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Article

Renewable resources are the future: The role of sustainable raw materials and the potential of biopolymers in Brazil

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Abstract

This article discusses the emergence of a global biopolymer market and the potential for economic use in the Brazilian case. The aim is to identify and discuss the potential of access to biopolymers, their uses, and transformations in Brazilian industrial production. It is considered that Brazil has a high production potential for biopolymers. However, it is known that these new materials are still in the initial phase of production and replacement of conventional plastic products. We present global data from regions that stand out in the production process of these raw materials, as well as data on countries that already use these sources to convert more sustainable products. After presenting data, an analysis of Porter's diamond was carried out to know and understand how the biopolymer chain is currently organized, its potential, and its challenges in Brazil.

Keywords: biopolymers, sustainability, Brazil, industry

1. Introduction

The realization of the United Nations Conference on the Human Environment, in Stockholm, in 1972 was the first meeting of global scope involving the theme of the environment and sustainable development (Correa do Lago 2006). The emergence of a worldwide agenda for the environment stems from the growing perception of the need to increasingly promote development from a perspective that includes the issue of environmental sustainability. The theme of sustainability is broad and involves several topics: sustainable use of water resources and soil, biodiversity, water pollution, and emission of gases that cause the greenhouse effect. Among these issues, we highlight the problem involving water and soil pollution from pollution caused by compounds mainly made of plastic and other traditional polymers.

The report From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution, published in October 2021, has become a reference document for various discussions and an essential document for the United Nations Environment Assembly (UNEA 5.2), which took place in March 2022. The paper in question brought several data and topics to demand the generation of urgent solutions, such as the case of plastic waste and the participation of this waste in the accumulation of problems linked to excessive carbon generation and its harmful effects on the environment.

In this sense, the document reinforced the understanding that the plastic production chain is directly linked to climate problems and presented data from this chain that 85% of the waste reaches the oceans. As a result, there was a warning for increasingly worse scenarios, such as by 2040, the volumes of plastic flowing into the sea could triple from today's levels. As a result, there will be costs and impacts of this pollution that reach diverse areas of human life, such as tourism, fisheries, and agriculture, which may reach US$ 6 to 19 billion in estimates in 2018. The economic cost for the government and private sector would also reach 100 billion US dollars by 2040.

In addition to the problems, it is known that in the last 70 years, plastic has been a revolutionary product in the history of techniques and the life of humanity, according to the report itself and other documents (McGlade et al. 2021). However, what is discussed today is the maintenance of the uses of plastics for activities and products that need their characteristics of excellent resistance, durability, and versatility for essential uses and that demand these types of features of the products, as in the health, hospital equipment, among others (here examples of essential plastic).

However, despite its great importance, as previously discussed, the environmental impacts are enormous and arise from uses that are not so necessary. The United Nations Environment Program (2018) report, for example, estimates that approximately 50% of the plastic that is dumped into the environment globally comes from plastic packaging. This data suggests that reducing plastic dumping globally or replacing it with packaging that causes fewer environmental impacts is possible. For this reason, as of 2021, documents from international agencies (McGlade et al. 2021) began to present the immediate need to reduce the consumption of conventional plastics from non-renewable sources.

It is also noteworthy that international agendas such as the 2030 Agenda and the Sustainable Development Goals (SDG) seek to support actions and transformations in all countries by understanding the importance of elements such as the eradication of poverty and hunger, universalization or expansion of access to health, well-being, quality education, gender equality, clean water, sanitation, clean energy, decent work, economic growth, industrialization, innovation, and infrastructure, reducing inequalities, sustainable consumption, and production, peace, effective institutions, among others (Zeferino de Menezes 2019). Strategies and goals can be recognized in each item presented by the 2030 Agenda as an objective. These arguments support the need to reduce pollution, control and manage waste, and preserve life.

Besides the international agenda, the pressures also come from social movements and civil society, which demand the reduction of pollution to reduce the environmental impacts of pollution. The private sector has also sought to invest in the innovation of new raw materials to produce new products that are more environmentally friendly. International foundations such as the Ellen Macarthur Foundation present projects such as a study - agenda called "The Global Commitment" that brings together more than 500 organizations and support from the United Nations for the environment with a shared vision of a circular economy for plastics, aiming to stop plastic pollution at its source. To this end, it articulated contact with large companies responsible for 20% of plastic packaging produced globally to encourage them to commit to goals to achieve this transformation. In this sense, companies such as Nestle, PepsiCo, Unilever, Coca-Cola, and Loreal are involved with plans to reduce plastic, recycle, and reuse, among other aspects.

According to McGlade et al. (2021), it is not enough to discuss recycling and reuse, among other techniques. It is necessary to reduce the use of plastic drastically. And here, it is worth noting that the 2030 Agenda, for example, does not explicitly address the need for urgent actions regarding specific products or sectors, as can be seen in the demand for a drastic reduction of particular products, such as in the case of plastic to guarantee life.

One of the actions implemented in recent decades is the recycling of plastic. In 2015, it was estimated that around 20% of plastic was recycled (Ritchie and Roser 2018). However, the increase in plastic consumption grows at rates much higher than the increase in recycling. The result is an increase in the inappropriate disposal of plastic in the environment.

For this reason, in an alarming situation, biopolymer solutions have been presented as necessary alternatives, as they come from renewable sources, are biodegradable, and are compostable, among other characteristics. Depending on the composition of the biopolymer, there are already solutions, formulas, industries, and products, and these still present themselves in smaller quantities on the market. In this sense, moving towards converting conventional plastic to biopolymers is paramount due to the environmental issues addressed here.

According to the Brazilian Association of Technical Norms (ABNT) standards (NBR 15448-1), biopolymers can be conceptualized as polymers or copolymers produced from raw materials from renewable sources such as corn, sugar cane, cellulose, chitin, and others. These products allow a complete alteration of a good part of the plastic products chain, and it is worth noting that, in general, single-use or disposable plastics accumulate in landfills, dumps, and plastic islands in the oceans.

However, the production price of conventional single-use plastic is still highly competitive, cheaper, reaches a large volume, serves several sectors, and is available to a large part of the global population. However, they are products with a high environmental, social, and economic impact from an unsustainable production chain.

The main objective of this article is to identify, map, and present Brazil's potential in expanding biopolymer production. Brazil, positioned as a potential market leader, has become one of the leading producers of raw materials and agricultural commodities used in the biopolymer industry. In this sense, the article presents and discusses the potential of Brazil based on Porter's diamond, pointing out the main factors that impact the country's competitiveness regarding the development of industries that produce biopolymers.

2. Literature review

During the 1950s and 1960s, there was substantial growth in the global plastic manufacturing sector. However, the ecological consequences of plastic have become a matter of concern worldwide (Zhou et al. 2021). It is approximated that the packaging industry is responsible for slightly more than 45% of the planet's plastic waste. Notably, a significant portion of this waste originates from products with a shelf life of 6 months or less (Wu et al. 2021).

