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IMPACT OF PLASTIC PACKAGING AND BIOPLASTICS ON SOLID WASTE MANAGEMENT

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ABSTRACT

After almost twenty years of discussion in Brazil, in the midst of a scenario that remained uncontrolled, the federal government enacted in 2010 Law 12.305, which established the National Solid Waste Policy, a regulatory framework that provides for the integrated management and management of solid waste, establishing a four-year deadline for the proper final disposal of waste. and the municipalities are responsible for the waste generated in their territories. Data from the Brazilian Association of Waste and Environment show that more than half of the municipalities have not yet adapted. The adoption of technologies is essential for the rescue and increase of the value incorporated into solid waste, for its reuse before it reaches landfills. In the present study, a bibliographic and documentary survey was carried out in order to investigate the solid waste scenario in Brazil, emphasizing the class of waste from plastics, identifying its impacts, proposing bioplastic as an alternative, with consequent contribution to the ecological economy. However, it can be said that there is a need for further exploration and more studies on the subject towards the scenario of management and reduction of this plastic waste, with the help of technologies, as well as studies with a view to alternative materials, such as bioplastics, thus potentially reducing the contamination of the environment with an approach of good practices for sustainability.

Keywords: Biodegradable packaging. Bioplastics. Solid waste management. Technologies applied to solid waste management. Plastic waste.

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INTRODUCTION

Behind only the United States, China and India, Brazil is the 4th country that produces the most garbage in the world, according to data from the *World Wild Fund for Nature* (WWF). The study "Solving plastic pollution: transparency and accountability", shows that the country produces 11,355,220 tons of plastic waste, and of these, only 1.28% is recycled, behind only the United States (1st), China (2nd) and India (3rd) (WWF, 2019).

Data from the Brazilian Association of Waste and Environment (ABREMA, 2023), show that in Brazil, about 3 million tons of solid waste are destined for rivers and seas every year, enough to cover 7 thousand soccer fields. This skyrocketing production and poor waste management has led to the scenario where between 4 million and 12 million metric tons of plastic enter the ocean every year (Ocean Society, 2022).

Among the waste, plastics are found in drinking water, rivers, oceans, soil or even inside aquatic animals, impacting the environment, human health and the health of other living organisms.

Plastic waste is a complex problem and needs a more amplified approach. This includes the search for better *designs*, more sustainable raw materials and partnerships between various stakeholders, including the manufacturing industry, the packaging industry, consumers, academics/researchers, decision-makers, politicians and the waste management industry itself. The *design* of plastic products should facilitate reuse, repair and recycling, as suggested in the "European Strategy for Plastics in a Circular Economy" (Grover *et al.,* 2023).

According to the United Nations Environment Programme (UNEP), when considering the current global situation of plastic waste, there are two emerging issues to address: one is to reduce the volume of uncontrolled or poorly managed waste streams that go into water bodies (including oceans) and the other is to increase the level of recycling (UNEP, 2021).

Plastics and Micro Plastics (PM's) have become, in this decade, one of the significant environmental issues for the world, due to the abundant use of products made from this material. Plastics are not only widely distributed, but also persistent in the environment. Waste plastics and PM's are mostly diverted from land and transported to the ocean through the freshwater system. A comprehensive understanding of the origin, destination, and transportation of plastics and PM's is required. The transport and

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destination models of the PM's can bring complementary information to understand the origin and distribution of this element, and thus help stakeholders to overcome the problem of plastic waste and PMs in the production chain and consequently in the environment.

Cowger *et al.* (2024) state that brands can be used to hold plastics companies accountable for their items that pollute the environment. In the research carried out by the authors, data from a global panorama considering 84 countries in the five-year period (2018–2022) were used, with the objective of identifying the product brands found in waste plastic items in the environment, through 1,576 audit events. It was found that 50% of the items had no associated brand, which would require mandatory reports from the producer, as they are called untraceable waste. Another important finding of the study occurred about the five main global brands, whose plastic waste is traceable, that is, linked to the brand name. These brands were: *The Coca-Cola Company* (11%), *PepsiCo* (5%), *Nestlé* (3%), Danone (3%) and *Altria* (2%), accounting for 24% of total traceable plastic waste (linked to brand names). In addition, 56 companies accounted for more than 50% of the total waste. There was a clear and strong signal of linear production relationship, pollution (%) between companies' annual plastic production and plastic pollution linked to their brand, with food and beverage companies being disproportionately big polluters.

