be mistaken for conventional plastics.

4.4.3 Other Utilization

Regarding 'other utilization', biodegradable bags for biowaste collection represent the most frequently named other potential application of bioplastics.

In Italy they introduced an innovative separate biowaste collection. Italians collect municipal biowaste more frequently than in Germany where waste bins are collected only every two weeks, whereas in Italy they use biodegradable bags which the citizens leave outside their door and the city collects them three times a week. Biowaste separation in Milan is considered an example of good practice. The municipality was implementing the system of biowaste collection between 2012 and 2016. Thanks to biodegradable bags, 90 kg per person per year is collected in Milan, whereas in Berlin only 20 kg per person per year. In Italy there is a special certification scheme for biodegradable bags (Siebert 2018).

The expert from Italy on separate collection adds that the use of bioplastics bags maximizes collection of biowaste in Italy, where overall 6.5 million tons of kitchen and garden waste is separated each year. The bags are made from PLA blends. Meadhbh Bolger supports his worlds that municipal biowaste collection goes very well with biodegradable bags. In Belgium, the separate biowaste collection has also been implemented but conventional plastic bags are used in the country.

Claims of the respondents are supported by the studies indicating that "the introduction of compostable waste bags for collecting biowaste does not lead to an increase in conventional non-biodegradable bags in the organic waste collection" (European Bioplastics 2015, 3), that would put a burden on composting facilities and potentially harm the compost.

Many Czech respondents agree that biodegradable bags for biowaste collection should be in place in the future, including Ivo Kropacek who remarks that composting facilities have to deal with the problem of conventional plastics getting there together with separated biomass. Hence, biodegradable bags might pose a big advantage. Ladislav Trylc argues that it has to be ensured that biodegradable bags do not contain harmful additives. Colours on the bag have to be biodegradable as well.

Anna Tvrdikova from the Municipality of Prague describes that in 2016 the delegation from the City of Prague was invited to Milan. Thus, in Prague, they are familiar with the Italian measures on the biowaste collection. In Prague's two quarters, there are projects for the collection of biowaste and kraft paper and starch bags are being tested. Hence, in Prague there are already considerations about the implementation of biodegradable bags. Identically, Anna Tvrdikova adds that the use biodegradable bags might be quite problematic because the bags may get wound onto a hopper. Furthermore, the bags are undistinguishable from conventional plastics bags and the quality and degradability of the bags by individual manufacturers vary.

Tomas Vanek identifies that in composting facilities, automatic rakes are used for mixing homogeneous biomass. Bioplastics bags have to be cut into smaller pieces, which might be a burden on composting facilities.

Roman Farion from an industrial composting facility in Trhovy Stepanov disagrees. In the facility, the biomass material is crushed at the beginning of the procedure. Breaking up of biodegradable bags is doable and would benefit their biodegradation.

Diapers are another product mentioned repeatedly by several respondents. Diapers have the potential to become biodegradable in the future because current diapers cause complications in landfills. In incinerators the product increases the creation of slag which anyway ends up in landfills. However, sorbet in diapers appears to be a difficulty (Kropacek 2018) The expert from Italy on separate collection supports Ivo Kropacek's words since he also finds the sorbet in diapers problematic. Meadhbh Bolger also emphasizes that it might be problematic to let diapers biodegrade together with kitchen and garden biowaste.

I admit that in my opinion industrial composting facilities would have to ensure achievement of the temperature that kills all dangerous bacteria. Diapers from biodegradable bioplastics might also be disposed in an anaerobic digestion process.

Ivo Kropacek suggests the bio-based outsoles because shoes can hardly be recycled. Expert on bioplastics from the Netherlands also mentions a similar idea for running shoes, not only outsoles. But in his opinion, the material should be bio-based and durable, not biodegradable.

Currently, bioplastics are also utilized in the automotive industry. Ivo Kropacek is however sceptical about the use of bioplastics in this sector. The reason is that an entire car is crushed during the liquidation. Pieces that look like plastics are headed for recycling where bioplastics might present a contamination risk. Jonathan Edmunds also regards the use of bioplastics in the automotive as risky.

In my point of view, the automotive industry prefers bio-based and non-biodegradable bioplastics. Hence, the issue of mixing with conventional plastics intended for recycling is not of concern. Meadhbh Bolger notes that also coffee cups from biodegradable bioplastics appear to be a good idea. The current multilayer coffee cups are not convenient for recycling and anyway end up in landfills or incinerators.

4.5 Bioplastics Waste Treatment

Bioplastics waste treatment pose a crucial area of the whole bioplastics issue. Bioplastics have their life cycle as conventional plastics. Despite the prefix 'Bio' which evokes the material is natural, ecological and easily compostable, the overwhelming majority of bioplastics does not disappear without proper treatment.

In this connection, it is important to point out that petrochemical materials can still be perceived as sustainable if they are at the end of their life cycle (Cooper 2017b). Reused, recycled or properly disposed conventional fossil-based plastics are also less harmful towards the environment than bio-based biodegradable bioplastics treated in the wrong way.

4.5.1 Recycling

In case of bioplastics when speaking about recycling it is necessary to distinguish between non-biodegradable and biodegradable bioplastics which are generally considered a concern for mechanical recycling. Whether the source is biomass or petrochemicals does not play a role in this case.

In each country, the market works a little differently. In the Czech Republic the plastics recycling is on the high level. Hence, there is a high risk of the plastics stream contamination. Recycling companies need the stream to be clean. Once there are more than 5 per cent of undefined plastic, recycling might be seriously contaminated. In the Czech Republic, the secondary separation is done manually. For employees, it is very difficult to distinguish the material that looks identically as conventional plastics. It is impossible to prevent errors. The potential solution would be to produce biodegradable bioplastics only of one colour but at present it is impossible to realize such an idea (Vanek 2018).

