sustainability

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*Review*

# Bioplastics and the Role of Institutions in the Design of Sustainable Post-Consumer Solutions

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**Abstract:** This article aims to understand the role of institutions, especially meso-institutions, in the construction of definitions of bioplastics that foster sociotechnical changes, so that a single language with epistemic quality can be defined for global governance in the solution of environmental problems arising from the plastic production chain. To this end, through a narrative literature review and documentary research on European and Brazilian legislation, this article applies theory to the case of the global definition of bioplastics. Clearly, the creation of definitions matters to institutions and global governance, since they ensure that these definitions follow the criteria of coherence, determination and epistemic quality. On the other hand, it is noted that these criteria are not met in the case of the definition of bioplastics, which suffers from a lack of global standardization. Furthermore, we conclude that the lack of a globally standardized definition of bioplastics promotes negative effects, such as greenwashing. Critical topics such as renewable contents and the biodegradability and compostability of materials are essential to a deeper comprehension of sustainability. From this perspective, this study highlights the intricate interplay between technological advancements and established standards in the rapidly evolving bioplastic market, which is underscored by a lack of clear definitions. Meso-institutions emerge as pivotal actors in bridging the gap between market demands and scientific progress that facilitate the development of standards and regulations essential to the sustainable dissemination of bioplastics.

**Keywords:** ecosystem; food; innovation; bioplastic; circular economy; meso-institutions; governance



**Citation:** Silva, V.L.; Freire, M.T.d.A.; De Almeida Oroski, F.; Trentini, F.; Costa, L.O.; de Batista, V.G.T. Bioplastics and the Role of Institutions in the Design of Sustainable Post-Consumer Solutions. *Sustainability* **2024**, *16*, 5029. https://doi.org/10.3390/su16125029

Academic Editor: Yanwei Li

Received: 5 March 2024
Revised: 17 May 2024
Accepted: 20 May 2024
Published: 13 June 2024



## 1. Introduction

According to current data from the Organization for Economic Cooperation and Development [1], global plastic production increased by 230 times from 1950 to 2019 and reached a production level of 460 million tons. With regard to waste, in 2019, around 353 million tons of plastic was discarded worldwide, of which only 9% was recycled. In addition, it is estimated that in 2019, about 22 million tons of plastic waste leaked into the environment, which totals as an accumulation of 109 million tons in rivers and 30 million tons in oceans.

In fact, the interest in other sources of raw materials for plastic production dates back several decades. The 1970s, in particular, when the so-called oil crisis took place, saw great motivation for technological development aimed at reducing dependence on fossil materials. Over time, other factors accentuated the interest in alternatives to conventional plastics, with emphasis on the concept of biodegradable resins. The vast environmental pollution from plastics, particularly those based on petroleum derivatives, has led the scientific community to seek more sustainable alternatives. Regarding this aspect, there was a move towards intensifying recycling through mechanical recovery and incineration (energy supply). Also, the prospect of obtaining plastics from renewable sources emerged [1]. At the same time, new materials obtained from partially or totally natural sources were being developed for application in the most varied sectors of the economy [2]. Nowadays, a systemic approach to the total carbon cycle and sustainability aspects, including economic, social and environmental aspects, leads to a process of sociotechnical transition in plastic production environments [3].

The concept of bioplastics relies on renewable feedstocks, and the carbon dioxide capture and release periods have been relatively short. There is a significant variety of materials sold based on starch, algae, soy, agro-industrial waste and microorganisms. Applications can be directed to the medical industry, food packaging, cosmetics, agriculture, the textile industry, electronics and construction, among others.

Nevertheless, the dissemination of bioplastics, although continuous, progresses slowly due to different factors, such as the global economic situation and technological aspects, high production costs, technical performance limitations and challenges regarding end-of-life management [4,5]. Barbado and Pamplona [6] established factors related to the diffusion of bioplastics in Brazil, including production monopolies, costs of technological innovation, market application opportunities, compatibility of innovation, recycling and biodegradation aspects, marketing, regulatory systems, business cooperation. It is worth highlighting that the compatibility of innovation is directly related to the source and end of life of the materials. Drop-in materials, i.e., those identical to fossil plastics but from renewable sources, can be transformed into plastic products with little or no adaptation of the conventional plastic production and processing system. Some examples of drop-in bioplastics are bio-based polyethylene (PE) and polyethylene terephthalate (PET). For instance, bio-PET made with up to 30% of bio-based content is currently used by Coca-Cola Company in beverage bottles. Non-drop-in materials require investments for transformation into final products and adaptation to production, processing and recycling methods, which can create difficulties in the adoption of bioplastics. PLA (poli lactic acid) is the most notorious case of non-drop-in bioplastic. Despite the challenges of being a material that is chemically distinct from other fossil-based materials, PLA is one of the most used bioplastics globally [7]. Over the years, PLA producers have made various efforts to improve its technical properties. These improvements have opened up a range of applications, including food packaging, electronics, textiles and 3D printing [7,8].

At the moment, the dissemination of bioplastics is reflected in an expected increase in production capacity from 2.2 million tons in 2022 to about 6.3 million tons in 2027 [9]. One of the arguments regarding their adoption is that these materials are considered "environmentally friendly". Among the potential positive effects of bioplastic adoption for the environment are the following: (1) Reduced dependence on fossil feedstocks due to the utilization of multiple renewable sources, such as agricultural, industrial and urban organic waste. This change can reduce the carbon footprint and enable the transition to circularity through the valorization of waste. (2) Minimization of problems associated with the disposal of fossil plastics, such as the significant amount of non-recycled plastic waste that ends up in landfills and leakages. (3) Reduction in greenhouse gas emissions along the fossil plastic production chain and absorption of $CO_2$ during the growth of renewable feedstock sources. (4) Biodegradable materials replacing fossil plastics, reducing harm to marine ecosystems, such as that caused by microplastics [5].