According to estimates, the global production of plastic waste exceeded 340 million metric tons, with the packaging industry accounting for approximately 46% of this total. Most of this waste is generated by products with a relatively short period of use, typically six months or less, unlike waste from the construction and building sectors, which typically has an average lifespan of 35 years (Wu et al. 2021).

Given the potential environmental contamination associated with synthetic plastics throughout their entire life cycle, which includes stages like monomer synthesis, landfilling, and recycling, there is a growing research focus on exploring alternative options such as biopolymers (Choe et al. 2021; Morya et al. 2018).

Belonging to a unique category of polymers, biopolymers are recognized for their environmentally friendly nature, characterized by being both biocompatible and biodegradable. These polymers are derived from renewable resources, such as biomass from forestry and agriculture (Unger et al. 2017; Polman et al. 2021). The synthesis and fabrication of biopolymers involve four distinct methods, each differentiated by the desired end product and the availability and utilization of raw materials or precursors.

Biopolymers are produced from living creatures as their polymeric structures. It is important to highlight that, in this case, a polymeric structure will require the presence of properties such as elasticity, and steadiness, and can be found in plants or obtained from animals and microorganisms. Several biopolymers can be obtained from animals, plants, and microbial. Aggarwal et al. (2020) organized into three tables divided by origin. The biopolymers of animal origin and their applications are listed in Table 1.

Table 1. Biopolymers of animal origin and their applications

	Name of polymer	Source of origin	Physical appearance	Uses/applications
1	Hyaluronic acid	The umbilical cord of newly born child, from rooster combs, fermentation broths of streptococcus and other bacteria.	Transparent, viscous fluid or white powder.	Gel preparation for drug delivery, wound healing, cosmetic products, viscosity agent, filler in medicine, antibacterial.
2	Chitosan	Shellfish and crustacean waste materials	Pale, white and flaky and its moisture content was 10.9%.	Cosmetic industry, medicine, agriculture, waste treatment, wound-healing treatment, paper manufacturing, food packaging, seed coating, plant growth regulator, recover protein wastes, manufacturing, personal hygiene products, anti-bacterial, anti-acid, drug carrier for controlled release, a flocculating agent, purify drinking water, bioremediation of toxic phenolic compounds, promote osteogenesis, fat absorbent action.
3	Gelatin	Cattle hides, bones, fish, pig skins, agricultural or non-agricultural	Water-soluble translucent, flavourless food ingredient, gummy when moist and brittle when dry	Stabilizer, thickener, texturizer, emulsifier, foaming, food wetting agent, pharmaceutical and medical usage.
4	Keratin	Feathers, hair, nails, wool, horn and hooves, stratum corneum And scales.	Insoluble in most organic solvents.	Absorbents, leather industries, drug delivery system, surgery, food industry, cosmetics, biomedical products, fertilizers, electrode material.
5	Collagen	Invertebrates in the body walls and cuticles.	Hard, fibrous, insoluble, protein, and molecules form long, thin fibrils.	Sutures, dental composites, sausage casings, skin regeneration templates, cosmetics, biodegradable matrices, solid support microcarrier in the production of enzymes

Source: Aggarwal et al. (2020).

The biopolymers of the plant's origin and their applications are listed below in Table 2.

Table 2. Biopolymers of plant´s origin and their applications

	Name of polymer	Source of origin	Physical appearance	Uses/applications
1	Cellulose	Plant tissue (trees, cotton etc), bacteria (Acetobacter xylinum).	Water indissoluble, chemical-free solvents odourless, hydrophilic, environment-friendly.	Controlled Drug Delivery Devices, Wound Dressings, Scaffolds for Regenerative Medicine, cellophane films, thickener, wrappers, adhesives, agricultural chemicals, coatings, ligature, preserver, dispersing agent, flow controller, tile sealant, board fixative, indelible inks, beauty products.
2	Pectin	Plant cell walls, citrus peels, apple pomace.	Coarse or fine-powder, yellowish white, odourless, mucilaginous taste, altogether soluble in 20 parts of water.	Reduce blood cholesterol, treat gastrointestinal disorders, remove metals such as lead, mercury from intestine and lungs, control hemorrhage, tablet formulations, antimicrobial action, improves coagulation, treatment of overeating, anti-inflammatory.
3	Carrageenan	Cell wall matrix of red seaweeds.	Large, pliant molecules and make helical structures, at room temperature, gets solidify.	Anticoagulant and antithrombotic activity, Antiviral activity, textural functionality particularly in dairy products.
4	Xylan	Hardwood (e.g.-Eucalyptus globules etc), almond shell, rice husk, corn cobs.	Yellow gummy highly complex pentosan.	Low-caloric sweetener, preventative agent, paper making, textile printing, drug delivery system.
5	Guar Gum	Cyamopsis tetragonolobus or Cyamopsis psoraloides.	White to an off-white colour, unscented, greyish white granulate 90% of which dissolves in water.	Disintegrating agent, binding agent, film-forming agent, viscosity-enhancing, thickening or gelling agent, stabilizer, emulsifier, bio adhesive agent, bulk-forming laxative, non-toxic nature.
6	Alginate	Brown algae of the genera 'Nacrocystis,Laminaria , Ascophyllum, Alario, Ecklonia, Eisenia, nercocystis, sargassum, cystoseria,fucus	White to yellow, fibrous powder.	Fruit texturization, diffusion-set gels, protein expulsion, increased shelf life of potatoes, restraining banana enzymes, crumble fish patties, flesh products, water-holding, ice cream stabilizers, dispersive ability.
7	Gum Arabic	Stems and branches of Acacia Seyal and Acacia Senegal tree.	Dried, gummy. white to yellowish white, practically with tasteless, and odourless	Stabilizer, thickening agent, emulsifier, fabric, ceramics, print photolithograph, beauty products, medicine manufacturing industries, treatment of internal as well as external inflammation , antioxidant, nephroprotectant.

Source: Aggarwal et al. (2020).

The various biopolymers of microbial origin and their applications are listed below in Table 3.