Jonathan Edmunds from DS Smith admits that recycling manufactures see the appearance of biodegradable bioplastics as a serious problem. The companies need to guarantee the quality of recycled plastics. If the quality is not satisfied, purchasers might stop using recycling products. Hence, introduction of biodegradable bioplastics and biopolymers endangers the whole recycling industry. He also explains that the reason why lots of plastics is not recycled is that it is mixed with extraneous material. Potentially all plastics is recyclable.

German researcher Michael Carus provides a slightly different explanation. According to him, volume of particular material is crucial in terms of potential recycling. He emphasizes that in general 55 fossil-based polymers are not included into recycling. Thus, only approximately 5 fossil-based polymers are being recycled regularly because they form the basis of the majority of fossil-based plastics. Once PLA and its blends represent enough large volume on the market, a separate recycling stream might be introduced. Moreover, it is already possible to separate plastics with infra-red light. He also points out that in many EU counties, the most of content of yellow containers is incinerated.

German researcher Stephan Kabasci supports the words of his fellow citizen that bioplastics like PLA, PHA and others can be sorted out from PE or PET using IR-sorting devices. Nevertheless, this technology is very costly and thus not widespread within the EU.

Lenka Mynarova points out that each material should have a clarified end of life. Lots of people think that biodegradability itself is a solution to end-of-life circle of plastics, but it is not the right attitude. Cosmetics poses only one of few examples where biodegradability might be considered an end-of-life solution. Instead of grinded PE, grinded biodegradable P3HB can be used in cosmetics where the rest of the product ends up in the sewage where it becomes feed for microbes and bacteria and disappears in 3 days. However, in case of common products like packaging biodegradability does not pose an end-of-life solution. Each blend has a different level of biodegradability. It is not given by the source of bioplastics but the whole composition influenced by the type and amount of additives. Nucleants have a major effect on biodegradability. In different words, the fact that a manufacturer produces an item made from biodegradable polymer does not mean that it decomposes in the announced ecosystem.

Lenka Mynarova adds that until a bioplastics product has resolved its end-of life circle, it should not enter the market. PLA in most of the cases does not have this end-of-life solution yet. Composting facilities face complications with PLA and PBAT that does not biodegrade as declared. Recyclable conventional plastics might be a more sustainable option than a bioplastics product which it is not known where it ends up.

4.5.2 Biological processes

Anaerobic decomposition and composting are involved in the biological methods of biodegradable waste treatment. The significant majority of biodegradable bioplastics need to be decomposed under special circumstances in industrial composting facilities although producers call their products compostable which evokes home-scale composting.

It is crucial to know that a home-scale compost can reach a maximum of 35°C and industrial composting facility up to approximately 57°C. Both composting facilities need a maintenance performed by specialists but industrial composting facilities are designed to process large volume of kitchen and garden waste that need a more complex processing ensuring the desired temperature. According to her, industrial composting facilities should be able to manage a high volume of bioplastics (Popescu 2018).

Roman Farion from the Czech industrial composting facility in Trhovy Stepanov admits that it is necessary to distinguish between common small-scale composts and industrial composting facilities which are specialised plant where the material is turned and mixed regularly to make sure that biomass is enough aerated. Running of such a plant requires skilled employees.

However, Meadhbh Bolger notes that in Belgium for example PLA cups and other biodegradable bioplastics would be thrown into communal waste intended for incinerator or landfill. She admits that these materials are confusing for people.

Based on the interviews, it is apparent that in general composting facilities are reluctant to accept bioplastics mainly due to the contamination risk and lack of information about these new materials.

German bio-waste treatment facilities are very careful to accept bioplastics. The main reason is that the distinction between compostable plastics and non-degradable plastics is difficult. And since, unfortunately, many people still use non-degradable plastics for collecting bio-waste, separating out any plastic material before waste treatment is the easiest option (Kabasci 2018).

Stefanie Siebert discusses that in Germany, only few composting facilities and anaerobic plants accept biodegradable bags. It is not considered a common practice. Composting facilities and biogas plants differentiate between conventional plastic and biodegradable bags with difficulties.

In the Netherlands, composting facilities and plants accept bioplastics but there are complaints that material does not degrade as well as announced. Biomass needs around one or two weeks to degrade, bioplastics needs much more time. However, composting facilities should know that biodegradable bioplastics are new on the market and they comply with composting conditions, although it is natural that there are issues at the beginning of each new innovation (Expert on bioplastics from the Netherlands 2018).

Conventional plastics or non-biodegradable bioplastics mistaken with biodegradable bioplastics designated for home / industrial composting do not represent the only possible contamination. Participants of the research were given also a question on the quality of bioplastics in terms of level of biodegradability and additives.

In the course of the certification process of compostable plastics, the materials are being analysed for heavy metals and halogens content in order to prevent these ecotoxicologically relevant substances from entering the compost. Additionally, ecotoxicity tests (plant growth tests) have to reveal, that compost with an extraordinary high concentration of approximately 10 per cent of the plastic material does not influence plant growth (Kabasci 2018).

Meadhbh Bolger identifies a big issue with the EU standards on industrial composting which allow for 10 per cent not to biodegrade up the end. Full biodegradation is actually 90 per cent. Compost is used by farmers and thus this measure might pose a potential risk of compost contamination. Colleagues from the organization work on proposal promoting the full biodegradation. In case of anaerobic plants, they use primary screening process that remove all plastics, no matter if conventional or bioplastics. Hence, bioplastics cannot be transported there.

Not only a contamination risk plays a role in the decision making of composting facilities. Bioplastics might be considered a technological risk as well. Ioana Popescu claims that composting facilities have various reasons for not taking biodegradable bioplastics. Not always contamination risks but often personal beliefs and personal attitudes to innovations are involved in the decision making.

According to Tomas Vanek, acceptance of bioplastics by composting facilities appears to be a complication. The operators would have to invest into new technologies although the bioplastics packages do not bring any benefit to the compost.