Nevertheless, it is crucial to comprehend the worries regarding the environmental impacts of bioplastics. Even if they are produced from renewable resources, it is necessary to understand their carbon footprint along the production process. Competition in terms of land use for food production is often highlighted as a key issue by the literature. Drop-in bioplastics such as bio-polyethylene are not biodegradable; therefore, they must be recycled. On the other hand, most biodegradable plastics present limited biodegradability, requiring specific conditions to degrade [5,7,10]. In short, life cycle assessment studies must be carried out to identify possible bottlenecks regarding the sustainability of bioplastics.

It is important to mention that the unfamiliarity of consumers with words like bio-based, biodegradable and compostable can result in misguided decisions and disposal practices. Further, the non-definition of end-of-life options for bioplastics may hinder their adoption at larger scales [7]. From this sociotechnical transformation, which aims to obtain new plastic materials with a sustainable purpose, numerous conceptual and practical doubts arise, hindering the relationships among the different actors involved, directly or indirectly, in the production chain of plastics. In addition, for the development of new regulatory approaches, clear concepts become essential with regard to alternative plastics, taking into account possible "greenwashing" practices.

Moshood et al. [11] consider that the lack of appropriate and harmonized concepts of sustainability and globally agreed-upon methodologies for sustainability evaluation can bring to the international trade of biomass and bio-based products not being recognized as sustainable in some countries.

In this scenario, global governance is gaining more and more importance, as it is possible for it to be exercised efficiently through the use of unified definitions about new technologies, such as bioplastics, by all actors (private and public) and at various levels (from local to international). In this sense, this article aims to understand the role of institutions, especially meso-institutions, in the construction of definitions that promote sociotechnical changes, in order to, by means of these definitions, achieve a unique language with epistemic quality that can be understood and officially adopted for environmental problems originating from the plastic production chain.

Few studies have applied the concept of meso-institutions to the diffusion of innovations, mainly concerning the adoption of sustainable materials such as bioplastics [12,13]. Meso-institutions play important roles in the rules, norms, and practices that govern the interactions and shape the behavior of actors at the intermediate level. Menard [14] proposes the meso-institutions approach to uncover the relationship between macro-level (rule of the game) and micro-level institutions (organization level).

It is clear from the above that the rapid technological development of more sustainable alternatives to conventional plastics brings with it difficulties associated with the correct understanding of the actors involved regarding the concept of sustainability (environmental aspects) and its complexity. With regard to bioplastics, the lack of clear definitions of terms associated with these new materials has resulted in doubts and questions on the part of users and society. These difficulties cause a domino effect, since these definitions are used in the development of regulations and standards that must be applied and, in turn, impact the application of these materials in the market. Thus, this article discusses the role of meso-institutions in the current scenario of the growth of applied research on and innovation in bioplastics.

This end is achieved through a narrative literature review and documentary research on European and Brazilian legislation, and this article is divided into three sections. The first one aims to relate institutions to governance in order to emphasize the indispensability of established definitions by institutions, so that governance can be exercised efficiently. The second section aims to apply the theoretical contribution to the case of bioplastics, which suffer from a lack of definitions at a global level. Finally, the third section relates the role of governance to the functions of meso-institutional intermediaries when considering the effects that the global lack of definitions of bioplastics has caused.

## 2. The Relationship between Governance and Institutions and the Importance of Definitions

In this article, governance is assumed, from the perspective of Arnaud [15], as a form of management established by a shared authority with collective participation and at various levels (local, regional, national and global) in the making of complex decisions. In order to relate governance to institutions, these are understood according to New Institutional Economics and divided into three layers.

At the top of the institutional environment are the macro-institutions through which rights are constituted, defined and allocated; these are the "rules of the game and the general conditions for their implementation". In the lowest layer, related to the organizations, there are the micro-institutions, through which "transactions are organized and the allocation and usage of resources are shaped" [16–18]. In the middle layer, there are the meso-institutions, which connect the macro-institutions to the micro-institutions. It is noteworthy that through meso-institutions, the rules are transformed into specific technical norms for operators and users through devices and mechanisms. These can be private or public and take the form of regulatory agencies, certification bodies or professional organizations that define standards for a particular type of industry [12,14]. In other words, meso-institutions functions encompass translating, adapting, allocating, monitoring and incentivizing rules and rights [12].

Thus, by recognizing that meso-institutions play a key role in implementing the rules that shape the organization of transactions, we also acknowledge that they are indispensable to the realization of sociotechnical change. From this perspective, meso-institutions are charged with four fundamental functions: 1) they translate the general rules and standards established at the macro level, making them specific to a sector operating in the given time and space; 2) they oversee the effective implementation of the rules and standards thus adapted by establishing protocols and/or procedures that actors must follow and that facilitate the monitoring of their compliance with the rules; 3) they play a key role as enforcers, which requires their formal qualification to do so and their empowerment to constrain defaulting actors, ensuring compliance with rules and regulations, with sanctions in case of non-compliance or rewards in case of compliance; 4) they provide feedback to micro-institutional intermediaries on the application or formulation of macro-institutions [19].

The functions of the meso-institutional intermediaries are especially important and are essential for sociotechnical change to be achieved. Meso-institutional intermediaries implement the objectives and rules of macro-institutional directives and can also transfer the requirements and motivations of micro-institutional intermediaries to macro-institutional intermediaries, so they serve as functional intermediaries between the higher and lower structural levels in both directions. Further to this perspective, they are responsible for detailing and specifying the macro-institutional rules in operational norms, monitoring compliance with these norms, and punishing non-compliance or rewarding compliance, as well as providing feedback to micro-institutional intermediaries on the application or formulation of macro-institutions [19].

