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SUMMARY

In providing and producing materials, the land is important, and bioplastics are not making an exception in that, although the bioplastic production is not relying on land significantly. That is, there is no direct rivalry between the renewable, biomass feedstocks for food, feed, industrial materials, and energy. Nevertheless, the availability of feedstocks for the production of bioplastics is an essential determinant of the growth of the bioplastic industry. The purpose of this report is to examine the availability of feedstocks, specifically for producing renewable biomass materials, and different elements influencing this availability.

Bioplastics are derived from different configurations of materials with differing properties and applications. Nevertheless, most bioplastics are produced from carbohydrate-rich plants, of which availability fluctuates significantly by the material type in Europe. The production of these 1st generation feedstocks is significant and stabilized, but they are primarily utilized for food and feed production. Thus, with an increasing global population, it is suggested that the availability of 1st generation feedstocks might be reduced in the future. Therefore, besides responsible and sustainable sourcing in the bioplastic production, the development of innovative technologies that permit transforming feedstocks into bioplastic with minimum energy and other input are required. Furthermore, the possibility of using non-food crops and agricultural waste in producing bioplastics requires more research. It is suggested that using food waste in the bioplastic production would create smaller demands for land and thus increase the availability of feedstocks for producing bioplastics. Nevertheless, there is no data available on food residue quantities and thus the question remains whether there is enough waste for the bioplastic production or not.

Responsible and sustainable sourcing remains thus critical in securing the availability of feedstocks and the growth of the bioplastic production. Furthermore, it is essential that new actors enter the market with feasible business models to develop technologies that transform feedstocks into biomaterials and to both gather and distribute the food waste. A level playing field for every bio-industry is required too to facilitate the growth of the bioplastic industry.

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ACRONYMS AND ABBREVIATIONS

EU	European Union
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PLA	Polylactic acid

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1. INTRODUCTION

Feedstocks are gathered and transformed into things and products utilized in daily lives, for example, food, textiles, sports equipment, packages, and automotive parts. In providing and producing materials, the humankind has always relied on land, and bioplastics are not making an exception in that. That is, the same motivation exists in the bioplastic production; it requires land to be produced. (Bioplastics Feedstock Alliance 2018.) The feedstock cultivation of bioplastics is at present 0.02% of arable land under cultivation (Institute for Bioplastics and Biocomposites 2017; European Bioplastics 2017). This illustrates that the use of land in the bioplastic production is not significant, and that is not predicted to change in the near future (Bioplastics Feedstock Alliance 2018).

Increasingly growing population demands are argued to increase the pressure on land. Therefore, strong disputes on whether we have enough arable land to meet everybody's needs; that is, food, feed, industrial materials, and energy, have emerged. Specifically, it has been discussed whether food crops should be used for other purposes than food and feed. (Bioplastic Feedstock Alliance 2018; Carus & Dammer 2013.) Researchers and practitioners are thus interested in investigating the utilization of non-food crops and agricultural waste in the bioplastic production (European Bioplastics 2016). For the same reason, it is vital that the availability of different types of feedstocks for producing bioplastics is known. This is important for the growth of the bioplastic industry.

Bioplastics are configurations of materials with differing properties and applications. Plastic materials are determined as *bioplastics* if they are biobased, biodegradable, or they feature both properties (European Bioplastics 2018a.) Biobased materials and products are derived from renewable biomass materials, which are not always biodegradable, or they are biodegradable plastics, which are either made of natural or fossil resources (Food Packaging Forum 2014). This report examines the availability of feedstocks, specifically for producing renewable biomass materials, and different elements influencing this availability (D1.2).

This report is structured as follows. The report begins with the introduction to the significance of feedstocks in the bioplastic industry. Furthermore, the purpose of this report is presented. Thereafter, the research materials and methods are shortly described. The results of this report are discussed by reviewing the availability of the most frequently utilized raw materials in the production of bioplastics and alternatives for them. Specifically, the availability of potato peels and sweet corn residues are discussed as these raw materials are applied to produce polyhydroxybutyrate (PHB) in the NewPack project. The report further discusses about responsible sourcing and European Union (EU) policies in assisting that there is enough arable land to meet the needs of food, feed, industrial materials (including bioplastics), and energy. Finally, the results of this report are summarized and limitations presented.