Table 3. Biopolymers of microbial´s origin and their applications

	Name of polymer	Source of origin	Physical appearance	Uses/applications
1	PHA Polyhydroxyacetonoate	Cupriavidus necator (Ralstonia eutropha or Alcaligenes eutrophus).	Pliant, adjustable, amorphous.	Shaving instruments, household articles, nappies, sanitary towels, beauty products, shampoo containers, bone plates, surgical stitches, and blood vessel replacements.
2	Pullulan	Aureobasidium pullulans.	White powder, dissoluble in water, uncoloured and gluey adherent solution, indissoluble in solvents such as ethanol, methanol, and acetone.	Inhibits fungal growth, low-viscosity filler, stabilizes the quality and texture, binder and stabilizer, protective glaze, stabilize fatty emulsions, denture adhesive, pharmaceutical coatings.
3	Levan	Rothis dentocariosa, Streptococcus salivarius, and Odontomyces viscosus, (Bacillus subtilis, Bacillus megaterium, Bacillus cereus, and Bacillus pumilus.)	Natural adhesive and surfactant, non-viscous and water and oil soluble	Emulsifying agent helps in preparation, preserver, gelatinize, surface-quality agent, encapsulate, carrier for savour and odour, photographic emulsion, molecular sieves for gel filtration, blood volume extender.
4	Dextran	Dextran sucrase, Leuconostoc mesenteroides, Saccharomyces cerevisiae, Lactobacillus plantarum, or Lactobacillus sanfrancisco.	Dissoluble in water, dimethyl sulfoxide, formamide, ethylene glycol, glycerol and indissoluble in monohydric alcohols, e.g., methanol, ethanol, isopropanol, and ketones, e.g., acetone and 2-propanone	Solidifying agent, thickening agent, improves surface quality, emulsifier in edible products, soothing, palatable, loaf mass, smoothness, storage life, cryoprotectant, viscosifier, creamy, lower synaeresis, antioxidant for food, water holding capacity, moisture content raised in non-fat mass, functional foods.
5	PHB (polyhydroxybutyrates)	Microorganisms (such as the Cupriavidus necator, methylobacterium rhodesianum or Bacillus megaterium).	Biodegradable thermoplastic polyester. Highly crystalline (>50%), brittle and hard.	Osteosynthetic materials, biodegradable carrier, biocompatible, maintain cell development, guide and arrange the cells, growth of tissue, scaffolds, food packaging.
6	Bacterial Cellulose	Achromobacter, Alcaligenes, Aerobacter, Agrobacterium, Azotobacter, Gluconacetobacter, Pseudomonas, Rhizobium, Sarcina, Dickeya, and Rhodobacter belong to the Komagataeibacter genus	Intact membranes (fibres form or pellets form,), disassembled BC, and BC nanocrystals (BCNC)	Packaging for foodstuffs, transparent covering, cell divider, permeable, medicine manufacturing industries, water investigation, beauty products, biocompatible, ethyl alcohol manufacturing, conduct electricity, magnetic stuff, manmade blood vessels, scaffolds for tissue engineering.
7	Curdlan	Agrobacterium genus, Gram-negative bacteria	White granulate, fragrance-free, nonpoisonous gel, steady at 3 to 9 pH scale	Stabilizer, bio thickener, immobilizing materials, Texturizer, binding agent, as immunostimulator.
8	Xanthan gum	Plant pathogens such as Xanthomonas campestris NRRL B-1459.	Motile, having a single polar flagellum, cream-coloured powder soluble in both cold and hot water.	Emulsifier and thickening agent texture, viscosity, flavour release, appearance, and water control.

Source: Aggarwal et al. (2020).

In literature, several possible sources of biopolymers are presented and may be considered. Specifically for packaging purposes, to substitute plastics because of their environmental impact, Othman (2014) describes a wide range of possible categories of biopolymers that may be useful (Figure 1).

Certain polymers have been transformed into various materials utilized in diverse sectors such as healthcare, pharmaceuticals, agriculture, food and beverages, toiletries, cosmetics, textiles, and other industrial, domestic, and personal care products. Traditional polymers like starch, cellulose, chitosan, alginate, and gelatin have gained prominence on a large scale. Additionally, there are natural polymers, including starch, wood, and natural rubber, which fulfill essential needs in our daily society, such as food, energy, papermaking, and transportation. These sustainable and natural polymer sources play a vital role in our everyday lives and the production of essential global commodities. However, due to disparities in capital growth and opportunities between Less Developed Countries (LDCs) and developed countries (DCs), the economic implications of technology and capital dependence result in an unequal distribution of the benefits provided by specific polymers. Market inefficiencies and policies further restrict the global access to the advantages of natural polymers. With the increasing importance of environmental sustainability for individuals, ecosystems, and industries, regulatory bodies should establish policies to promote the production and utilization of biodegradable polymers in a sustainable environmental and economic framework (Aggarwal et al. 2020).

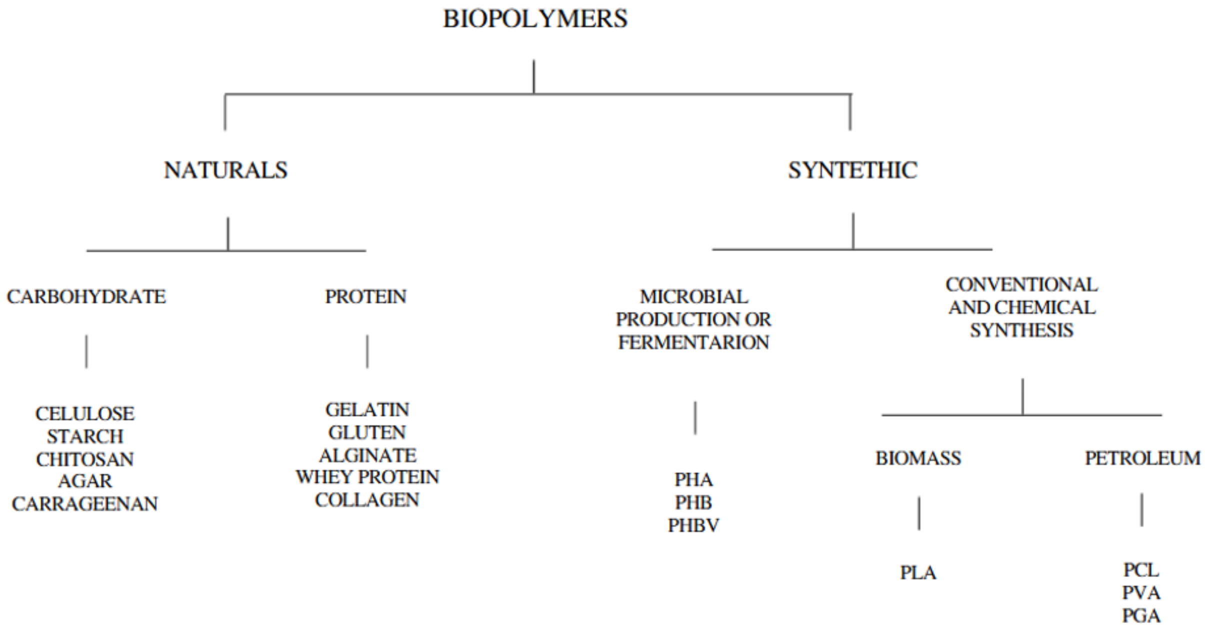

Figure 1. Categories of biopolymers. Source: Othman (2014)

The global production chains of biopolymers

The global production of plastics in 2015 reached approximately 400 million tons. Global plastic consumption is led by the packaging sector (36% of global consumption), construction (16%), and textiles (14%). In this sense, production and consumption are primarily linked to the consumption of manufactured goods and civil construction (World Economic Forum 2022).

The productive structure of polymers broadly represents the region's participation in the production of manufactured goods at a global level. The United Nations Environment Program (2018) report demonstrated the involvement of each region (production and consumption) at a global level in 2015. The Asian continent leads global production because of the region's positioning in manufacturing production. The Asian continent, despite being the leading global producer of polymers (49% of global production), consumes around 37% of world production. Latin America consumes twice its production, which positions the region as a consumer of polymers (Table 4).