Certainly, meso-institutions contribute to the manifestation of governance, either through the development of regulatory agencies or through the interference of normalizations arising from standards [15]. In this way, they also include technical standards, which are in turn defined as a document that is 1) consensual; 2) approved by a recognized organization; 3) endowed with rules, guidelines or characteristics for activities or their results; 4) common and repetitive in use; and 5) attempting to obtain an optimal degree of ordering in a given context. It should also be noted that its contents should be based on "consolidated results of science, technology and accumulated experience aimed at optimizing benefits for the community", as well as being available to the public [20,21].

This social purpose of technical norms, which contributes to the collective character of governance, was acquired by considering that technology inevitably results from the interaction of human actions in a given social context with no way of disconnecting technical and social relations [22]. In this regard, technical norms are now considered sociotechnical norms, and by transforming general rules into specific standards, they should aim to reduce social impacts in the field of best technological practice.

Given this, governance encompasses several actors, and it is in this plurality of actors (public and private) and levels (local, national and international) that global environmental governance is established; however, this multiple coexistence in the same thematic area, characterized by fragmentation and the absence of a clear hierarchy, favors conflicts and generates a scenario of insecurity. To help resolve this diversity of uncertainties and interconnected governance, Keohane and Victor [23] propose six criteria: 1) coherence, 2) accountability, 3) effectiveness, 4) determinacy, 5) sustainability and 6) epistemic quality.

In linguistic terms, a concept is the compilation of true statements about a certain object that is fixed by a linguistic symbol, so that the definition is the delimitation or fixation of the content of a concept [24]. In this respect, definitions are needed by institutions and, consequently, global governance, since they guarantee the criteria of coherence, determinacy and epistemic quality. This facilitates the possibility to fill gaps and obtain a common goal by all the other actors at the most varied levels.

However, the analysis and implementation of an adequate definition becomes a challenge for global governance and counts on sociotechnical assistance, particularly from meso-institutional standardization intermediaries. It is in this context of governance that the institutional terminological difficulty of "bioplastic" is problematic, especially when one considers the constant and growing development of new plastic materials that are obtained from partially or totally natural sources and are strategically designed to reduce environmental impacts.

## 3. The Absence of a Global Definition of Bioplastics

In order to apply the theory of the previous section to the concrete case of the definition of bioplastics, it is first necessary to define the terms polymer and plastic. According to the International Union of Pure and Applied Chemistry (IUPAC), the international non-governmental organization and world authority on chemical nomenclature and chemical terminology, a polymer is defined as a substance composed of molecules of large size which is characterized by multiple repeating units (a single atom or a group of atoms). These units are known as monomers, or constitutional units, and, in the case of polymers, are covalently linked to each other in sufficient quantity to provide a set of properties that do not vary substantially with the addition or removal of some constitutional units [25].

In turn, plastics are a special group of polymers with characteristics that differentiate them from other materials, such as fibers and rubbers, among others, which are also polymers. The main characteristic of plastics is their ability to flow and be shaped through the use of controlled heat and pressure. A plastic, by the action of heat and pressure, easily softens to fit the shape of a mold. During subsequent cooling, the plastic becomes solid again, retaining the shape of the mold. Some plastics, known as thermoplastics, are those that can be repeatedly subjected to heating, molding and cooling processes. Other plastics, called thermosets, can be formed only once, making it impossible for them to melt and flow repeatedly [26–28].

It is in response to the environmental impacts caused by synthetic plastics that bio-based materials, a growing class of polymeric materials that have been promoted as alternatives to conventional synthetic plastics, have emerged. Concomitantly, new questions are enunciated regarding the possible environmental impacts related to these new materials [1,7,29–31] and, consequently, their governance.

This fact brings to light the discussion regarding the environmental contamination resulting from the incomplete degradation products of plastics, microplastics. Microplastics are low-density fragments that vary in size, shape, color and composition. They are classified into primary and secondary. Primary microplastics are made up of polymers in the form of micropellets, microspheres and microfibers with applications in personal hygiene products and paints, among others. Secondary microplastics correspond to the decomposition products of plastics in the environment from bags, plastic bottles, plastic cutlery, nets and fishing lines, as well as agricultural waste such as weed mats and ropes [32].

There is a large recent scientific collection with approaches related to microplastics produced with conventional petroleum-derived polymers. Different aspects are addressed in relation to environmental impacts, taking into account both the physical aspects of the fragments and the chemical composition of the microplastics. The distribution of microplastic into the environment as well as the possible impacts on human health have also been highlighted in scientific publications [32–38].

As with conventional plastics, bioplastic degradation processes can produce microplastics, whose degradation kinetics can be slow in environments such as natural soil and aquatic environments, causing accumulation in the environment [30,39,40]. A relevant factor to be considered refers to the influence of the intrinsic properties of biopolymers on degradation processes, since new technologies allow for the production of blends or composites with the aim of meeting different performance demands [30,41]. Products resulting from different biodegradation processes are also dependent on environmental conditions and are measured by means of parameters considered in life cycle analysis, such as the generation of methane, water, carbon dioxide, hydrogen and ammonia. In this sense, extensive scientific research on bioplastics seeks to understand the degradation mechanisms involved, with particular interest in their behavior in different environments (natural and industrial) and environmental conditions (aerobic digestion, anaerobic digestion, composting, etc.) [29,30,42,43]. According to life cycle assessment techniques based on ASTM and ISO, standards developed to evaluate bio-based products and their environmental performance, for a polymer to be considered compostable, it must convert 90% of its carbon content into carbon dioxide.