2. MATERIALS AND METHODS

For this report, information was gathered from multiple bioplastic industry reports, statistics and web pages of related organizations, and journal articles (Tab 2.1). Qualitative thematic interviews (Tab 2.2) further supplemented the data by giving insights into the food packaging plastic industry and how bioplastics are potentially changing the industry structures.

Tab 2.1 Written data.

Data provider	Data type	Data details
Bioplastics Feedstock Alliance	Web page	http://bioplasticfeedstockalliance.org
Camia et al. (2018)	Written report	Biomass production, supply, uses and flows in the European Union: First results from an integrated assessment
Carus and Dammer (2013)	Article	Food or non-food: Which agricultural feedstocks are best for industrial uses?
European Bioplastics	Written reports; web page	Bioplastics: Facts and figures; Bioplastics market data 2017; Industrial use of agricultural feedstock; Biobased plastics – fostering a resource efficient circular economy; https://www.european-bioplastics.org
Institute for Bioplastics and Biocomposites (IfBB)	Written report	Biopolymers: Facts and statistics 2017
Scarlat et al. (2010)	Article	Assessment of the availability of agricultural crop residues in the European Union: Potential and limitations for bioenergy use. *Waste Management, 30*, 1889–1897.

Tab 2.2 Qualitative interview data.

Role in the food packaging plastic industry	Informant(s)	Interview details
Food Producer	R&D Director and two Product Technicians	4.9.2018, 30 minutes
Food Producer	Innovation Manager	8.10.2018, 60 minutes
Material Producer and Package Designer	R&D Engineer	14.8.2018, 90 minutes
Consulting Organization	Senior Sustainability Consultant	12.9.2018, 55 minutes

The data was analyzed both qualitatively and quantitatively. Quantitative data analysis provided statistics to understand the availability of feedstock resources for producing bioplastics, whereas qualitative data aid in providing answers to the questions of *why* and *how* different elements influence the availability of required raw materials in the bioplastic production.

3. RESULTS AND DISCUSSION

This report is interested in the availability of feedstocks for producing renewable biomass materials, and different elements influencing this availability. The report introduces the feedstocks of bioplastic production and their availability. Furthermore, the question of how responsible sourcing and EU aid in securing that there is enough arable land in the future to meet the needs of food, feed, industrial materials, and energy, is discussed.

3.1 Feedstocks for Bioplastics

Bioplastics derived from renewable biomass materials imply that they are produced from plants (Bioplastic Feedstock Alliance 2018). Indeed, most bioplastics are produced from carbohydrate-rich plants; that is, food crops. These 1st generation feedstocks are highly efficient and profitable for the bioplastic production as they produce the highest yields and withstand pests and demanding weather conditions (European Bioplastics 2018a). The most frequently utilized carbohydrate-rich plants are sugar cane, sugar beet, corn, potato, wheat, and castor oil plant (Institute for Bioplastics and Biocomposites 2017).

The production of the food crops that are rich in carbohydrate fluctuates significantly by the material type. The production of sugar in EU, for example, is high; that is, the EU is the world's leading producer in sugar beet. In 2016, the EU's sugar beet production was 110.77 million tonnes, and this is estimated to increase significantly in 2017–2018. (FAO Stats 2018; European Commission 2018.) The EU is further predicted to produce 59.8 million tonnes of corn and roughly 137.5 million tonnes of wheat in 2018. These numbers are decreasing from the preceding year by -2.37% with corn and by -9.35% with wheat. (United States Department of Agriculture 2018.) In 2016, the largest area of root crops (1.7 million hectares) was planted by potatoes. In 2016, 56 million tonnes of potatoes were harvested in the EU, which shows a decrease in their production from 2000. (FAO Stats 2018.) Table 3.1 summarizes the production quantities of sugar beet, corn, potato and wheat in EU and contrast them to their production in Europe in 2016 (FAO Stats 22.10.2018).

Tab 3.1 Production quantities for different carbohydrate-rich plants in EU and Europe.