Table 4. Regional participation (%) in global production and consumption of polymers in 2015. Source: United Nations Environment Programme (2021)

Region	Participation in global production (%)	Participation in global consumption (%)
Asia	49	37
Western Europe	19	18
Commonwealth of Independent States	3	6
North America	19	21
Latin America and the Caribbean	4	8
Africa	5	4
Oceania	0.3	1

The potential for expansion of biopolymer chains at a global level is enormous due to the high dependence on the consumption of traditional polymers. In the case of the plastic industry, one of the leading sectors for conventional polymers, biopolymers represent only 1% of global plastic production. Forecasts point out that the global production of biopolymers will jump from 2.41 million tons in 2021 to 7.59 million tons in 2026. This indicates an average annual growth rate of 22% for the sector. As a result, the industry will generate US$ 29.7 billion in 2026, compared to US$ 10.7 billion in 2021 (European Plastics 2022). Even with this sector growth, only 2% of global plastic consumption in 2026 will come from biopolymers, demonstrating potential expansion in the coming decades (Table 5).

Table 5. Share of regions in bioplastic production (in % of global production) by region in 2021 and 2026 (forecast). Source: McGlade et al. (2021)

Region	2021	2026
Asia	49.9%	70.8%
Europe	24.1%	16.9%
North America	16.5%	8.5%
South America	9.1%	3.7%
Oceania	0.4%	0.1%

Globally, the number of companies investing in producing and commercializing biopolymers has increased in recent years. In addition, there are still investments led by well-known multinational companies that even work in making plastics using traditional polymers, as seen in Table 6.

Table 6. Multinational companies produce traditional polymers and their country of origin. Source: McGlade et al. (2021)

Company	**Country**
NatureWorks	United States
Biome Bioplastics	United Kingdom
Braskem	Brazil
Basf	Germany
Biotec	Germany
Total Corbion	Netherlands
Toray Industries	Japan
Novamont	Italy
Plastic Technologies	Australia

3. Methodology

This research presents itself as a qualitative exercise that discusses uses and possibilities of biopolymers, especially the case of Brazilian potential for the sector. To do so, firstly, a review was carried out on the concept of biopolymers, its main possibilities and uses, through norms that conceptualize biopolymers, and access to articles and data referring to reports from international institutions. The main themes, documents, and institutions used for the approach and conceptual contextualization are available in the table below.

Table 7. The main themes, documents, and institutions used for the approach and conceptual contextualization of biopolymers. Source: Research results

Theme	Document	Institution
Concept of biopolymers	NBR 15448-1	Associação Brasileira de Normas Técnicas (ABNT)
Scenario of environmental challenges	From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution	United Nations Environment Programme
The global production of plastics	Plastic pollution is a public health crisis. How do we reduce plastic waste?	World Economic Forum, 2022
Demands for generating urgent solutions	From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution.	United Nations Environment Programme
Circular economy for plastics	"O Compromisso Global – The Global Commitment"	Ellen Macarthur Foundation

After the conceptual and theoretical analysis, data from the global production of biopolymers in different countries were surveyed, for which data from international institutions and documents were used. And, to get to know the Brazilian scenario of production of raw materials for organic biopolymers, data were collected on the main possibilities of raw materials such as sugar cane, corn, cassava, rice, wheat, potatoes, and sweet potatoes. The main topics, documents, institutions, and references to data sources are listed in the table below.

Table 8. Themes, documents, and institutions for Brazil's biopolymer industry. Source: Research results

Theme	Document	Institution
Planted area of main tree species in Brazil	Production of Plant Extraction and Silviculture	Brazilian Institute of Geography and Statistics – IBGE.
Cultivation area, production, and average yield of main starch crops in Brazil	Municipal Agricultural Production - PAM	Brazilian Institute of Geography and Statistics – IBGE.
Projections for starch crops, corn, and sugar cane area and production in Brazil,	Agribusiness Forecasts - Brazil. Long-term projections.	Ministry of Agriculture, Livestock and Supply – MAPA.
Land use in Brazil and the supply chains for the polymer industry	ABC Plan - Low Carbon Emission Agriculture.	Ministry of Agriculture, Livestock and Supply – MAPA.

Regarding the discussion on Porter's Diamond, an exercise was carried out to consider the quadrants of the diamond, according to the work On Competition, by Porter (1999), and propositions were made about each element of the diamond and, subsequently, potentialities and weaknesses were considered according to the Brazilian reality.

To account for a closure of ideas about the sector, a survey of impressions was carried out using a form that made use of a site specialized in data collection and open responses, called Survio (survio.com) and contact was made with a representative of the newly created industry, installed in Brazil with questions about the strengths and weaknesses of the sector. The answers were subjected to content analysis and were described in the Results section.

In the end, considerations were made with an articulation of conceptual, theoretical, and data concepts in the international and national scenario, compared and problematized possible strengths and weaknesses in the light of

Porter's (1999) competitiveness ideas, and finally compared to the speeches brought by an entrepreneur in the sector.

4. Results

4.1 The raw material supply chain for biopolymers in Brazil

Several potential sources of biopolymers may be considered in Brazil. They may be obtained through the action of microorganisms (fermentation processes) and materials based on renewable sources like cassava starch, corn, sugar cane, chitin, and others. From the Othman (2014) list, for Brazil, we consider three primary sources, considering its domestic supply potential:

1. Natural > Carbohydrates > Cellulose and starch;
2. Synthetic > Microbial production or fermentation > PHB; and
3. Synthetic > Conventional and chemical synthesis > Biomass (PLA).

4.1.1 Cellulose and starch

Cellulose is an essential component of plant tissues, giving rigidity and firmness to plants, and is useful for numerous applications. It is a carbohydrate of the polysaccharide type formed by glucose monomers. It is the most abundant organic molecule on the planet and consists of up to 50% of the composition of wood.

Furthermore, it is one of the most present materials in everyday life. It serves as raw material for various types of paper, disposable diapers, fabrics, toilet paper, absorbents, pill filling, emulsifiers, thickeners, stabilizers of processed foods, adhesives, biofuels, and construction materials.

The production of pulp and paper is of great importance in the Brazilian economy due to its significant impact on countless other production chains. This chain stands out for its modernized factories, the qualification of professionals, highly productive forests, and a business that respects sustainability criteria.

It is composed of producing and extracting wood, manufacturing cellulose, and manufacturing paper. Among so many cellulose applications, paper production is still bigger and better known.

In Brazil, cellulose is obtained from planted forests only (AgroPos 2022). According to IBGE (2022b), the primary sources of cellulose are eucalyptus (77%), pines (19%), and other species (4%) (Table 9).

Table 9. Planted area of main tree species in Brazil, 2020. Source: IBGE (2022b)

Forest species	Planted area (hectares)	Share (%)
Eucalyptus	7,431,761	77.28
Pines (several species)	1,830,372	19.03
Other species	354,024	3.68
Total	9,616,157	100.00

Remarkably, the major tree species for cellulose production are exotic ones. They were introduced in Brazil (Eucalyptus, from Australia; Pines, mainly from the US and Canada).