Besides the important advances in biopolymer technology, there are still many doubts as to the proper definition of bioplastics. Table 1 illustrates the misunderstanding of the use of the term bioplastics given the lack of consensus among the main reference organizations in the sector. From this point of view, the IUPAC has not conceptualized bioplastics; rather, it launched recommendations in 2012 focusing on terminologies that can be used in relation to bioplastics and implemented in the areas of medicine, surgery, pharmacology, agriculture, packaging, biotechnology and polymer waste management, among others. In this publication, the importance of these terminologies in the context of human health and environmental sustainability was emphasized, considering that they are increasingly interdependent. The importance of these terminologies was also emphasized in the field of research and micro-institutions, as they are still developed independently in each sector and in the field of public use by non-specialized professionals such as journalists, politicians and stakeholders from complementary disciplines [25].

Although the IUPAC does not conceptualize bioplastic, it does conceptualize bio-based polymers as being "derived from the biomass or issued from monomers derived from the biomass and which, at some stage in its processing into finished products, can be shaped by flow". Furthermore, the IUPAC makes three important notes: 1) "Bioplastic is generally used as the opposite of polymer derived from fossil resources"; 2) The term bioplastic "is misleading because it suggests that any polymer derived from the biomass is *environmentally friendly*"; 3) "The use of the term "bioplastic" is discouraged; the expression "bio-based polymer" is more accurate [25].

In addition to the IUPAC, another important international non-governmental organization that aims to develop global standards for the market is the International Organization for Standardization (ISO), based in Geneva, Switzerland. However, although the ISO has a wide global presence, it does not have a standardized definition regarding what is considered bioplastic. It is worth noting that the ISO is made up of more than 800 technical committees and subcommittees, which include specialists appointed by the full members for the area of standardization. These specialists develop a draft standard from a market need within a specific area, for example, plastics. The experts' draft is considered a standard to be followed only after the full members vote; therefore, there is a true marketing nature to the standards created by the ISO, although an attempt is made to dialogue with consumers through the Consumer Policy Committee [44].

**Table 1.** The misunderstanding of the use of the term bioplastics given the lack of consensus among the main reference organizations in the sector.

| **How the term bioplastic is generally presented by the literature** | **Organization and its definition/understanding of 'Bioplastic'** | | |
|---|---|---|---|
| Bioplastic as a sustainable alternative for conventional plastic. | **IUPAC (International Union of Pure and Applied Chemistry)** | **ISO—International Organization for Standardization** | **EUROPEAN BIOPLASTIC** |
| Partially or totally from natural sources.<br><br>Materials made from biopolymers (made in nature), for instance made from maize starch and potato starch OR from bio-based polymers (made in a factory).<br><br>But without consensus by Standards & Techinical Norms. | 'Bioplastic' generally used as the opposite of polymer (derived from fossil resources).<br><br>A material that at some stage in its processing into finished products, can be shaped by flow.<br><br>Discouraged the use of 'bioplastic', because it suggests that any polymer derived from the biomass is environmentally friendly.<br><br>Suggested the expression 'bio-based polymer'. | Do not present definition of bioplastic.<br><br>Presents other accessory definitions, such as:<br><br>- bio-based (ISO 16620 series/bio-based content of plastics) and<br><br>- biodegradability (extensive list of stan-dards/environmental impacts; carbon footprint, anaerobic digestion, biodegradation). | Bioplastic: encompasses all plastic material other than not the conventional plastic.<br><br>It does not delimit a minimum percentage of the bio-based to be used in the composition of the plastic material.<br><br>It does make it possible that any material that presents even tiny percentages of biomass can be called bioplastic. |

Although the ISO does not present the definition of bioplastics, it presents other accessory definitions relevant to environmental aspects, such as bio-based and biodegradability. With regard to bio-based, one can mention the ISO 16620 series, which seeks to standardize the determination of the bio-based content of plastics and which is reflected by European Norms (ENs) 16640, 16785-1 and 16785-2 [28]. With regard to biodegradability, there is an even more extensive list of standards, such as those referring to a) the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (ISO 14040 and 14044, reflected in ENs 16760 and 16751); b) measuring the carbon footprint, or green footprint (ISO 14067 and 22526); c) anaerobic digestion and industrial composting (ISO 18606 and 17088, reflected in EN 13432 and 14995); d) the aerobic biodegradation of plastics under controlled composting conditions (ISO 14855); e) biodegradation in marine environments (ISO 18830, 19679, 22404, 22403 and 22766); f) biodegradability in soil (EN 17033); and g) more currently in 2022, the conditions or home composting of biodegradable plastics (CEN/TC 261 SC 4 WG 2) [9,45].

Still, in this context, it is important to mention the crosscutting standards developed by the European Technical Committee for Standardization for bio-based products (CEN/TC411), which offer guidance on aspects such as measuring methods of bio-based content, and business-to-business and business-to-consumer communication. These voluntary standards are widely used by the market, and their application is recommended, as it ensures a consistent approach.

It is clear from these standards that bio-based materials are those that use biomass resources, such as organic materials available on a renewable or recurrent basis, and crop residues, wood residues, grasses and aquatic plants, or according to the IUPAC concept, "living systems and collection of organic substances produced by living systems that are exploitable as materials, including recent postmortem residues" [25].

In addition to the terminological recommendations presented by the IUPAC and the absence of a definition of bioplastics by the ISO, one can find the concept used by European Bioplastics, which is used and disseminated worldwide [9,46]. This organization is a private association based in Berlin, Germany, whose direction is given by representatives of member companies from distinctive sectors (bioplastic manufacturers, petrochemical companies, plastic converters, agribusinesses and others). These, in turn, are listed on the association's website, and among them, it is possible to observe large transnational companies in the industrial sector [9]. It should be noted that European Bioplastics, although it is recognized as a relevant association when the subject is bioplastics, unlike the ISO and the IUPAC, does not have as its fundamental function the elaboration of international standards, and its concepts are followed by the market only as a reference.