It is well known that effectively addressing global plastic pollution requires corporate plastic waste producers to reduce plastics in their products and especially avoid single-use plastic items. They need to use safe and sustainable product design techniques, reducing the global demand for new products, while increasing the capacity for reuse, repair and recycling. In addition, it is necessary to invest in non-plastic alternatives with better proven quality, with safety and environmental profiles, and that support alternative distribution models (e.g. refill-reuse), which reduce pollution.

For Silva *et al*. (2020), vegetable raw materials are viable in the production of biodegradable packaging, as they have physical and chemical characteristics that allow optimal protection for products. It should be noted that these vegetable raw materials are easily found and present a good way of using plant residues.

According to Onofre *et al.* (2018), biodegradable polymers can represent a source of minimization of the environmental impact caused by the large volume of synthetic polymers extracted from non-renewable sources, such as the main source, oil. The biggest challenge is to encourage the conscious consumption of these products.

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The National Solid Waste Policy (PNRS) aims to stimulate changes in the way solid waste is managed in Brazil through Law 12.305 of August 2010 (Brasil, 2010). Among the various challenges, the PNRS defined the mandatory sending of waste for recycling and composting. Sanitary landfills have become the legally appropriate form of final disposal only for waste called tailings, that is, waste that, after exhausting all possibilities of treatment and recovery by viable technological processes, has no other possibility than its final disposal (Brasil, 2010).

In view of the above, how could technologies help to increase the efficiency of solid waste management processes?

The present research allows a non-limiting overview of plastic waste in Brazil, in the context of its generation and form of management, giving a dimension to the problem and, in a way, alerting to the emergence of discussion on the subject. The scenario of plastic waste, if replaced by bioplastics, is also briefly presented, setting a precedent for new research, which brings emphasis to the subject that is of great relevance, urgency and interest.

It is also the focus of this research to investigate a part of the available data on plastic waste from fossil sources generated in Brazil, how solid waste management is presented using technologies as support and present bioplastics as an alternative to fossils.

METHODOLOGY

For the present study, the methodology of scientific research was considered. The present research is characterized as to its nature as basic research, as there is no perspective of immediate application, being without pretense of solving a real problem, thus invoking the social responsibility of the scientific community.

Regarding the objectives, the approach has an exploratory characteristic since the idea was to bring to light the scenario in which solid waste management is involved in Brazil. With regard to the approach, it is qualitative, as it favors the understanding of the facts researched in a scientific way (Godoy, 1995). Qualitative research contributes with more in-depth information on the subject, without presenting numerical representativeness on the object of study (Gerhardt; Silveira, 2009).

As for the procedures, there was a concern to look at works already prepared, that is, it was outlined through a bibliographic and documentary survey, using the scientific

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research platform Scielo, as well as visiting public documents, such as panoramas on the subject, published by class associations that are authorities on the subject under study (Gerhardt; Silveira, 2009).

For the search, the following keywords were used: "Biodegradable packaging", "Bioplastics", "Solid waste management", "Technologies applied to solid waste management", in an individualized way. The period considered was between 2012 and 2022. For data analysis, the number of studies was considered, whose filter fit the research objectives.

THEORETICAL FRAMEWORK

In this section, some concepts related to solid waste and its management are presented, addressing a potential alternative to fossil-based plastics, bioplastic. Additionally, potential technologies for a more efficient management of this waste are presented.