Starch, a polymeric carbohydrate composed of multiple glucose units linked by glycosidic bonds, serves as an energy storage molecule in various green plants. It is the predominant carbohydrate found in human diets globally and is abundantly present in staple foods like wheat, potatoes, maize (corn), rice, and cassava (manioc).

From those crops, in Brazil, the most relevant sources of biopolymers (i.e., with the highest amount of production) are corn, sugar cane, and cassava.

While cassava is a native species, sugar cane and corn were introduced to Brazil. All three species are significant to the Brazilian economy by providing food, feed, energy, and other uses like biopolymers. Other starch crops like rice, wheat, potatoes, and sweet potatoes are used mainly as food and feed. Yet, their amount of production does not allow other uses on a large scale. The cultivation area, production amount, and average yield are shown in Table 10.

Table 10. Cultivation area, production, and average yield of main starch crops in Brazil, 2020. Source: IBGE (2022a)

Starch crop	Cultivation area (ha)	Production (mt)	Average yield (mt/ha)
Sugar cane	10,014,198	757,116,855	75.6
Corn	18,253,766	103,963,620	5.7
Cassava	1,214,015	18,205,120	15.0
Rice	1,677,705	11,091,011	6.6
Wheat	2,434,703	6,347,987	2.6
Potatoes	117,253	3,767,769	32.1
Sweet potatoes	59,481	847,896	14.3

Considering the projections for the next ten years (2021/22 - 2031/32), among the main starch crops, corn and sugar cane will increase cultivation area and production in Brazil, while cassava and other starch crops are expected to decrease area and production in the same period (MAPA 2022).

4.1.2 PHB

Polyhydroxybutyrate (PHB) is a polyester class polymer of interest as bio-derived and biodegradable plastic (Lichtenthaler 2010). They are also known as thermoplastic polymers.

Although the majority of commercial plastics are synthetic polymers derived from petrochemicals, PHB-derived plastics possess appealing qualities due to their compostability, renewable sourcing, and biodegradability. Microorganisms such as *Cupriavidus necator*, *Methylobacterium rhodesianum*, or *Bacillus megaterium* are responsible for the production of PHB, presumably triggered by physiological stress conditions such as nutrient limitations (Ackermann et al. 1995). This polymer is primarily synthesized through the assimilation of carbon, typically derived from glucose or starch. Microorganisms utilize PHB as an energy storage molecule to be metabolized during periods of limited energy availability.

Thus, its production potential is flexible and scalable, with the availability of the necessary carbon substrates that can be produced by some glucose and starch crops. Since Brazil can increase its production of starch crops, the production of thermoplastic polymers PHB has remarkable potential to substitute commercial synthetic plastics.

The summary of findings is firstly that video conferencing possibilities have become mainstream and are adding additional tools to the educators for existing target groups. Online tools have also widened the educational scope: schools can reach new target groups which have been underserved, leading to new educational opportunities for students and new revenue sources for educational institutions. Secondly, the issues and solutions encountered on three continents and different learning cultures were largely similar, and so were the solutions applied. This leads to the conclusion that things learned from one continent may be transferable to other learning/teaching situations. These conclusions are somewhat tentative and need corroboration by other researchers.

4.1.3 Biomass (PLA)

Polylactic Acid (PLA) is a linear aliphatic thermoplastic polyester that can be derived entirely from renewable sources, such as corn. Although its initial applications were primarily limited to medical uses like sutures, this polymer is now widely employed in various industries, including packaging, textiles, manufacturing plastic containers, and the production of biodegradable polymers (Eslahi Nopashayi et al. 2013).

Several agricultural products and residues can be used for PLA production. Therefore, the potential production is massive since several renewable sources can be used.

4.2 Land use in Brazil and the supply chains for the polymer industry

As an important carbon dioxide net emitter from land use and land cover change, Brazil represents 17% - 29% of global total land use and land cover change. Country ecosystems play an important role in global carbon stocks. Since livestock and agriculture traditionally act as competitors for land use, it is relevant to verify how public policies encourage one sector of the Brazilian economy. Thus, we will briefly analyze this important issue with the Integrated Crop-Livestock-Forest (ICLF) system.

As per the Ministry of Science, Technology, Innovation, and Communications, a significant portion (44%) of Brazil's greenhouse gas emissions stem from changes in land cover, specifically deforestation. In response, the government introduced the ABC Plan (Low-Carbon Agriculture Plan, known as *Plano de Agricultura de Baixo Carbono*, in Portuguese) to promote the implementation of low-carbon agricultural practices. The ABC Plan facilitates this by offering subsidized credit to support the adoption of integrated systems. These integrated systems typically involve a combination of crop-livestock-forestry production and are regarded as more environmentally friendly in terms of carbon emissions.

The ABC Plan has two main goals, to recover 15 million hectares (Mha) of pastures and expand the Integrated Crop-Livestock-Forest (ICLF) system by 4 Mha. However, the ABC Plan presents a pace of adoption below the requirements to achieve the goals. On the other hand, the target for pastures and ICLF makes it possible to achieve the reduction target of up to 51.8 million tons of carbon equivalent (tCO2eq) per year when it is reached, which represents between 32% and 39% of the total emission reduction target foreseen for the ABC Plan as a whole (Plano ABC 2017). The main results expected by the ABC Plan are:

- If pasture recovery were prioritized in areas with the highest level of degradation (those with the lowest carrying capacity of animals per hectare). - or we could call it "Priority Areas" - we would have an economic cost to society equivalent to withdrawing R$ 3.71 from each inhabitant's consumption to achieve the goals of recovery of pastures and ICLF.
- If the ABC Plan prevails, the result would be a gain of around R$ 41.19 in additional consumption per inhabitant. The free choice of allocation of areas for recovery could generate a positive economic impact on collective consumption because of technologies in food production.
- The cost of implementation in the priority areas is low for society, considering that the priority areas have significant economic challenges, with greater climate risk, less proximity to markets, and less potential gain in productivity. There would also be a more significant indirect environmental benefit due to the "land-saving" effect - in making land available for cultivation - and the potential accumulation in the carbon stock of forests and natural vegetation.
- In a situation of free allocation, a reduction of around 51.8 million tCO_2eq would be possible. In annual emissions, when 15 Mha of recovered pastures and 4 Mha of expanded ICLF are reached, which would represent between 32% and 39% of the total emission reduction target foreseen for the ABC Plan while regionally speaking, the distribution of the effects of the ABC Plan can be quite different. This depends, of course, on your implementation strategy. If the focus is on the recovery of pastures in priority areas, the Northeast would receive more significant volumes of resources and could reduce the pressure on natural resources. If the recovery of pastures occurs by the free will of agricultural markets, the South and Southeast would receive more significant volumes of resources and free up more areas for conservation.
- Regardless of whether resources are allocated to priority areas, the ABC Plan tends to provide greater specialization in the Southeast and South in crop production, while the Midwest and North tend to specialize more in livestock production.