Up to this point, it appears that the definition does not involve concepts related to sustainability, including clear definitions for biodegradability and compostability. In the EU policy framework for bio-based, biodegradable and compostable plastics, concern about this topic can be noted: Bio-based plastics are fully or partially made from biological resources, rather than fossil raw materials. They are not necessarily biodegradable or compostable. It is important to examine the full life cycle of bio-based plastics, to ensure that they are beneficial to the environment beyond the reduction in the use of fossil resources. This includes changes in land use.

In this regard, European Bioplastics brings together bio-based and biodegradability to formulate its concept of bioplastics. According to European Bioplastics, "A plastic material is defined as a bioplastic if it is either bio-based, biodegradable, or features both properties". European Bioplastics, which represents the interests of the bioplastics industry in European states, suggests that both bio-based and biodegradability directives can foster a European circular economy for mechanically recyclable bio-based plastic packaging and compostable bio-based plastic packaging.

Nevertheless, the concept of bioplastics has its conceptualization derived from these two initial concepts, which are notoriously complex. In this sense, it is notable to remember that there are several standards that seek to regulate the definition and measurement methods of bio-based and biodegradability; among them are the standards issued by the ISO, by the European Committee for Standardization (CEN) and the American Society for Testing and Materials (ASTM); however, they do so without going into the definition of bioplastics itself.

Therefore, considering the current state of such norms and concepts, for a plastic material to be considered bioplastic, from the perspective of European Bioplastics [9], it must either be bio-based (even if partially) or be biodegradable, or both. Given this, the private association European Bioplastic has concluded that bioplastics can assume two major forms, as shown in Figure 1: a) all the plastic material that has biomass in its composition, whether or not it is biodegradable, and b) all biodegradable plastic material, whether or not it contains biomass in its composition. In this regard, only conventional plastic is excluded from this concept of bioplastics; thus considered, it is a plastic material that does not contain biomass (fossil-based) in its composition and is non-biodegradable [9].

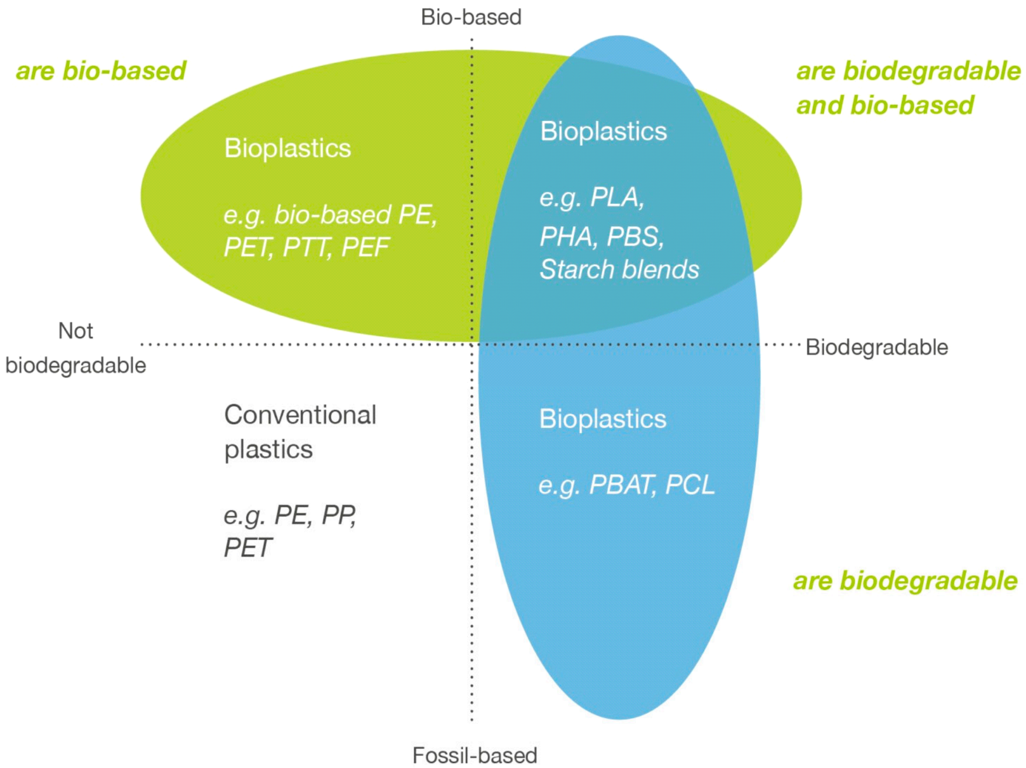


**Figure 1.** The bioplastics concept by European Bioplastics. Source: European Bioplastics [9].

The concept by European Bioplastics can, therefore, be considered generic, because it encompasses all plastic material other than conventional plastics. Besides that, the conceptualization of this association, while it does not delimit a minimum percentage of the bio-based material to be used in the composition of the plastic material, it does make it possible that any material that presents even tiny percentages of biomass to be called bioplastic [46].

Further to this, Costa [27] points out that the concept of biodegradability can be criticized for not defining a criterion for the time of degradability. This means that it could take years for the material to degrade and still be considered biodegradable. In this regard, the author points out that the ideal concept for the preservation of the environment would be "compostable material" that completely biodegrades into neutral elements within a period of 45 to 90 days.

Another important factor that is subject to criticism in the concept of bioplastics by this European association is the fact that biodegradability is measured under specific laboratory conditions that are not always consistent with the destination of plastic materials in day-to-day life. This means that although a material may be considered biodegradable for testing purposes, it can take several years for it to degrade in uncontrolled environments, and it may generate secondary microplastics, whose impacts on the environment are as harmful as those of conventional plastics [40,46].