IMPACTS OF FOSSIL-BASED PLASTICS (PETROPLASTICS)

For Shaftel *et al.* (2023), the plastic sector is the second largest industrial source of Greenhouse Gas emissions and the fastest growing in the world. Its composition is 99% derived from fossil fuels. Another important impact of the plastic waste is that it has already been detected in the deepest place on Earth, the Mariana Trench, at a depth of 10,984 kilometers. Szigethy and Antenor (2023) state that recycling is not enough, the challenge is on an industrial scale. There is growing evidence of microplastics being absorbed by plankton. Although some countries have limited plastic production, the global rate is still increasing.

Table 1 highlights the *ranking* of the countries that generate the most plastic waste, as well as the corresponding recycling rate.

Table 1. *Ranking* of the largest generating countries of plastic waste and recycling rate.

Country	Total plastic waste generated (Ton/year)	Total Incinerated (Ton/year)	Total recycled (Ton/year)	Production/recycling ratio (%)
USA	70.782.577	9.060.170	24.490.772	34,60
China	54.740.659	11.988.226	12.000.331	21,92
India	19.311.663	14.544	1.105.677	5,73
Brazil	11.355.220	0	145.043	1,28

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Indonesia	9.885.081	0	362.070	3,66
Russia	8.948.132	0	320.088	3,58
Germany	8.286.827	4.876.027	3.143.700	37,94
United Kingdom	7.994.284	2.620.394	2.513.856	31,45
Japan	7.146.514	6.642.428	405.834	5,68
Canada	6.696.763	207.354	1.423.139	21,25

Source: WWF (2019).

BIOPLASTICS

According to EUBP (2024), bioplastics are a large family of different materials, they are not just a single material. They are composed of a whole family of materials with different properties and applications. A plastic material is defined as bioplastic if it is bio-based, biodegradable, or has both properties.

Benefits of Bioplastics: Less pollution of the atmosphere when degraded, they generate a small volume of greenhouse gases, in some cases, the emission is even negative, when considering the entire life cycle of the product, (Dornburg; Hermann; Patel, 2008; Mores, 2013; OECD, 2013), since they come from plant sources that absorb CO2 and release oxygen through photosynthesis (Brito; Carbone; Blanquart, 2008).

BIODEGRADABLE PACKAGING

They are packaging, whose chemical origin allows microorganisms present in the environment to convert them into natural substances, such as water, carbon dioxide and compost (without artificial additives), according to the Brazilian Association of Compostable Biopolymers and Composting, ABICOM (2024) and *European Bioplastics,* EUBP (2024).

Bio-based: It means that the material or product is (partially) derived from biomass (plants). The biomass used for bioplastics comes from, for example, corn, sugarcane or cellulose.

Biodegradable: Biodegradation is a chemical process during which microorganisms available in the environment convert materials into natural substances, such as water, carbon dioxide, and compost (no artificial additives are required). It depends on the surrounding environmental conditions (e.g. location or temperature), the material and the application.

Biobased is not the same as biodegradable. The property of biodegradation does not depend on the resource base of a material, but is rather linked to its chemical structure.

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In other words, 100% bio-based plastics can be non-biodegradable, and 100% fossil-based plastics can be biodegradable.

Bioplastics are driving the evolution of plastics with two major advantages of bio-based ones compared to their conventional versions: they save fossil resources through the use of biomass that regenerates (annually) and provides the unique potential for carbon neutrality. In addition, biodegradability is a complementary property of certain types of bioplastics and offers additional means of recovery at the end of a product's useful life.