According to information from Plano ABC (2017), something around R$ 26.7 - R$ 31.3 billion would be needed to recover 15 Mha of pastures and between R$ 7.7 billion and R$7.8 billion for the expansion of 4Mha of ICLF.

As seen in Table 11, it is possible to achieve the goals of the ABC Plan with lower disbursements than expected. However, until the end of the 2015/16 crop year, disbursements reached almost R$ 13.8 billion. Such amounts represent only 16% of the amount foreseen only for the recovery of pastures and ICLF.

Table 11. Impacts and scenarios. Source: Plano ABC (2017)

Impacts	Scenarios	
	Priorities Areas	**Allocation Free**
Expenses with pasture recovery (R$ million)	31,288	26,685
Expenses with integrated systems (R$ million)	7,789	7,732
Total expenses (R$ million)	39.077	34,417
Change in well-being (R$ million)	-724	8,027
Recovery cost (R$/ha)	2,086	1,779

Finally, according to the Plan ABC report, the different levels of pasture recovery in the scenarios simulated in the ABC Plan imply different patterns related to redistributing the "saved" area via productivity gains in pastures and integrated systems. Agricultural cultivation areas increase in the Southeast regardless of the simulated scenario, while, in the South, these areas increase only in the free-flowing scenario.

In the Midwest, North, and Northeast, the recovery of pastures causes a reduction in the crop area. This result is closely related to the change in good-quality pastures. In the Southeast and South, these pastures increase less than the recovered pasture area, meaning that part of the good pastures is converted into areas for crops, forests, and secondary vegetation. In the North and Midwest, areas of good quality pastures grow more than the areas of recovered pastures, and part of the cropland is converted to good quality pastures. Areas with natural vegetation and forests increase in net terms in almost all regions, emphasizing the Southeast and South, while they reduce in the Midwest. Those results suggest that the increase in pasture productivity minimizes the need for areas of agricultural production in most of the Brazilian territory but leads to greater specialization in the production of vegetable crops in the Southeast and South and livestock production in the Midwest and North.

4.3 Diamond analysis of biopolymers in Brazil and SWOT of the use of biopolymers and the Brazilian chain

As presented, the production chain of biopolymers exposes, in some aspects, complexity, great reach, and several possibilities. Michael Porter's intellectual production seems to be precisely about the transformations from a theory of comparative advantage to competitive advantages. According to Porter (1999, p. 173): "*The classical theory explains the success of countries in specific sectors based on so-called factors of production, such as land, labor, and natural resources [...] However, this theory has been overshadowed, in advanced sectors and countries, by the globalization of competition and the power of technology*".

In this sense, this article can be an example of the challenges that a country, inserted only as a producer of raw materials, faces to climb the production scale in the biopolymer sector. Therefore, for Porter, competitiveness requires thinking beyond access to countries' natural wealth, as expressed in his own words, "... *competitiveness results from the productivity with which companies in a given location can use inputs to produce valuable goods and services. Furthermore, the potential for productivity and prosperity in a given location does not depend on the sectors in which they operate of the company but on its form of competition"* (Porter 1999, p. 13).

In addition to analyzing the business scope, Porter (1999) also examines how competitiveness becomes a political and national characteristic. He states, "*The competitiveness of a country depends on the ability of its industry to innovate and improve. Companies gain a position of advantage over the best competitors in the world due to pressures and challenges*" (Porter 1999, p.167).

The author structured an analysis instrument entitled the Diamond Theory of National Advantage to support the understanding of competitiveness as a complex element. This instrument was widely used to analyze the productive structures of countries and productive agglomerations and currently has variations, complementation, diversification, and criticism. An analysis of the model proposed by Porter is essential in this article, mainly since it analyzes a recent sector in the economy. This profile of the productive sector of biopolymers allows analyzing or drawing attention to the theoretical-conceptual framework defined by Michael Porter to point out the transformation of the understanding of comparative advantage to competitive advantage.

The "Diamond of National Advantage" model combines factor conditions, demand conditions, related and supporting industries, and company strategy, structure, and rivalry.

As Factor Conditions, Porter understands the country's position on production factors (labor, infrastructure, natural resources). As Demand Conditions, Porter includes the degree of demand of the domestic market, for example. Concerning the Related and Supporting Industries, the presence or absence of supplying and other related sectors are listed and, as Strategy, Structure, and Rivalry of Companies, the country's business conditions are gathered, as well as determinations on how companies are managed, organized and the existence and nature of rivalries in the internal market.

In this tangle of relationships, with great complexity of elements, a business environment or the national environment in which companies are born and learn to compete is constituted.

Therefore, in the present case study, it is necessary to pay attention to the elements that make up the productive sector linked to biopolymers in an initial phase in Brazil. As previously presented, there are already industries worldwide considering biopolymers as part of their projects and products.

In Brazil, the first biopolymer industry began to operate in 2021. Although Braskem, a significant industry in the plastics sector, already has projects and products linked to biopolymers. Earth Renewable Technologies (ERT) is the first national industry dedicated to producing only polymers of biological origin. It should be noted that this is not only the first Brazilian biopolymer industry but also the first biopolymer industry in Latin America.

ERT emerged in 2009 in the United States as a startup at Clemson University, an institution that has activities related to biopolymer engineering in South Carolina. In 2019, a research project was carried out with the Federal University of Paraná (UFPR) to think about developing polymers made from sugarcane bagasse. These activities gave rise to a fiber patented by ERT, entitled Short Fiber Reinforced Polymer (SFRP).

Considering the essential elements in the production chain of biopolymers, it is possible to structure a Diamond of National Advantage to identify the potential and fragility of the sector in Brazil. In any case, this does not exhaust all the elements for a complete analysis of the industry, but it is important because it brings some aspects that demonstrate the potential for the case of Brazil.

Table 12. Theory of Diamond of the National Advantage in the Biopolymer Sector. Source: Research results.

Factor Conditions	Demand Conditions	Related Industries	Strategy, Structure, and Rivalry between Companies
Labor availability	High demand for plastic products	Highly competitive agroindustry to supply raw material	Low national production competition,
Availability of natural resources	National industry international competitive - Braskem as an example,	Uncompetitive national transport infrastructure, high transport costs	High competition with the paper industry sector for some products,
Internationally competitive agribusiness	Consumers' demands are below international standard	Manufacturing industry and final consumers	Low global competition, as it is the first industry specialist in Latin America, and few exist in other countries.

So, in a way, the production of biopolymers from renewable resources from agriculture can be structured from a design involving agricultural production, transport, transformation industry, coil generation, coil transport, secondary transformation industry, and products. From a certain angle, the production of renewable resources and destination for Brazilian industries or not already have defined courses that alternate according to social, political, and economic dynamics. Suppose, by chance, in a short period, it is more profitable to allocate part of the production of starch derivatives to the generation of biopolymers. In that case, Brazilian producers could do so without significant changes. But this is a question worth considering: for the biopolymer sector, would it be strategic to guarantee the transformation of starch into products in Brazil?