As there is no globally standardized definition of bioplastics, for example, via an ISO standard, the tendency is for macro-institutions interested in environmental protection to exclude any concept of bioplastics. The absence of a definition generates, on one hand, room for the perpetuation of environmental impacts and, on the other, an extreme measure of macro-institutional exclusion of anything that might be considered bioplastic. Moreover, the term bioplastic means that its use is not uniform. The journal *Sciences et Avenir* has defined bioplastics as a neologism coined by the industry to cover plastics of widely varying composition and ecological interest [47]. The term bioplastics is used to designate two distinct realities: the origin of the resource (bio-based) and end-of-life management (biodegradable and compostable).

It is worth mentioning once again that the biodegradation of a bioplastic depends on specific environmental factors, such as temperature, humidity, oxygen, pH and the chemical structure of the polymer itself [48,49]. According to [50], bioplastics can be categorized in several ways. Among other things, they can be classified according to their chemical composition, synthesis methods, manufacturing processes, economic importance or applications. Constraints limiting the development of bioplastics, confusion over terminology, high costs, properties that are not always favorable, end-of-life management issues and a negative image in terms of agricultural practices are all obstacles to the development and dissemination of bioplastics.

Consumer perception and confusion about the concept of bioplastics is becoming an issue, and a major problem with bioplastics is confusion over terminology. Definitions of biodegradable, compostable and bio-based bioplastics show that the distinctions among these terms are subtle and increase consumer confusion. The differences among the terms are unclear, and knowing how to distinguish these bioplastics is not obvious. This confusion leads many consumers not to pay attention to labels or certifications. A study in Australian consumers found that the bioplastics concept is unfamiliar and that the biodegradability and bio-based terms are hard to distinguish and their relationship is confusing [51]. The study by Herbes et al. [52] identified that consumers were more concerned about end-of-life options (recyclability and biodegradability) of packaging materials, while less attention was given to the renewable origin. Confente et al. [53] explored how consumers perceive innovative products made from bioplastics. The high perceived value of bioplastic products leads to greater purchase and exchange intentions, and in turn, this value is over-stimulated by consumers' green self-identification. Consumers thus show their willingness to accept bioplastic products whenever there is clarification of the product's value and potential positive effects on the environment and when the alignment between the characteristics of these products and consumers' personal values is highlighted; moreover, Brockhaus et al. [54] found that potential bioplastic adopters in Germany see greenwashing as an important barrier to the adoption of these materials.

These factors can foster a bad perception among customers, because it is difficult to distinguish between the various types of bioplastics concepts and the format in which manufacturers market them are not the same.

## 4. The Relationship between Global Governance and the Roles of Meso-Institutional Intermediaries in the Case of Bioplastics

In this scenario of growing and agile technological development and the search for sustainable sociotechnical transitions, the case of the definition of bioplastics is just one of the many uncertainties that present themselves today. Global governance in this regard is of vital importance, as through institutions and intermediaries, it has the function of internationally unify definitions for environmental protection.

For this purpose and as an example at the macro-institution level, there is Directive (EU) 2019/904 of the European Parliament and of the Council of June 5, 2019, which aims at "the reduction of the impact of certain plastic products on the environment". That Directive defines plastic as "a material consisting of a polymer as defined in point 5 of Article 3 of Regulation (EC) No 1907/2006, to which additives or other substances may have been added, and which can function as a main structural component of final products, with the exception of natural polymers that have not been chemically modified" [55]. Therefore, the term includes not only fossil-based plastics but all plastics that have been chemically modified, including bio-based plastics, biodegradable plastics and those that have both characteristics, such as polylactic acid (PLA), a plastic which contains lactic acid as a monomer and can be obtained from the fermentation of natural sources, such as sugarcane bagasse.

In addition, this Directive, in order to achieve its objective of reducing environmental impacts, regulates "single-use plastic", i.e., plastic that is not conceived, designed or placed on the market to make multiple trips or rotations in its life cycle upon its return. Thus, the

Directive focuses on the circularity of the product only. For example, plastic cutlery, as per part B of the Annex to this Directive, will be restricted from being placed on the market, as it is considered single-use plastic, even if it is made from biodegradable plastics or from biomass, or both [55].

In this globalized scenario, it is also worth analyzing Chinese and American regulations due to the notorious economic activity of these two countries. With regard to China, two standards issued by the China's State Administration for Market Regulation should be highlighted: (a) GB/T 39514-2020, dated November 19, 2020, "*Terminology, definition, identification of bio-based materials*" [56], and (b) GB/T 41010-2021, dated November 26, 2021, "*Degradability and identification requirements of biodegradable plastics and products*" [57]. These standards, although they seek to define relevant terms such as biodegradability and bio-based, do not present the term "bioplastic" in a specific way. From the US point of view, as mentioned above, the ASTM standardization norms do not specifically define the term "bioplastic" either [58], but consequently, private institutions define it, like the US Plastics Industry Association (PLASTICS), which adopts a definitions in the same sense as European Bioplastics, i.e., any biodegradable or bio-based plastic, or even biodegradable and bio-based [59].

In Brazil, however, there are still no macro-institutions that regulate plastics in the national territory. In this regard, the lack of federal law that deals specifically with the use of conventional plastics stands out. What is observed is action, when existing, at the state or municipality level through ordinary laws. As an example, we can cite Law No. 17.261, of January 13, 2020, of the Municipality of São Paulo, which concerns the prohibition of the supply of plastic products in specific places. The Law of São Paulo, in art. 2, determines the following: "In place of plastic products, others with the same function may be supplied in biodegradable, compostable and/or reusable materials, in order to enable recycling and accelerate the transition to a circular economy". Another Law, this time at the state level, concerning the use of bioplastics is No. 16 268, of May 29 2008, of the State of Goiás. This Law prohibits the use of plastic bags in certain establishments, such as supermarkets and emporiums; however, its validity has already been modified twice, from 01 to 05 years and from 05 to 10 years. The lack of public regulation at the national macro-institutional level is compounded by a lack of certification at the meso-institutional level. This fact points to a deficiency in national and macro-institutional standardization on the subject in Brazil [60].