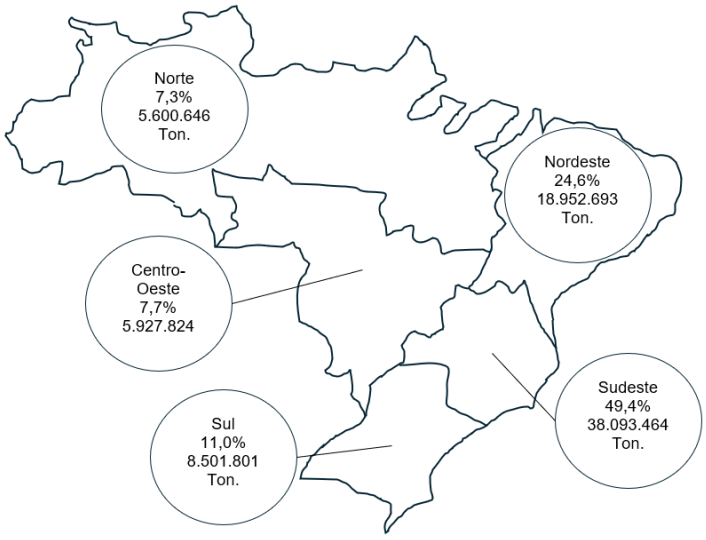
SOLID WASTE MANAGEMENT

According to Santos (2007), the amount of waste generated by a country is related to the evolution of its population, the level of urbanization, the purchasing power of the inhabitants, among other factors. The population of Brazil in 2022 reached 203,080,756 inhabitants and is the 5th largest country in territorial extension in the world, according to data from the Brazilian Institute of Geography and Statistics, IBGE (2022).

According to ABREMA (2023) and IBGE (2022), the generation of solid waste in Brazil in 2022 reached the value of 380kg per inhabitant per year, totaling 77,170,687.28 tons per year.

Figure 1 highlights Brazil's regional share in solid waste generation during 2023.

Figure 1. Regional participation in the generation of solid waste.



Source: ABREMA (2023).

Figure 1 shows that the Southeast region is the largest generator of solid waste, being responsible for almost 50% of the total waste generation in Brazil, which collaborates

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with the previous statement that the production of solid waste is related to the purchasing power of the population.

TECHNOLOGIES APPLIED TO SOLID WASTE MANAGEMENT

According to Barbosa *et al.* (2023), *Robotic Process Automation* (RPA), is an emerging computational technology when it comes to business process automation that allows the creation of robots that perform tasks previously performed only by humans. For Marques Júnior and Maciel Júnior (2023), the convergence between the physical and digital worlds brings several challenges and opportunities, such as better connectivity, personalized experiences, new business models, optimized decision-making, innovation, and economic growth. Internet of Things (IOT) allows the interconnection of devices, objects, and people, leading to automation, data sharing, and greater efficiency in processes. Some techniques and computational models that contribute to the management of urban Solid Waste (MSW) already exist, such as decision support systems (SAD), assisting in the planning and management of waste, and geographic information systems (GIS) allowing the identification through georeferencing and geoprocessing of waste deposition areas. DSS are widely used due to the growing concern with waste management, which has driven selective collection companies to adopt management systems to manage their processes. The search is for the collection of all waste with an adequate frequency with the minimum possible resources (Thorneloe; Jambeck; Weitz, 2007).

ECOLOGICAL ECONOMY

According to May, Lustosa and Vinha (2003), there is a need not only to seek better efficiency in the use of resources, within the support capacity, but also to eliminate pollution and, mainly, to change values directed to environmental education and sustainability.

From an economic perspective, environmental problems persist because they involve market failures. In this dilemma lies the absence of property rights, because no one owns the atmosphere or the earth's water bodies, and there is no market incentive to pay for the right to protect these resources, nor for the right to pollute them (Thomas; Callan, 2014).

In environmental conflicts, involving the extraction or transport of raw materials, in local or regional pollution, the use of different languages is observed. It may be that the