According to the National Accounts of the Brazilian Institute of Geography and Statistics, in 2017, the manufacturing industry was responsible for 11.8% of the national GDP. Brazil is a country whose GDP mostly comprises the service sector, industry, commerce, agriculture, civil construction, and mineral extraction, with few oscillations in the order of importance presented. Compared with the entire industry, only the manufacturing industry data presents half the amount. In 2021, of the 22.1% corresponding to the Brazilian GDP, the manufacturing industry reached 11.3%, according to the Industry Portal.

This data will be necessary because the biopolymer production chain will require decision-making on the part of the public and private sectors, to invest in the transformation of the tremendous productive potential of renewable resources that the country has.

In a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, it is possible from some of the elements listed to analyze the formation of a productive sector and each scenario's strengths and weaknesses. It was possible to perceive that there are elements involved that can be considered in each of the four features that make up the Diamond of National Advantage.

Considerations follow to understand weaknesses, potentialities, and investment possibilities for each element that makes up the diamond. Regarding the Factor Conditions, the following comments are listed in Table 13.

Table 13. Theory of Diamond of the National Advantage in the Biopolymer Sector (Production Factors). Source: Research results.

Factor Conditions	Strengths and Opportunities	Weaknesses and threats	Recommended actions and investments
Labor availability	High potential if investments are made in specific areas.	High labor availability, but unskilled workers.	Need for investment in technical and technological qualifications to support new sectors and sectors of new materials, theoretical and critical qualifications for attention to environmental and socioeconomic sustainability issues, among others,
Natural resources availability	Vast productive areas of renewable resources and high technical and technological capacity in the agro-industrial sector are internationally competitive.	Environmental, social impacts, depletion of water resources, soil depletion due to excess or inadequacy of production techniques,	Investment in techniques and technologies for sustainable production,
Internationally competitive agribusiness	Brazil has advanced knowledge in agro-industrial production, being a productive and competitive global agent with a historical trajectory of production and supply for national and international chains.	Environmental and social impacts of the concentration of production and wealth, inadequate transport and logistics with high costs, and infrastructure deficient to support the activity	Qualification of the population to support activities, both technically and technologically, and critically, with a solid formation of environmental and social awareness to understand the importance of the success of the agro-industrial sector for international competitiveness with environmental and socioeconomic sustainability.

Regarding the demand conditions, it is possible to identify possible strengths and weaknesses, as shown in Table 14.

Table 14. Theory of Diamond of the National Advantage in the Biopolymer Sector (Demand). Source: Research results

Demand Conditions	Strengths and Opportunities	Weaknesses and threats	Recommended actions and investments
High demand for polymers and plastics	High demand for plastic products in the national and international markets, so the potential for service and supply of products for the transformation industry and others is enormous.	The plastic industry demands low prices, so there is a certain conservatism in the entry of alternative products. Even if it is more sustainable, the price keeps conventional plastic from non-renewable resources highly competitive.	Fiscal incentives and subsidies support and change raw materials' matrices to replace conventional plastic, from non-renewable sources to biopolymers.
National industry international competitive - Braskem as an example	The conventional plastics industry has several projects to change its products to products based on biopolymers. The perspective of expansion of biopolymer industry.	Maintenance of plastic products from non-renewable resources in aggressive price competition, under penalty of serious environmental problems	Investment in material sciences, qualification of the population to work in the area of new materials, and critically support the conscious transition of uses of sustainable products. Law regulation to induce the reduction of traditional polymers.
Consumers and the domestic market are in low demand (products below the law's standard available on the market, for example)	Present products to the domestic and foreign markets as better quality and sustainable solutions in the medium and long run.	Low competitiveness because of meager prices practiced by the conventional plastic sector and its negative characteristics for the environment	Analyze, monitor, and demand adjustments to conventional plastic products so that they are delivered to the market within the quality standards required by international markets, as well as encourage the use of new materials that are more sustainable through the qualification of the population and incentive policies.

Regarding related and supporting industries, it is possible to problematize possible strengths and weaknesses, as shown in Table 15.

Table 15. Theory of Diamond of the National Advantage in the Biopolymer Sector (related and supporting industries). Source: Research results

Related and supporting sectors	Strengths and opportunities	Weaknesses and threats	Recommended actions and investments
Highly competitive agroindustry to supply raw material	Increase and converge competitiveness within the raw materials production chain	Environmental and social impacts of raw material production not carried out in a sustainable way	Improve incentives and policies to increase the sector's productivity based on sustainable and efficient use of natural resources.
Uncompetitive national transport infrastructure, and high transport costs.	Potential to improve logistics from new investments in infrastructure.	Encouraging low production costs to remain competitive, increasing the price of raw materials, and making the conventional plastics industry still durable through price differentiation,	Investment in the road, rail, waterway, and communications sectors, as well as in health, education, and social rights structures for populations settled in productive rural areas,
Manufacturing industry and final consumers	Stimulate and ensure a new lease of life, differentiation for the competitiveness of the national manufacturing industry due to the use of sustainable raw materials	Low demand for the manufacturing industry.	Convergence of actions between the transformation industry and employers' unions. More significant parameterization among the existing industries.

Finally, about the Companies' Strategy, Structure, and Rivalry, comments and reflections were gathered about the strengths and weaknesses as shown in Table 16.

Table 16. Theory of Diamond of the National Advantage in the Biopolymer Sector (Companies' Strategy, Structure, and Rivalry). Source: Research results

Strategy, structure, and rivalry between companies	Strengths and opportunities	Weaknesses and threats	Recommended actions and investments
Low national production competition, it is the first specialist industry,	Encourage new industrial groups to invest in the new segment. Sector expansion potential in the medium and long term.	The concentration of production, the concentration of the market, the concentration on decision-making, and the definition of prices, projects, and products.	Encourage science and technology of new materials, encourage new biopolymer production industries, and encourage new base industries.
High competition with the paper industry sector for some products,	Stimulate development and competition of biopolymers for existing products in pulp and paper to provide diversification of uses and raw materials,	Biopolymers' difficulty is entering the market and economic uncertainties in the sector.	Stimulate research and development of new materials and diversified uses to meet internal and external market demands and stimulate compositions between materials to support different sectors. Long-term planning for the industry.
Low global competition, as it is the first industry specialist in Latin America, and few exist in other countries.	High probability of market dominance and leadership for companies that take risks.	The concentration of production, the concentration of the market, the concentration on decision-making, and the definition of prices, projects, and products. Uncertainties about the market.	Encourage science and technology of new materials, encourage new biopolymer production industries, and encourage new base industries. Strategic planning anchored in disruptive technologies.

To compose the understanding of the elements of the Diamond Theory of Competitive Advantage, especially from the perspective of the business sector, a script of questions was carried out and sent to ERT executives to support the understanding of the vision of the industry installed in Brazil in 2021. Thus, below are the questions and answers obtained.

To compose the understanding of the elements of the Diamond Theory of Competitive Advantage, especially from the perspective of the business sector, a script of questions was carried out and sent to ERT executives to support the understanding of the vision of the industry installed in Brazil in 2021.