As there is no globally standardized definition, such as through an ISO standard, the tendency is for macro-institutions interested in environmental protection to exclude any concept of bioplastics. In this way, macro-institutions prevent the negative effects of the absence of a definition from being perceived; on one hand, its absence leaves room for the perpetuation of environmental impacts, while on the other, there is an extreme measure of exclusion of everything that could be considered bioplastic by macro-institutions.

The apparent impetus of this movement allows us to say that the definition of bioplastics is not in the interest of the organizations of technical standardization, such as the ISO, since they do not define it, whereas the total exclusion promoted by the European Directive creates a landscape characterized by uncertainties regarding the adoption of bioplastics. In addition, exclusion individually does not remedy the lack of a global definition, thus protecting from negative effects only those States that have macro-institutional strength for bioplastics to be regulated, while in States with fragile macro-institutions, the negative effects continue to exist, enabling the creation of a market of certifiers with different concepts or even the absence of certifiers due to this lack of a definition.

Conversely, at the meso-institutional level, the function of the transformation of rules into specific sociotechnical norms would make it possible to adapt the term "bioplastic" to operational norms, so that meso-institutions, whether international or national, whether public or private, implement purposes of environmental preservation and sustainability. With this, through an internationally unified definition and with epistemic quality in favor of environmental protection, it is understood that it is possible to reduce the negative effects of the lack of definition, such as greenwashing. Figure 2 discusses the expected role of meso-institutions in the bioplastic case based on the general institutional framework.

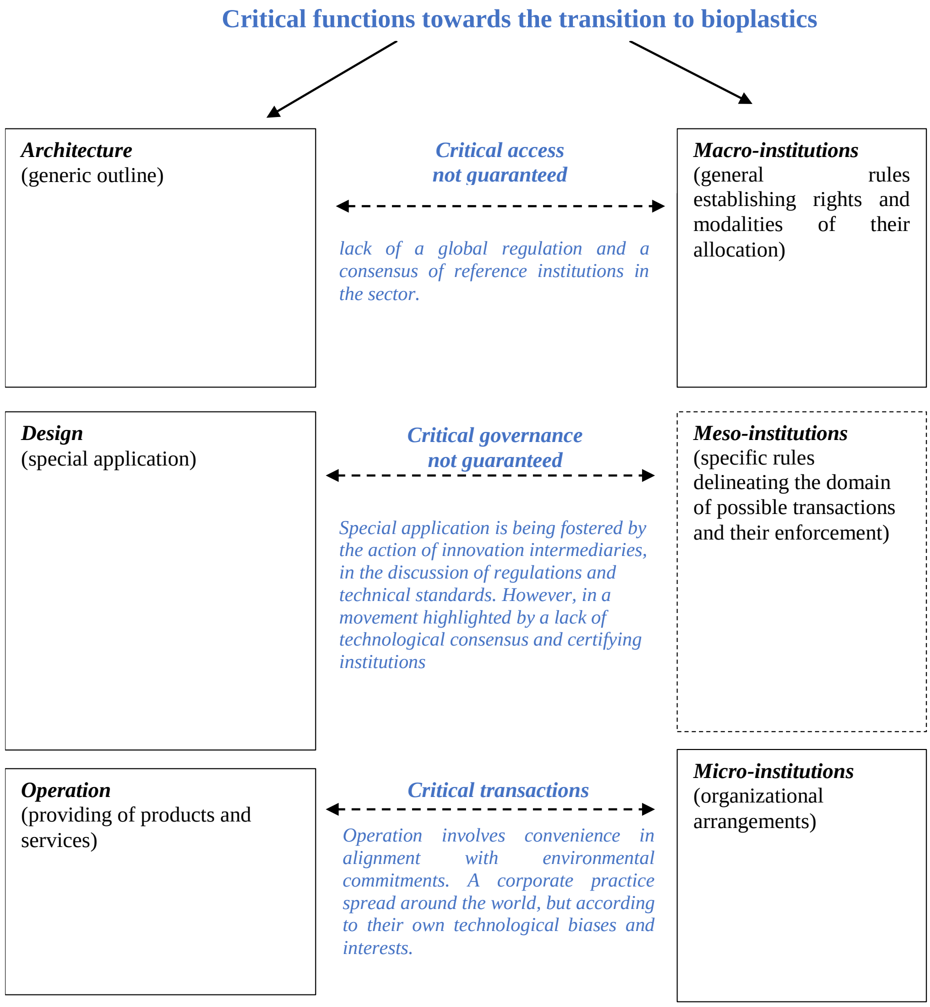


**Figure 2.** The expected role of meso-institutions in the bioplastic case based on the general institutional framework. Based on Ménard [12]. Note: Blue color and dashed lines show the absence of the functions expected by meso institutions, i.e., translating, adapting, allocating, monitoring and incentivizing rules and rights.

It is important to remember that the term "greenwashing" was used for the first time by Jay Westerveld in 1986 and has been widely used since the 1990s by non-governmental organizations (NGOs), including Greenpeace. These organizations popularized the term and began to denounce companies that falsely show themselves to be environmentally friendly [45,61–64]. Several authors and institutions sought its conceptualization, understanding it as a verbal or non-verbal, commissive or omissive communication, which masks real environmental problems of organizations or individuals [45,63,65–67].