Food crop	Production quantity (Europe) (tonnes)	Production quantity (EU) (tonnes)
Sugar beet	185090592	110768272
Corn	117413713	62667522
Potato	117555648	56224047
Wheat	250126499	142652612

The bioplastics industry is further examining the possibility of using non-food crops in producing bioplastics (2nd generation feedstock), for example, ligno-cellulosic feedstocks that include plants not eligible for food or feed production. This feedstock also includes non-edible by-products of food crops, for example, straw and bagasse, which are typically left on the field to biodegrade. (European Bioplastics 2018a; 2016.) To increase the availability of feedstocks for the bioplastic production, new technologies that utilize agricultural waste for the bioplastic production are thus emerging (European Bioplastics 2018a). Furthermore, the 3rd generation feedstock, derived from algae, has also emerged (Bioplastic Feedstock Alliance 2018). The technologies of 1st generation bioplastics are important facilitators in the transitioning towards these later generation feedstocks (European Bioplastics 2015).

In the NewPack project, the potential of potato peels and sweet corn residues are specifically investigated in producing PHB that would permit creating novel biodegradable plastic food packaging films. This is for the reason that potato and sweet corn are produced and processed in significant quantities, and thus as by-products, potato peels and sweet corn residues are regularly produced in different regions worldwide. Therefore, the process is replicable to other areas. Furthermore, specifically, potato peels are by-products that include large quantities of starch, non-starch polysaccharides, lignin, polyphenols, protein, lipids, which make them an inexpensive raw material for extraction of other products and fermentation processes (Panersar & Kaur 2015; Sepelev & Galoburda 2015.) Indeed, both potato peels and sweet corn residues include sugar that should be easy to digest to facilitate the fermentation and produce PHB. Addedly, by being inexpensive food waste, using potato peels and sweet corn residues in the production of bioplastics reduces the costs of polyhydroxyalkanoate (PHA), and it should not create any ethical issues. Potato peels and sweet corn residues are also zero value waste for processing plants and thus identifying an integrated, environmentally-friendly way to manage them is necessary (Arapoglou et al. 2010). That is, waste disposal and by-product management in the food processing tend to pose problems for the areas of environmental protection and sustainability (Russ & Meyer-Pittroff 2004).

Nevertheless, although the production of feedstocks required in bioplastics is significant and stabilized, it is challenging to estimate how much of these feedstocks are produced in EU to produce bioplastics and how much do they engender by-products. These questions are discussed next by presenting statistics on the use of harvested agricultural biomass and how much waste the processing of potato and sweet corn tend to create. That is, this report is specifically interested in the availability of agricultural feedstocks as the purpose of the NewPack project is to examine potato peels and sweet corn residues in the production of PHB.

3.2 Availability of Feedstocks for Bioplastics

The total agricultural biomass produced yearly is estimated to be 956 Mt of dry matter (average from 2006 to 2015) (García-Condado et al. 2017). From this, 54%, which is 514 Mt, is produced in the form of the primary products, for example, fruits, grains and roots (Camia et al. 2018). Nevertheless, guarantying food and feed are the priorities for using this biomass. In 2008, the worldwide use of biomass for animal feed was 60% and food 32%, when energy and material usages (including bioplastics) were merely 4% of each. (Carus & Dammer 2013.) In the EU, the agricultural biomass is similarly used primarily for food and feed. Therefore, with an increasing global population, the availability of 1st generation feedstock for bioplastics might be reduced in the future. This reflects the significance of later generation feedstocks in facilitating and reinforcing the sustainable growth of the bioplastic industry. Figure 3.1 illustrates the use of harvested agricultural biomass worldwide (2008) (Carus & Dammer 2013).