The separate biowaste collection and industrial composting is fundamental for spread of biodegradable bioplastics. Meadhbh Bolger points out that separation of biowaste will be mandatory in the EU but nobody knows if also biodegradable plastics will be accepted.

4.6 Policy and Costs of Bioplastics

4.6.1 Bioplastics Energy Demand on Resources

Bioplastics, no matter if biodegradable or non-biodegradable, are more expensive than conventional plastics. One of the reasons is that that majority of bioplastics is considered more energy demanding. Despite this claim, several experts consider several types of bioplastics to produce lower GHG emissions.

Generally speaking, bioplastics production is more energy intensive, albeit of course it depends on the type of feedstock. LCA should tell us all the potential negatives, but for example in case of some raw materials, such as corn, a possible erosion would have to be included, but no LCA has capacity to cover these factors. Furthermore, for example PLA is energy-intensive because PLA is made by polymerization of lactic acid and starch is added artificially. PLA on its own is unusable substance (Trylc 2018).

Tomas Vanek explains that bioplastics naturally have to be more energy-intensive. Oil or coal represent concentrated source of chemicals in a low-volume, but for instance corn biowaste has lower energy yield. Furthermore, procession of bio-based bioplastics involves more steps than fossil-based plastics.

Ioana Popescu admits that producing bioplastics is extremely energy intensive and often they do not perform better than fossil-based. The data for all bioplastics are lacked. LCA only for single types of bioplastics. Lenka Mynarova notes that Bio-PET needs many steps in the production. Bio-PET, as well as Bio-PE are very demanding for feedstock, energy and water as presented in the figures below.

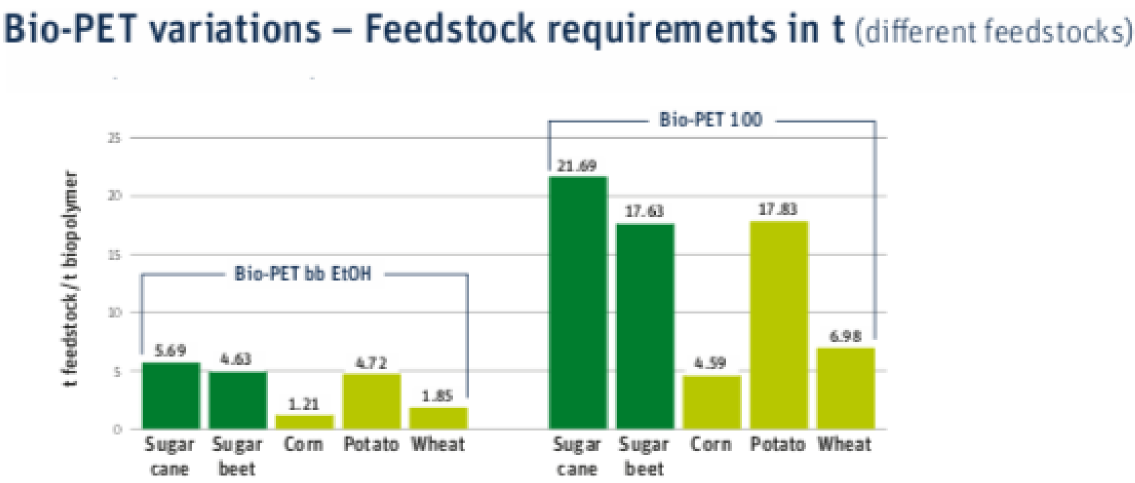

Figure 6: Bio-PET variations - Feedstock requirements in t (IfBB – Institute for Bioplastics and Biocomposites 2018)

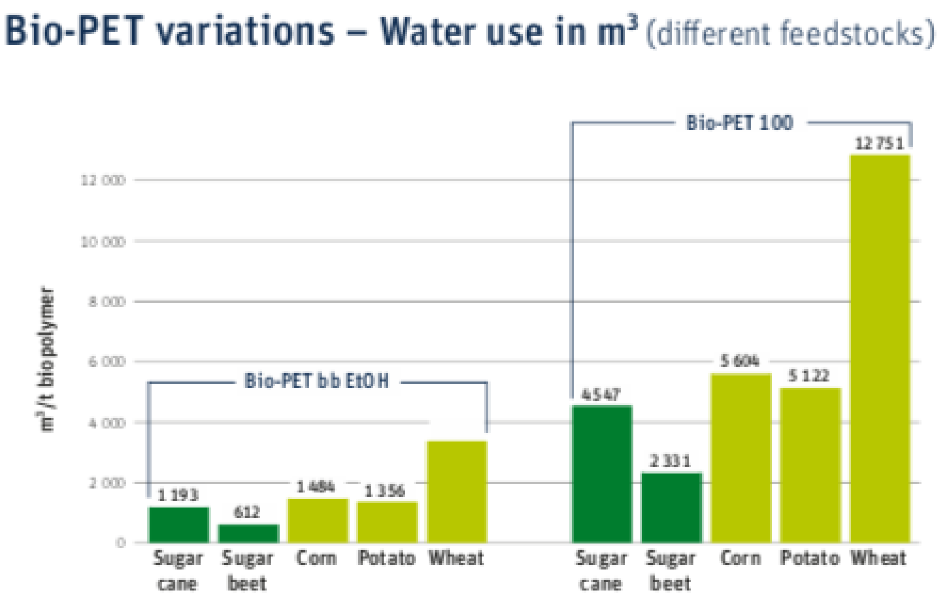

Figure 7: Bio-PET variations - Water use in m3 (IfBB – Institute for Bioplastics and Biocomposites 2018)