ERT was settled in Brazil in 2020, and to begin the interview we questioned why they decided to invest in the biopolymer sector. The interview was carried out virtually with the participation of a representative business who pointed out elements of comparative advantage for Brazil to be highlighted. So, the representative claimed: "We believe that Brazil has abundant raw materials, advanced research, developed technologies, and a geographic and economic advantage (production cost) over competitors in Southeast Asia, in addition to being strategically positioned to supply growing markets in Latin/Central America and Europe." To understand how Brazil positions itself as a global representative of this nascent branch of business, we questioned how the company perceives the country as an essential player in biopolymers production. And the representative pointed out that the country in question may be one or the most important platform for exporting bioplastics, and that it should consider exporting products with added value in addition to commodities, so he stressed: "We should export PLA instead of sugar." When asked about the availability of raw materials to deal with this nascent sector, the businessman claimed that they are abundant, safe, and of high quality.

However, considering Porter's theory about the importance of the transformation of comparative advantage to achieve competitive advantage it requires thinking and strategies for this leap. Therefore, we asked what the main restrictions or challenges for the development of the Brazilian biopolymer industry would be. In response, he told us: "Today, encouraging sustainable products is the main determining factor for us to continue. Laws promote the use of compostable/sustainable materials and discourage products that are harmful to the environment. Brazil needs to encourage by law both the production of compostable plastics and ban the use of conventional and oxo-biodegradable plastics in single-use applications (delivery packaging + plastic bags)."

Towards becoming competitive, a sector therefore needs to make its products more sophisticated, and the concept of demand conditions suggests that the process to turn complex public and market demands is necessary, in this sense, we question how they evaluate the market demand for biopolymers. And the ERT representative pointed out that he considers this demand still immature, a little encouraged, but claimed to have confidence in the growth and acceptance of new offers.

Regarding the structures for a cluster, we questioned which stages of a biopolymer production chain you consider available to be done, and the answer involved the consideration of Sugar produces lactic Sugar produces lactic acid - PLA, and in the future, in developing 2G PLA from sugarcane bagasse. And then we asked which sectors support more efficient performance in the nascent sector in Brazil, and which sectors they consider still incipient, and the answers obtained were that no sector sufficiently supports the demands of this nascent sector, as well as considering that final consumers still not mature enough. In this way, there are elements of Porter's Diamond that are fragile such as Conditions of Demand and Related Sectors.

After this step, to better understand the representative's view of the current structure and the potential of this sector, we questioned what is needed for the development of the sector, how it could be stimulated, or become competitive, and which companies are involved in this effort. After this, we received responses that involve activities from large companies such as Braskem, Raizen and ERT, and the ERT representative pointed out that: "It was strongly encouraged via legislation for some final applications and benefits for producers of compostable resins. With the increase in the supply of materials in Brazil, the price and availability also tend to drop, making these materials closer to conventional resins." In addition, he reinforced that Brazil can be undoubtedly the most competitive country in biopolymers in the world, especially if you consider specialization in the production chain of lactic acid.

From the answers collected from a representative of ERT, it is possible to perceive knowledge on the part of the representative of the potential coming from Brazil, especially regarding access to raw materials. This understanding corroborates Michael Porter's (1999) perception that accessing abundant, quality raw materials give you elements for a production chain to organize itself and seek to be competitive. However, as pointed out earlier, Porter (1999) points out the need to establish connections and deepen the other elements that make up a competitive production chain, which requires specialization beyond privileged access to raw materials. The ERT representative also presents the location for the distribution of production as an essential element for competitiveness, as he considers that accessing the foreign market will be possible and presents itself as reasonably practicable due to the already existing trajectories and the proximity of Brazil to European and other markets. It also argues that the government's role is fundamental in encouraging productive activities and restricting the use of conventional plastic materials from non-renewable resources.

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Finally, it is considered that the presence of this type of enterprise in the national territory points to a use of raw materials and natural resources that advanced from a model in which Brazil would only export these materials to be transformed in other countries and returned as products with added value, and with investments in research and development, and higher-paying jobs in other locations.

The international scenario, as seen above, points to social, governmental, and business concerns with the situation of conventional plastic production today. Residues, lack of disposal control, water, and soil pollution, among other factors, corroborate the stimulus to the biopolymer market. Thus, considering the amount of possibility linked to new materials, natural or synthetic, as well as the quality that has been demonstrated, being possible to make different uses, and having renewable resources as a source, as well as countries with arable areas that can make use for this sector, as well as residues from the agro-industrial industry being used in addition to biomass, for the production of biopolymers, the productive sector, therefore, receives this boost from the conjuncture.

In this way, one can perceive the complexity of understanding and judging the positive possibilities or risks for the stage of the productive sector, according to the decision-making process.

5. Concluding remarks

This article brought together elements to discuss the use of conventional plastics, coming from non-renewable resources, and the unfolding of heavy criticisms regarding this production chain, due to the environmental impacts of this highly durable product on the planet.

From the exposition of some data on the impacts of conventional plastic in the world, a new segment of the market was presented that is in its initial phase, which brings together efforts to produce bioplastics, polymers, and new materials, which make use of renewable resources, and that therefore, they are better absorbed by nature, being considered biodegradable or compostable.

A session was held to present the concept of biopolymers and their varieties. Since then, global efforts have been made to produce biopolymers, companies, and countries that stand out. To advance to an analysis of the Brazilian conjuncture, possibilities for producing biopolymers from national products were presented in an agro-industrial scenario of supplying raw material for biopolymers, as well as an argument about land uses and the possibility of expanding these uses. Subsequently, a reflective exercise was presented on the organization of a productive sector of biopolymers in Brazil, from installing the first biopolymer production industry in Brazil and Latin America. For this purpose, Michael Porter's ideas of Competitiveness were used, the Diamond of Competitive Advantage by the same author and potentialities and weaknesses related to each component of the productive segment of biopolymers about diamond items were problematized.

As the main results, we point out that it is a sector in which Brazil has a tremendous comparative advantage but needs economic, social, political, environmental, and technological investments, among others, to advance to competitive advantage.

Regarding the contributions to the literature, it is possible to consider the consequences of possibilities on Porter's Diamond due to the consequences on existing productive industrial segments that that are under technically and sustainability changes. For example, in this case it was possible to see how the existing plastic sector could unfold into a more complex sector with the advent of bioplastics, with high investments and knowledge in chemistry, new materials and others.

As limitations of this study, we present the lack of data on the bioplastics sector, since in general it is a recent follow-up, with knowledge production still concentrated in European countries, and with several initiatives sprouting all over the world, considering different raw materials such as avocado, palm, algae, among others that still do not have data available for deeper analyses of the potential and complexity of this sector.

When it comes to future studies, we highlight the need to understand and study existing efforts in industries that are not specialized in bioplastics, but also producing bioplastic types, and being large and important players in plastic sector, such as Braskem, Raizen, Bunge, among others. We also suggest the need of mapping and considering different efforts in companies, startups and the various organic and non-organic sources and raw materials to learn about potentialities and challenges for the future of plastic materials, especially bioplastics, and the consequences of these in business and in the environment.

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