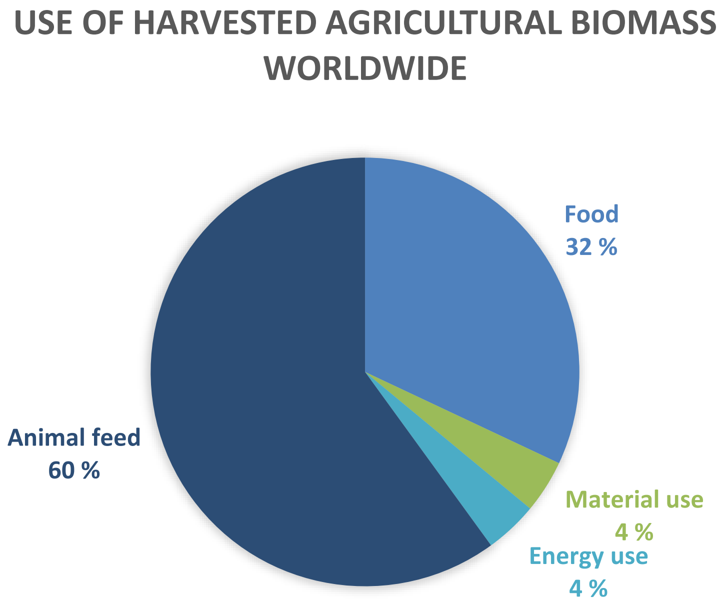

Fig 3.1 Use of harvested agricultural biomass worldwide (Carus & Dammer 2013).

The remaining part of the biomass (442 Mt or 46%) with no primary purpose in the production process are residues that are potential feedstocks for the production of bioplastics. The quantities of these residues from agriculture have tended to increase during the past years. Nevertheless, using agricultural biomass for the fabrication of biomaterials remains under-researched. (Camia et al. 2018.) That is, although there is data available on crop yields, the agricultural waste data is limited as it is highly specific to the type of crop and plant (Scarlat, Martinov & Dallemand 2010). To estimate the availability of potato peels, though, it is stated that peeling potatoes during processing tends to create production losses regarding potato peel waste from 15% to 40%, depending on the way of peeling (Arapoglou et al. 2010). In the potato industry, the specific waste index is between 0.3–0.5 (Russ & Meyer-Pittroff 2004). Similarly, sweet corn residues are by-products of the sweet corn processing accounting for 60–70% of the harvest (Mustafa, Hassanat & Berthiaume 2004).

Nevertheless, the reusing and disposing of this waste is challenging for multiple reasons. For example, waste materials might already include large quantities of microbes or they are altered through microbial activity, thus increasing the growth of pathogens. Furthermore, the high water content tend to increase transportation costs, whereas a high-fat content makes waste materials susceptible to oxidation, which leads to the release of foul-smelling fatty acids. Finally, in many types of waste materials, waste enzymes are still active, which accelerate and intensify the reactions involved in spoilage. (Russ & Meyer-Pittroff 2004.) In this report, this is suggested to reflect the need for new actors entering the market with feasible business models to develop innovative technologies to transform these later generation feedstocks into biomaterials and to both gather and distribute the food waste.

3.3 Influencing the Availability of Feedstocks

The technology applied in the bioplastic production derived from non-food crops and agricultural waste are not entirely developed, yet. Therefore, the bioplastic industry must pursue to increase the availability of 1st generation feedstocks, for example, through responsible sourcing and EU policies.

3.3.1 Responsible Sourcing

Different crops require different degrees of land to be produced. For example, 34 hectares of sweet corn is needed for the production of 100 tons of polylactic acid (PLA) when 100 tons of biopolyamide need 588 hectares of castor oil. (Bioplastic Feedstock Alliance 2018.) Nevertheless, the production of bioplastics is not using land significantly, and that is not predicted to change in the near future (Bioplastic Feedstock Alliance 2018; Institute for Bioplastics and Biocomposites 2017). In 2017, the use of land for growing renewable feedstock for the bioplastic production was roughly 0.82 million hectares, which is less than 0.02 percent of the global agricultural area of 5 billion hectares, 97% of which were used for pasture, feed, and food. Regardless of the market growth predicted for the upcoming years, the share of bioplastics in using of land remains in 0.02%. (European Bioplastics 2018a.) That is, if the bioplastic industry reaches the market of 2.44 million tonnes by the year 2022, the land use of bioplastics will increase merely to 1.03 million hectares. This estimation does not include the increased share of later generation feedstocks, which creates smaller demands for land than predicted. (European Bioplastics 2017.) Nevertheless, the use of land for the bioplastic production shows that there is no direct rival from renewable feedstocks between food, feed, industrial materials (including bioplastics), and energy. Figure 3.2 illustrates the share of the bioplastic production from the global agricultural area in 2017 and 2022. (European Bioplastics 2018a.)