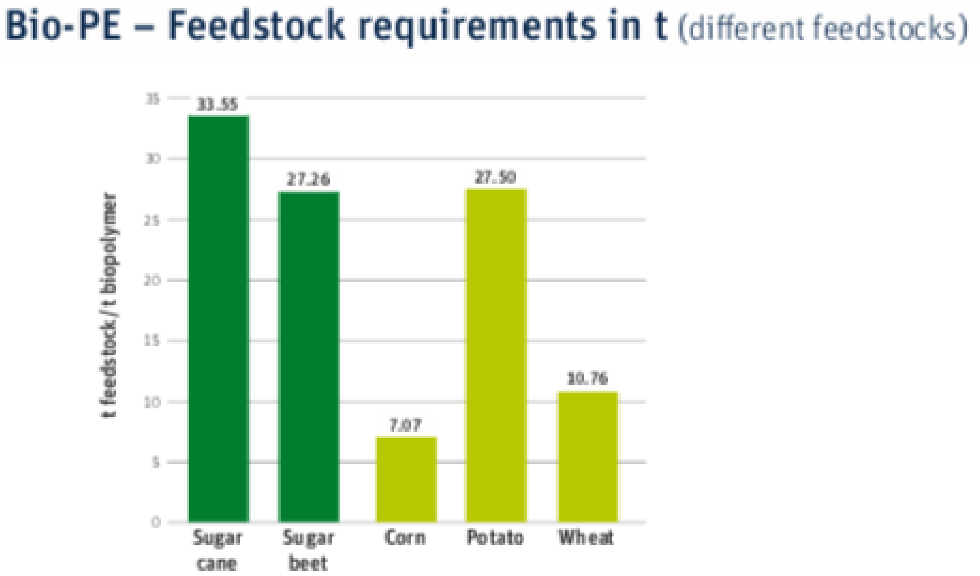

Figure 8: Bio-PE - Feedstock requirements in t (IfBB – Institute for Bioplastics and Biocomposites 2018)

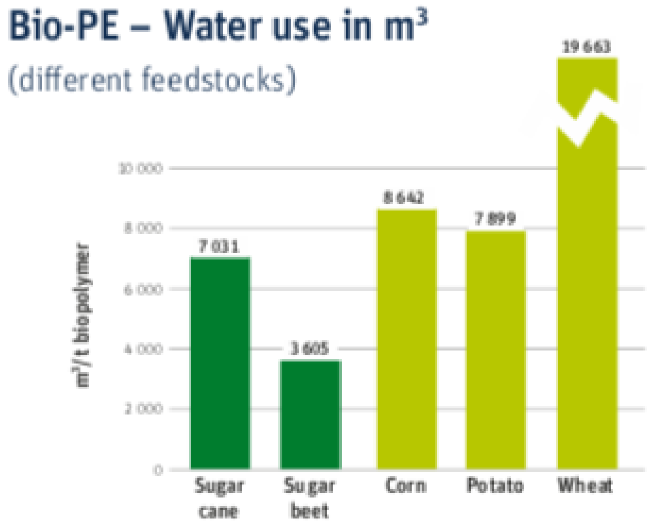

Figure 9: Bio-PE - Water use in. m3 (IfBB – Institute for Bioplastics and Biocomposites 2018)

According to Stephan Kabasci, it is impossible to say that bioplastics in general have a lower carbon footprint that fossil-based plastics or vice versa.

> "Some of them, e. g. bio-based PE and PLA do have a lower carbon footprint (CFP), at least for a cradle-to-gate calculation. However, in looking at the complete life-cycle, CFP calculations are highly sensitive regarding the end-of-life option (mechanical recycling, incineration, composting, landfilling etc.) that is assumed in the model. Additionally, assumptions regarding energy supply in plastics production (for fossil- and bio-based materials) and transportation distances can also affect the CFP. Some

bioplastics, like the biodegradable co-polyester poly(butylene adipate-co-terephthalate) PBAT, on the other hand do have a higher CFP than e. g. PE".

Michael Carus emphasizes that although most bio-based bioplastics need more energy to produce, most bio-based bioplastics have 30-60 per cent lower carbon footprint.

4.6.2 Certification and Labelling

Most of certification systems inform about a product's compostability / biodegradability, but it is useful to highlight the fact that not all bio-based bioplastics are biodegradable and not all fossil-based plastics are non-biodegradable since on the market there are also biodegradable bioplastics from petrochemicals. Moreover, the significant majority of biodegradable bioplastics may undergo efficient biodegradation only under "special conditions" which can be hardly understandable for consumers.

As already mentioned, there are no European or international specifications regarding biodegradation in soil, although bioplastics claimed to be bidegradable in soil are already available to customers. For compostability there are in place several certification systems which contributes to the current confusions connected to these newly emerging materials.

As Narayan (2017) points out, many bioplastics producers often make unqualified proclamations of biodegradability and label their plastic product 'biodegradable' or 'compostable' without providing actual per cent biodegradability values obtained in the test. "Any degradability claim is potentially misleading if not referred to a testing scheme, specific test methods and specific performance requirements. Even materials which show a very slow rate of biodegradation or abiotic degradation can be considered 'biodegradable', if the time scale of the degradation process is of no interest. This is clearly not the case: the timescale is of great importance if biodegradation is to be used to solve the waste problem" (Briassoulis *et al.* 2017, 155).

The revised final report of DG Environment on Plastic Waste in the Environment (2011) set several targets to increase inclusion of recycled plastics and bioplastics in place while one target is aimed at maximization of effectiveness in terms of a labelling system and initiatives to increase public awareness and education about different types of plastics. “A biodegradable material should be labelled by recognized certification organisms as being biodegradable in a specific medium condition in accordance with the relevant standard testing methods as specifications described earlier” (Briassoulis *et al.* 2017, 153).