Moreover, even in the case of the EU, although the issue of definition is overcome, a problem is created in the roles of monitoring and enforcement. This is because macro-institutions, although they can regulate inter-individual relations, do not have the capacity to modify behaviors by themselves. In this regard, it is necessary to create, through meso-institutional intermediaries, a whole apparatus for monitoring the use of the term "bioplastics", as well as a means to punish non-compliance and compensate for compliance, when applicable. Moreover, it is necessary to create a feedback mechanism for micro-institutional intermediaries on the use of this product.

Essentially, it is understood that the complexity of global governance related to environmental problems is not solved only with the creation of the appropriate institutional definition, despite it being a possible alternative for limiting negative effects such as greenwashing. The definition must also be accompanied by sociocultural reinforcements that aim at valuing the environment, not only at the individual level but also at the political and collective levels. Given this, it is necessary that institutional intermediaries act in order to achieve international unity and, in particular, that meso-institutional intermediaries monitor, enforce and provide feedback on the use of bioplastics.

## 5. Conclusions

Some general lessons emerge from the bioplastic case. First, when identifying and analyzing the different concepts used by meso-institutions and macro-institutions, the contrast of institutional scenarios is confirmed, and this arises from the absence of efficient global definitions with epistemic quality, which consequently creates diverse situations. Second, these conceptual differences raise the issue of different effects for private agents and consumers, mainly with respect to what sustainability regarding the adoption of these materials means.

The basic message conveyed by our analysis is that meso-institutions are important, mainly for the unification of concepts that are used by private actors and public policymakers, specifically in the environmental field, as well as for the reduction in informational asymmetry, since the consumer has little or no information regarding the quality attributes of the products. In fact, it is also suggested that the lack of a dominant meso-institution leads to efficiency problems in global environmental governance and favors the practice of greenwashing, in addition to creating disincentives to differentiate products, through certifications, from what can actually be considered bioplastic, situations that are experienced in Brazil. The lack of a definition for the term allows for different materials with different characteristics in relation to their origin (bio-content) and in relation to their end of life (recyclable or biodegradable/compostable) to be considered bioplastics, which hinders the adoption and diffusion of these materials.

In this scenario, greenwashing is a negative effect of the diffuse and sometimes generalist conceptualization of bioplastics in so far as the prefix "bio" is used by various agents in an opportunistic way. This symbolic imposition generated by the improper use of the prefix "bio" conveys to consumers an environmentally positive image of the product, which masks its negative environmental implications. Furthermore, the misuse of the prefix on the product also misleads the consumer about the organization that sells it, or that earns credit for its use, since it conveys the erroneous appearance of it being an environmentally friendly organization.

Considering the current scenario of climate change caused by human action and its harmful consequences for the planet, developing innovative and sustainable solutions to mitigate the environmental pollution produced by plastics is of great importance. Although several studies suggest that the accumulation of microplastics produced by bioplastics is unlikely, they cannot be considered the only solution to this major challenge. There is great technological development in the production of new bio-based materials, but there are many doubts about their degradation processes, particularly for chemically modified materials or bio-based composites. Important advances have already been achieved with the development of standards and methods for evaluating the degradation of bioplastics, but they are insufficient for the effective assessment of the real impacts caused to the environment. Likewise, our review demonstrates that despite the large number of scientific studies on the different mechanisms of bioplastic degradation, whether in controlled or uncontrolled environments, there are many unanswered questions. There is consensus among the scientific community that a greater understanding of degradation mechanisms is needed to achieve adequate standards and regulations.

Still, there is more to learn from the situations herein identified. In Brazil, given the absence of a macro-institutional definition of bioplastics, there is inhibition of an environment that promotes the development of sustainable productive activity and the incorporation of sociotechnical changes. Another point worth mentioning is that the absence of pressure to change the rules and clarify the relevant definitions benefits a group of companies, which are probably those that do not actually work effectively with environmentally suitable plastics that are fully bio-based and, simultaneously, biodegradable.

On the other hand, in Europe, the absence of a definition of bioplastics at the macro-institutional level, with the consequent favoring of greenwashing, causes its total exclusion by Directive (EU) 2019/904. Although this measure aims to reduce environmental impacts, it only considers plastics that fit the idea of circularity, even if these plastics are fossil-based or non-biodegradable. In another way, biodegradable and bio-based plastics, when they are created for the purpose of single use, are discouraged by this Directive, even though they simultaneously have bio-based and biodegradability characteristics and present less environmental impacts than conventional plastics.

The discussions presented in this study point out the complexity of the topic and reveal a mismatch between technological and technical–scientific development and established standards, given the fast pace of the market. This gap is closely related to the lack of clear definitions regarding the universe of bioplastics. This scenario highlights the importance of meso-institutions as essential actors in the connection between market and science to create innovative and sustainable solutions. They also play an important role in interfacing with entities involved in the elaboration of clear definitions essential to the development of standards, certifications and regulations, which in turn leads to security and reliability in a greater dissemination of bioplastics on the market.

**Author Contributions:** All authors contributed to the review article. V.L.S. contributed for both research funding and organization of the study; V.L.S. and F.D.A.O. wrote about the role of meso-institutions; M.T.d.A.F. and F.D.A.O. contributed with the technological aspects related to bioplastics; F.T., V.G.T.d.B. and L.O.C. collaborated with the regulatory aspects in light of the law involving the role of meso-institutions. All authors reviewed, revised and made relevant contributions and suggestions for the submitted manuscript. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by the São Paulo Research Foundation (FAPESP) through the Center of Science for the Development of Solutions for the Post Consumer Waste: Packaging and Products (Grant #2021/11967-6), as well as through the Project 'How do we go blue? Sociotechnical transitions and institutional levels' (Grant #2020/13307-0). Special thanks also to the All4Food.

**Informed Consent Statement:** Not applicable.

**Conflicts of Interest:** The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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