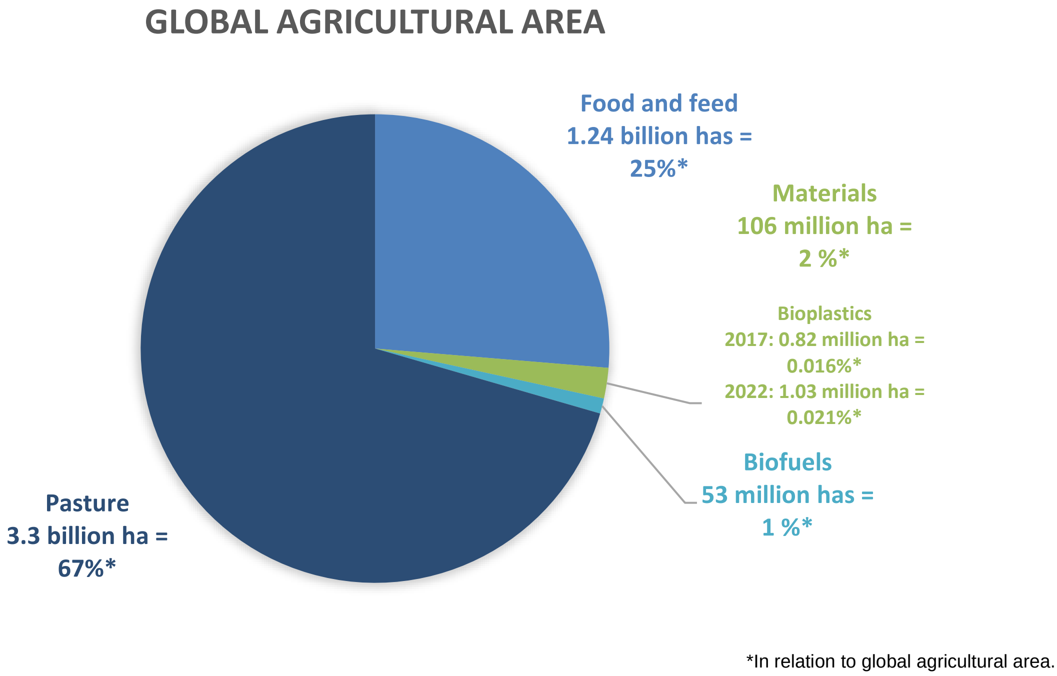

Fig 3.2 Land use for bioplastics from the global agricultural area (European Bioplastics 2018a).

Regardless of the insignificant using of land, selecting specific biomasses for an industrial purpose should be dependent on the sustainability and efficiency of the feedstock (European Bioplastics 2015a). Using renewable biomass materials in producing plastics have different kinds of impacts on the planet than using fossil fuel resources. Nevertheless, this does not imply that bioplastics are produced without environmental impacts and therefore responsible sourcing is essential in providing them. (Bioplastic Feedstock Alliance 2018.) Responsible sourcing is not just environmentally friendly, but sustainable, and thus it is argued here to influence the availability of feedstocks required in the production of bioplastics.

Responsible sourcing relates to the implementation of good agricultural practice and social standards. It requires the dilution of different negative impacts; for example, the deforestation of protected areas and environmental damage created by harmful agricultural practice. (European Bioplastics 2018b.) Bioplastic Feedstock Alliance (2018) has argued that responsible bioplastic feedstock is legally sourced and derived from renewable biomass. Furthermore, responsible feedstock should not adversely impact food security and destroy critical natural ecosystems. Responsible sourcing should thus provide environmental benefits. (Bioplastic Feedstock Alliance 2018.)

There are many ways to reinforce the sufficient supply of biomass for the production of food, feed, material uses (including bioplastics), and energy. For example, feedstocks should be broadened more strongly into plant residues and ligno-cellulosic feedstocks. Searching innovative methods to improve the efficiency and effectiveness of transforming raw materials into bioplastics would further increase their yields. (European Bioplastics 2018b.) Important for the performance of feedstocks is thus the availability of new technologies that make it possible to transform the feedstock into bioplastics with minimum energy and other inputs (Bioplastic Feedstock Alliance 2018). Finally, there is still arable land available in different geographical regions, especially fallow land that could be used in the bioplastic production more thoroughly (European Bioplastics 2018b).