The EU is currently working on the adoption of the norm for domestic composting that would help prevent people from throwing biodegradable bioplastics into their home compost since most biodegradable bioplastics are compostable only under special conditions in industrial composting facilities. Certification and labelling are problematic. There is only one norm labelling a package as compostable, EN 13432. Lots of materials do not meet the standards. Private institutes, such as European Bioplastics also issue their own certificates. At present, despite proclamations about biodegradability and compostability, the manufacturer does not guarantee anything. Although, products should comply with ISO standards, even ISO standards do not guarantee anything reliable regarding compostability. They refer only to biodegradation under the ideal conditions. Hence, manufacturers and sellers are not at risk, if they declare that the product is biodegradable. On the other hand, all plastics packages which are manufactured with an intention to be in contact with food, need to meet the standards of the Ministry of Agriculture of the Czech Republic. In the Packaging Act – it is said that the packaging has to be recyclable, compostable or to be energy used (Trylc 2018).

Lenka Mynarova admits that various international standards do not address the real conditions, and explains that under the leadership of the Ministry of the Environment, the Czech Republic is currently working on seting national specifications for biodegradation under real conditions.

On the other hand, the expert on separate collection from Italy (2018) insists as long as the material comply with standard EN 13432, the product is safe for the local utilization.

4.6.3 Policy Measures

This chapter refers about policy measures on bioplastics that are already or should be in place. The issue is closely related to the policy measures on conventional plastics because the approach towards bioplastics will have an impact on conventional plastics and vice versa. The broadly discussed topics among interviewees were reduction of all plastics, implementation of higher taxation on plastics, positive stimuluses motivating producers to behave more sustainably and responsibility of food and packaging companies.

Lots of respondents agree that in order to tackle plastic waste issue it is fundamental to reduce all plastics, regardless if conventional or bioplastics. For example, according to the expert on bioplastics from the Netherlands, the main point is to reduce all plastics in general. He divides plastics into functional and marketing plastics, regardless whether conventional plastics or bioplastics. Functional plastics have many good properties. For example, they help prevent food waste in case of long distances imports. On the other hand, marketing plastics should be strictly minimised. Furthermore, societies should be stricter in terms of collection and recycling, especially in case of PET bottles.

The first step should be the reduction, the second step collection and recycling. Bioplastics are considered the third step, i.e. they should be launched only if the material cannot be collected and recycled, then it should be biodegradable (Luben 2018).

Jonathan Edmunds identifies that it is necessary to reduce plastics in general since changing people's behaviour plays a significant role. Especially the use of single use plastics should be decreased. Customers should know that they are also responsible. Conventional plastics do not have to be replaced only with bioplastics. Another option is paper fibres.

I agree with Mr. Edmunds that mainly in food sector many plastics packages might be replaced by paper or straws such as packages for leftovers from restaurants, trays, cups or straws in restaurants.

Regarding regulations, representatives of NGOs prefer higher taxation imposed on all plastics including bioplastics. Ioana Popescu notes that higher taxes should be imposed on conventional and bioplastics as well since conventional plastics producers belong to main bioplastics producers as well. Hence, from their side there is not a strict opposition towards conventional plastics.

Ioana Popescu also highlights that in general plastic packages do not help prevent food waste. The amount of plastic packages produced has increased in accordance with food waste. Packaging help prevent food waste in cases if a long transport is involved but it brings no positive impact on short distances. Thus, the first step is to prevent plastic production. In general, it is necessary to minimise the use of plastics, including bio-based and biodegradable. The second point is to ask for what purposes that package is designed, like for medical applications, agriculture and others, and then to decide what properties are needed from the material based on this knowledge. If biodegradation is needful, then material should be biodegradable. In general, there is no point in replacing most of conventional plastics. Meadhbh Bolger adds that NGOs promote reusable materials, i.e. durable recyclable plastics.

On the contrary, the expert on bioplastics from the Netherlands notes that current plastics which are oil-based are still extremely cheap. People should pay also for carbon emissions.

Several respondents find important to distinguish between virgin and recycled plastics, such as the expert on separate collection from Italy who clarifies that the EU plans to impose higher taxation on virgin conventional unrecyclable plastic.

Jonathan Edmunds admits that there should be taxes on virgin plastics. The gathered money might be injected into the recycling sector. Ladislav Trylc disagrees. In his point of view, the implementation of this regulation is not feasible. There is not an institution that would be able to control the amount of recycled plastics in a plastics product.

A part of respondents argues for the necessity of higher responsibility of producers in terms of the manufactured material and its end-of-life that is related to the area of taxation debated above. Ioana Popescu presents that producers should take more responsibility into their new materials introduced to the market. These new materials often cause difficulties for waste companies as they for instance lack technologies necessary for this new materials waste treatment. Indeed, there should be better discussion on the chain among all stakeholders.

Ivo Vicher and Jindrich Kalivoda come up with an idea to compel a manufacturer to use materials which have resolved its end-of-life circle and its recyclability. The legislator has an option of burdening or favouring particular products, such as to impose lower taxes on recycled plastics. Michael Carus notes that politicians should give a clear guidance to companies what to do. He regards the current EU as weaker in terms of decision-making ability. On the contrary, for example Tomas Vanek believes that the market itself will be the main mover of a potential bioplastics success. The role of state is overestimated.

According to Stephan Kabasci, it would be the best if the EU (and/or the member states) took care for equal subsidies for the use of biomass, regardless of the type of utilization: energy production (which is subsidised!) or material use (which is not).

Regarding the responsibility of the big brand companies which switch into bioplastics, several respondents admit that companies should be more responsible for the reuse and recycling of their products, however, there was not an agreement.

Lenka Mynarova agrees that manufacturers should be more responsible for a misleading labelling guaranteeing particular properties of the material such as home compostability etc. and she gives an example of PE bags with oxo-plastics which are presented as “biodegradable”. Lenka Mynarova also agrees that rise awareness among consumers about bioplastics is highly important.

A significant number of interviewees consider the introduction of bioplastics by big brand companies like Coca Cola, Nestle or Danone to be more a result of marketing decision than an interest in the environment. However, on the other hand, various participants do not want to judge the companies on how much marketing and how much caring about sustainability is behind their activities and leave the question without the answer.