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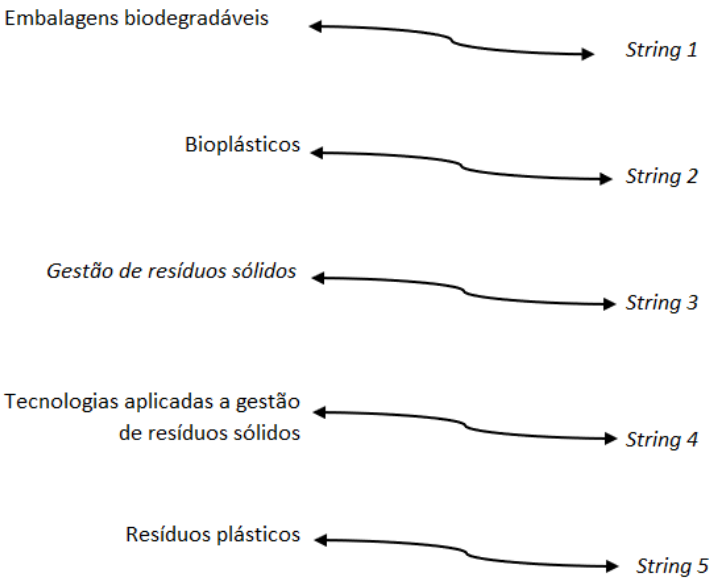
public sector and companies want to impose economic language, promising a cost-benefit analysis with all externalities translated into money. But it may happen that those affected understand this economic language differently, defending their ecological and cultural values, based on the right to subsistence of the populations. And finally, arguing that the land and the subsoil are sacred, and that "culture itself is priceless" (Martinez-Alier, 2007, p.3).

RESULTS AND DISCUSSION

There was a concern to bring data on the management of solid waste in Brazil, focusing specifically and mainly on those from plastic objects, whose company of origin is petrochemical, that is, the focus was on petroplastic waste, a global concern and of great relevance. The impacts of these wastes on the environment were highlighted and, on the other hand, the benefits of the use of alternative plastics, bioplastics, were presented. Another issue, of great importance, is the way in which the management of this waste has been done from the point of view of technologies, that is, how they help in the management process and associated benefits.

With the study, given the keywords used individually, it was noted few repetitions of articles brought as a search result, however, Figure 3 shows the keywords, as well as the degree of freedom between them, that is, in the search there was no need to chain between them, therefore, the *strings* were individual.

Figure 3. Degree of freedom of *the strings* during the search.



Source: The authors.

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During the searches, it was possible to verify that, when searching for the first *string*, "Biodegradable packaging", on the Scielo platform, 20 journals were returned, 17 of which were eliminated for not being related to the interest of the study. With the second *string*, "Bioplastics", the return was only 1 article, whose theme is related to what was sought. In the third *string*, "Solid waste management", the return was 157 journals, of which 128 were excluded, due to lack of adherence to the theme. In the fourth *string*, "Technologies applied to solid waste management", 9 articles were returned, and 6 of them were eliminated due to non-adherence. In the fifth and last *string*, "Plastic waste", 48 were returned, and 42 articles were deleted. The data can be better visualized (Table 2).

Table 2. Results of the data searched according to *strings*.

String	**Total**	**Eliminated**	**Used**
Biodegradable packaging	20	17	03
Bioplastics	01	0	01
Solid waste management	157	128	29
Technologies applied to solid waste management	9	6	03
Plastic waste	48	42	06
Total:	**235**	**193**	**42**

Source: The authors.

Table 2 presents a universe of 193 articles returned on the Scielo platform, of which only 42, which results in 21.76%, corresponds to articles that are related to the topic of interest, at the time represented by *strings* 1 to 5.

In the individual analysis, each of the keywords presented a relatively low number of studies related to the theme. From the point of view of the context of the studies found, the approaches were not directly related to the context of sustainable cities, ecological economics and technologies.

CONCLUSION

Data on the generation of plastic waste comparing some main countries show that Brazil occupies the 4th place, behind only the USA, China and India.

In the search carried out, totaling 03 applicable articles out of a total of 09, only two computational technologies that deal with solid waste were found: SAD and GIS.

However, it is plausible to say that there is a need for more studies on the subject for the integration of these concepts and improvement, especially in the direction of reducing this plastic waste, with the help of technologies, as well as studies with a view to alternative

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plastic materials, such as bioplastics, which have the potential to reduce the contamination of the environment by waste and with greater efficiency in management.

Phasing out single, short-term use in plastic items used in products by the biggest polluters would greatly reduce global plastic pollution.

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