3.3.2 EU Policy

In the future, Asia is predicted to expand its role in the bioplastic production. In 2019, more than 80% of bioplastics is presumed to be produced in Asia whereas Europe is left with less than 5% of the global bioplastic production. (European Bioplastics 2015b.) The EU’s commitment to the transition towards a circular economy is nevertheless stimulating the momentum of growth of the bioplastics industry in Europe. The EU has recently acknowledged the benefits of biomaterials and taken important steps towards paving the way for bioplastics by allocating funds and other resources to research and development in this sector (European Bioplastics 2018a; 2018c.) For example, to include the plastic industry in the transition towards the circular economy, the European Commission has taken a new strategy on plastics as part of their Circular Economy (CE) Action Plan (Community Research and Development Information Service 2017). At the beginning of 2018, the European institutions further approved a revised EU waste package that encourages Member States to facilitate the usage of biomaterials in the production of packaging and to improve the market environment for such products. (European Bioplastics 2018c.)

Nevertheless, the European market for bioplastics is described limited by the lack of economic and policy measures, permitting a larger scale-up of production capacities in Europe (European Bioplastics 2015). Therefore, to unfold the potential of bioplastics, a supportive legislative framework is required to enable and promote the market for bioproducts and materials. Specifically, European Bioplastics (2018c) has suggested that the European bioplastics industry is lacking a level playing field for access to biomass and regulatory measures to boost market penetration and ensure long-term investment security. For example, measures extending producer responsibility and product design rules regarding the minimum degrees of bio- and recycled content in plastic products, or a carbon pricing mechanisms to incorporate the external climate change costs into product prices would aid in boosting bioplastics and stimulating the production and development of biomaterials in Europe. (European Bioplastics 2018c.)

In different levels, many measures do exist, for example, subsidies and taxes, but they are argued to favor in some extent specific industries. Indeed, the energy industry is claimed to receive immense subsidies, whereas the bioplastics industry receives none. This distorts the effectiveness of biomarket segments. Thus, to secure the availability of feedstocks for the production of bioplastics, the bioplastic industry has brought forward their demand for equal treatment of every pillar of the bioeconomy. (European Bioplastics 2015a.) This is find to be necessary for the further growth of the bioplastic industry.

4. CONCLUSIONS

In this report, both quantitative and qualitative data were gathered to analyze the availability of feedstocks, specifically for producing renewable biomass materials, and different elements influencing this availability.

The report shows that most bioplastics are derived from carbohydrate-rich plants, for example, sugar beet, potato, and wheat, of which availability fluctuate significantly by the material type in Europe. The production of these 1st generation feedstocks is significant and stabilized, but they are primarily utilized for food and feed production. With an increasing global population, the availability of this feedstock might be reduced in the future. This urges the development of innovative methods and technologies to improve the efficiency and effectiveness of transformation of raw materials into bioplastics, chemicals, and other materials with minimum energy and other inputs to further increase the yields. Responsible and sustainable sourcing in the production of bioplastics is further required. Specifically, bioplastic feedstocks should be broadened more strongly into plant residues and ligno-cellulosic feedstocks. This would create smaller demands for land and thus increase the availability of feedstocks for producing bioplastics. Nevertheless, there is no data on the availability of food residues and therefore the question remains whether there is enough waste or not for the bioplastic production to protect the sufficient supply of increasing use of bioplastics.

Responsible and sustainable sourcing remains to be the critical in securing the availability of feedstocks and the production of bioplastics. Regarding the supply of later generation feedstocks, it is also important that new actors enter the market with feasible business models to develop innovative technologies that permit transforming these feedstocks into biomaterials and to gather and distribute the food waste. This together with the level playing field for every bio-industry assuring the highest value creation and the most beneficial environmental benefits (European Bioplastics 2015a) can enable and facilitate the growth of the bioplastic industry.

This analysis of the availability of feedstocks for bioplastics in Europe is limited to the available data that does not include interviews regarding raw material producers and feedstock suppliers. In this report, it is expected that these actors could have provided valuable insights into the feedstock availability.

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