In opinion the companies should take the responsibility for the environment. If Coca Cola wants to sell plastics bottles, the company should take more responsibility for collecting their bottles. In Europe there is good collection system but in many other countries it’s not like that. They should be obliged and create such a collecting system. Such as a target that all PET bottles are being collected in three years. According to Jonathan Edmunds, for example Coca Cola should be put more effort into the reuse and recycle of their bottles.

Speaking about positive stimulus supporting the grow of the bioplastics market share, Ioana Popescu describes that the bioplastics industry looks for subsidies and other positive stimulus because the materials are not competitive in terms of price. Hynek Balik from the company MIWA emphasizes the importance of the public sector to adapt to the innovations, use modern technologies etc. in order not to burden the private sector by using pointless packaging.

5 Recommendations

5.1 Policy Recommendations

In this chapter I provide a list of recommendations related to the area of bioplastics, including recommendations on the treatment of conventional plastics. The recommendations are generally aimed at the Czech Republic and European Union authorities and companies, if not mentioned differently. Based on my own research experience, the subchapter deals with a guidance for the future researchers on the topic of bioplastics.

- **To ban oxo-degradable plastics within the EU.**

As already explained in detail, according to the final report of the European Commission DG Environment (2016), oxo-degradable plastics, or so-called oxo-plastics, are designed to degrade more slowly than industrial composting requires. Their application on to the land is risky because they might be a source of microplastics. Oxo-plastics are labelled as biodegradable also on the markets outside the EU. The ban of these materials would send a clear signal not only to the European producers but also to the companies and authorities in non-European countries.

- **To make manufacturers more responsible for the plastics / bioplastics product's end-of-life.**

Currently, the producers manufacture various products that lack their proper end-of-life, such as multilayer coffee caps, which cannot be recycled and end up in landfills or incinerators. Manufacturers should be held responsible for the final stage of a product's existence. In the majority of the European countries, including the Czech Republic, there is the system of the companies' financial involvement in the costs of recycling, however, it is insufficient. Producers might be motivated to use less plastics / bioplastics material or for instance to get involved in the bottle and can deposit refund scheme. One of the means could be an increase of the recycling fee, various incentives for the companies that invest into innovative packaging approaches. Furthermore, the producers could also provide a report indicating the end-of-life circle – so called passport of the plastics / bioplastics providing information on the sustainability of the product.

- **To motivate food producers, retailers and entrepreneurs to use less plastic material.**

The annual production of plastics is enormous in comparison to several decades ago and this trend will likely to continue. On the market, there is the surfeit of marketing plastic packaging of which the benefit may be at least questioned (based on Marcel Luben's division into functional and marketing packaging) and customers are confronted with it on a daily basis. Therefore, a simple replacement of conventional plastics with bioplastics does not pose a solution. Food and packaging producers together with retailers and entrepreneurs should be motivated not to use as much marketing packaging. The motivational tools may be various campaigns of the environmental authorities and NGOs as well as marketing of the private sector

- **To support recycled plastics compared to 'virgin' plastics.**

According to the report A European Strategy For Plastics in a Circular Economy, "demand for recycled plastics today accounts for only around 6 per cent of plastics demand in Europe. The plastic recycling sector has suffered from low commodity prices and uncertainties of sales on the market which has led to low profitability of recycled plastics commodity" (European Commission 2017b, 6).

In general, for the companies it is favourable to produce packaging from 'virgin' plastics than from recycled plastics. The recent ban on import of collected plastics into China revealed the problem of high amounts of collected plastics in the West, including the EU, that in fact lacks recycling manufacturers and the market of recycled plastics.

Waste experts consider a regulation in the form of lower taxation imposed on recycled plastics to be very complicated. In the practice, it is impossible to control if a product is made of recycled plastics from 5, 50 or 100 per cent. Hence, rising awareness among producers and citizens appear as a better, at least short-term, solution. A growing number of companies find sustainability fundamental to their business since consumers expect to be provided with more 'sustainable' product.

- **To introduce the deposit refund system on particular PET and glass bottles.**

The deposit refund system on PET bottles is in place in several European countries, however, despite its name, the majority of the collected PET bottles are not reused but crashed and recycled. Thus, the system does not minimise the use of single-use PET bottles.

Nevertheless, the beverages producers may introduce the real deposit refund scheme since it is more ecological and also more economical because the companies would not have to pay for a recycling fee. In the Czech Republic, the system was already in place in the 1990s and beer producers apply the scheme to their beer bottles until present. The introduction of this system in other EU countries could also provide an inspiration to other non-European countries that can join the system as well.

- **To introduce a separate biowaste collection in the Czech Republic including the cities.**

Although in the Czech Republic several towns and cities' quarters are successful in the separate collection of biowaste and represent examples of good practices, in general the collection of biowaste is on the lower level in comparison to several old EU Member States, partly due to landfilling in place and a low fee of communal waste. However, as the revised final report of DG Environment on Plastic Waste in the Environment points out, "decent separate waste collection system is fundamental to implementing organic recycling and thus industrial composting" (2011, 3), that is a prerequisite of successful application of biodegradable bioplastics on the local market. Furthermore, biowaste might be used as a potential feedstock for bioplastics manufacture or as an energy source, while in landfills biowaste contributes to the release of methane.

- **To prefer industrial composting facilities.**

In several old EU Member States, industrial composting facilities are already well established, but non-industrial composts prevail within the EU. Therefore, it is necessary to catch up the countries, such as Germany, Italy, Belgium or Austria in order to achieve the targets related to industrial composting.

- **To involve bioplastics manufactures into the bioplastics waste treatment.**

As noted by Tomas Vanek, acceptance of bioplastics poses a complication for composting facilities and anaerobic plants. If manufacturers produce materials that degrade in industrial composting facilities, it is necessary to get involved into the cooperation on the whole chain. I find inappropriate that in general Czech composting facilities lack the proper knowledge about the material and do not know how to deal with it, although bio-based and biodegradable bioplastics are already on the Czech market. The manufactures may be more responsible for the end-of-life of their product, i.e. for instance participate on the subsequent infrastructure development in the country. The duty to draft the product passport, as indicated above, could force the manufactures to review and consider if their products have a suitable end-of-life disposal option.

- **To avoid misleading advertising and “greenwashing”.**

Based on the principle of deceptive advertising, the manufactures should avoid misleading advertising and “greenwashing”. If manufacturers declare the biodegradability of their products, they should be prepared to prove their allegations based on the certification standard etc.

For purposes of any further research on the topic, there are two recommendations as follows:

- **To plan the research for a longer period than in case of this thesis.**

The topic of bioplastics is complex which insists on longer in-depth research.

- **To involve a higher number of interviewees in the research.**

In order to gain as in-depth knowledge as possible, I recommend to involve a higher number of the interviewees. With each next participant the researcher gets more information.

6 Conclusion

Bioplastics is a term which was until recently unknown to the general public. At present, in the media and social networks, bioplastics are often presented as one of the potential solutions in order to mitigate petroleum-based single and limited use items. However, the topic of bioplastics is very complex and opinions vary even among the scientists and experts from the bioplastics industry. Bioplastics do not provide easy solutions to mitigate petroleum-based single and limited use items, nor the plastic waste pollution.

The thesis's objective was to do in-depth and clear analysis of the topic which would enable me to provide a list of recommendations. The key focus of the thesis was on the interrelated areas, i.e. sources of bioplastics feedstock, bioplastics application and disposal of bioplastics waste since high concerns are related to the end-of-life of these rapidly developing materials. My purpose was not to compete with specialised chemical publications, nor to bring a new theoretical approach.

In order to accomplish the aims and objectives of the research, I used a qualitative method of semi-structured interviews.

My interviews were divided into six categories representing various stakeholders from the Czech Republic and particular old EU Member States with different involvements in the field of bioplastics:

1. Research
2. Business – Bioplastics and plastics production
3. Business – Waste Management
4. Public sector
5. Non-profit organizations
6. Bioplastics users

Out of each category, on average five interviewees participated in the research. The only exceptions were 'Public sector' and 'Bioplastics users' groups from which less respondents provided me with the answers. The respondents were given open-ended questions and interviews were conducted via Skype or phone call, email or face-to-face meeting in case of the interviewees from the Czech Republic.

The main question of the research set in in the thesis was: *Do bioplastics pose a suitable material to mitigate petroleum-based plastics?*

Based on the research, I am able to claim that the main question of the research was not formulated accurately. The purpose of bioplastics is not, and should not be, the complete mitigation of fossil-based plastics. One of the reasons is that bioplastics can be also petroleum-based. Nevertheless, bio-based biodegradable and non-biodegradable bioplastics have their capacity to replace a part of conventional fossil-based plastics, especially if made from the third generation feedstock.

Furthermore, I set four research subquestions:

1. **What are the opportunities and challenges of the current varieties of bioplastics?**

In case of bioplastics it is impossible to speak about opportunities and challenges without a proper distinguishing between categories of bioplastics, i.e. bio-based and biodegradable, bio-based and non-biodegradable or fossil-based and biodegradable. Sustainability of bioplastics depends on many factors, such as the source of feedstock, design of a product in terms of polymer choice, thickness, and additives etc., or end-of-life disposal options. However, bioplastics bring various opportunities and challenge. What is considered an opportunity for one person, might be perceived as a challenge for a second person.

Bioplastics' mechanical and physical properties are improving. They might be used in all market sectors, especially in the service packaging, food services, agriculture, automotive industry, textiles/fibres, medical/pharmaceutical sector, cosmetics and many others areas. Various experts agree that certain types of bio-based bioplastics are less toxic and have better end-of-life options for disposal.

On the other hand, most of bioplastics (biodegradable and non-biodegradable) are highly energy demanding. Although various experts agree that a significant part of bioplastics have lower carbon footprint in a cradle-to-gate calculation, it might be considered one of the disadvantages of the particular materials and further research and development is needed.

Probably one of the most serious challenges of biodegradable bioplastics is the fact that they are indistinguishable from conventional fossil-based plastics. Thus, biodegradable bioplastics can cause a contamination of conventional plastics recycling streams. Bioplastics are also more expensive than conventional plastics. For instance, PLA is 25 per cent more expensive that its fossil-based counter-part, PET (Chidambarampadmavathya 2017).

Biodegradable bioplastics also pose challenges in terms of potentially harmful additives exceeding levels of ecotoxicity, and the biodegradation in the real conditions where certain bioplastics degrade for significantly longer time than under ideal circumstances.

2. What is the most suitable application of bioplastics?

As suggested above, there is no suitable application for all bioplastics without distinguishing between categories of bioplastics. First, it is necessary to ask for what purposes that package is designed, like for medical applications, agriculture or single-use-items, and then to decide what properties are needed from the material based on this knowledge.

3. How do particular EU Member States and the Czech Republic deal with bioplastics?

Within the EU there is no common approach towards bioplastics. The EU considers bioplastics a crucial component of the circular bio-economy, although biodegradable bioplastics might endanger the principles of the circular economy through the contamination of the plastics recycling streams. The EU actively supports the research and development of these materials. Moreover, the EN 13432 certification system for biodegradable bioplastics treated in industrial composting facilities was adopted. Nevertheless, no policy measures have yet been agreed by the European Commission concerning biodegradable municipal wastes other that the Landfill Directive.

4. **Why do bioplastics in general do not enter the waste collection and treatment systems, including mechanical recycling and energy recovery?**

First of all, bioplastics are rapidly developing material but still rare on the market. At present, bioplastics account for about 6 per cent of the global plastics market share while New Economy bioplastics represent only around 1 per cent of the global plastics market share. Mostly, the waste disposal treatment is not prepared for the coming of bioplastics. The volume of bioplastics is inconsiderable for the separate collection.

Secondly, as explained already, it is necessary to distinguish between categories of bioplastics, i.e. bio-based and biodegradable, bio-based and non-biodegradable or fossil-based and biodegradable. Bio-based non-biodegradable bioplastics may enter the waste collection and treatment, including recycling, as conventional plastics since they have the identical chemical composition.

However, biodegradable bioplastics pose a contamination risk for the recycling stream. The recycling companies considers the introduction of biodegradable bioplastics and biopolymers to be a danger to the whole recycling industry.

Furthermore, I would like to stress out that plastic waste prevention stands on the highest place since it is important to reduce plastics in general, regardless if conventional plastics or bioplastics. Despite the prefix “bio”, bioplastics items are still plastics that need to be treated in terms of an existing infrastructure and efficient waste management system. The materials do not disappear on its own, as people might assume based on the name bioplastics.

On the one hand, I consider bioplastics production a courageous innovative action in the field of new materials. The bioplastics producers have invested enormous amounts of finances into the research and development which bring results in the form of ne polymers and types of the feedstock. As other innovations, bioplastics will bring a positive value once they are widely accepted. At present, these materials are still waiting for the opportunity to show the benefits.

The future of bio-based bioplastics will be derived also from the policies on fossil resources. Europe is oriented to be more energy self-sufficient and naturally decrease its dependence on oil imports. Although the reasons standing behind the political decisions have basis in energy security, the EU climate policy with binding climate and energy targets also play a role. The EU belongs to the front world's actors in the field of climate and environmental protection. The EU is also keen on implementing the principles of the bioeconomy.

In my opinion, it is important to develop plastics from biomass, albeit it depends on the intention of the countries to limit oil extraction as mentioned above. Continuously, it is necessary to ensure that the agriculture sector will not get into similar complications as with biofuels production. Bioplastics producers should primarily focus on the utilization of the third generation feedstocks.

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8 Appendices

Communication with the Interviewees:

CATEGORY+A1:I34	NAME	COMPANY	CONTACTED	QUESTIONS SENT	REPLY	INTERVIEW
Business - waste management	Jindřich Kalivoda, Ivo Vicher	FCC	11.6.	12.6.		15.6.
	Expert from a Czech authorised packaging company	Authorised packaging company	5. 6.	14.6.		20. 6.
	Hynek Balik	MIWA	30. 5.	13.6.		15. 6.
	Roman Farion	Composting facility Ekoso Trhovy Stepanov,	19.6.,23.6.	29.6.		4.7.
	Jonathan Edmunds	DS Smith	29.6.	29.6.		11.7.
	Marco Ricci-Juergensen	Italian Composting Council, the chair of ISWA's working group biological waste treatment.	29.6.	29.6.		
	Josef Venzara	Transform Bohdanec	5. 6.	14.6., 24. 6.		
Business - bioplastics and package production	Lenka Mynářová	Nafigate	30. 5. , 6. 6., 19. 6.	25.6.		12.7.
	Pavel Komurka	Orkla				20. 6.
	Katharina Haag	IFAM	28. 5.	18. 6.		
	Expert on bioplastics from the Netherlands	Bioplastics producer from the Netherlands	28. 5.	18.6.		25.6.
	Christian Garaffa	NOVAMONT	29.6.	29.6.		
	Tom Berckmans	Cardolite	31.5.	18.6.		
	Ducth representative of a bioplastics producer		31.5.	18.6.		21.6.
Bioplastics users	Šárka Osičkova	Farma Nový Dvůr	16.6.	19.7.		20.7.
	Lenka Pechova	Fruitisimo	19.7.	19.7.		
		Vegetarian restaurant	17.6.			21. 6.
		Lehká hlava restaurant	20.6.	20.6.		28. 6.

	Michael Carus	Nova-Institut	28. 5.	18.6.		2.7.
	Stephan Kabasci	Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT	28.6.	5.7.		10.7.
	Expert from Italy on separate collection		3.7.	17.7.		19.7.
	Zorbas Haralabos		28. 5.	18.6.		
Research	Jan Kolek	University of Chemistry and Technology Prague.	30. 5.			
	Vratislav Duchacek	University of Chemistry and Technology Prague.	5. 6.	15.6.		18. 6.
	Dr. Tomáš Vaněk	Institute of Experimental Botany AS CR	5. 6., 23.6.	16.6		26.6.
	Ladislav Trylc	Minisry of the Environment of the CR	30. 5.	16.6		27. 6.
	Anna Tvrdikova	Municipality of Prague	19.7.	20.7.		20.7.
Public Sector	Jiri Koubek	Prague Libus	31.5.	18.6.		3.7.
	Ondrej Lochman	Mnichovo Hradiste	31.5.	18.6.		
	Miloslav Šatra	Písek	12. 6., 19.6.			
	Ivo Kropacek	Hnuti Duha	30.5.	12.6.		14. 6.
	Stefanie Siebert	European Composting Network	16.6., 23.6.	25.6		29.6.
	Delphine Lévi Alvarès	Zero Waste Europe	30.5.			
	Meadhbh Bolger	Friends of the Earth Europe	19.6.	19.6.		3. 7.
	Ioana Popescu	ECOS	19.6.	19.6.		20.6.
NGOs	Milan Havel	Arnika	30.5.	11.6.		12. 6.
	Ondrej Prochazka	CEMC	31.5.			
	Miroslav Šuta	Centrum pro životní prostředí a zdraví	14. 6., 19.6.			
	Hejatkova	ZERA	5. 6., 19.6.			
EU - DG Environment	kontaktni formular		10.6.			