EnPress Publisher

Journal of Polymer Science and Engineering 2025, 8(1), 11816.
https://doi.org/10.24294/jpse11816

Review

Benefits of producing and using biodegradable polymers over conventional polymers: A literature review

Soleni dos Santos Kuhn Sette, Luciano Luiz Silva, Márcio Antônio Fiori, Francieli Dalcanton, Josiane Maria Muneron de Mello, Natieli Bauerman*

Community University of the Chapecó Region, Chapeco 89809-900, Brazil
*** Corresponding author:** Natieli Bauerman, nbnatieli@unochapeco.edu.br

CITATION

Sette S dos SK, Silva LL, Fiori MA, et al. Benefits of producing and using biodegradable polymers over conventional polymers: A literature review. Journal of Polymer Science and Engineering. 2025; 8(1): 11816. https://doi.org/10.24294/jpse11816

ARTICLE INFO

Received: 5 March 2025
Accepted: 30 April 2025
Available online: 8 May 2025

Abstract: With modern society and the ever-increasing consumption of polymeric materials, the way we look at products has changed, and one of the main questions we have is about the negative impacts caused to the environment in the most diverse stages of the life cycle of these materials, whether in the acquisition of raw materials, in manufacturing, distribution, use or even in their final disposal. The main methodology currently used to assess the environmental impacts of products from their origin to their final disposal is known as Life Cycle Assessment (LCA). Thus, the objective of this work is to evaluate how much the biodegradable polymer contributes to the environment in relation to the conventional polymer considering the application of LCA in the production mode. This analysis is configured through the Systematic Literature Review (SLR) method. In this review, 28 studies were selected for evaluation, whose approaches encompass knowledge on LCA, green biopolymer (from a renewable but non-biodegradable source), conventional polymer (from a non-renewable source) and, mainly, the benefits of using biodegradable polymers produced from renewable sources, such as: corn, sugarcane, cellulose, chitin and others. Based on the surveys, a comparative analysis of LCA applications was made, whose studies considered evaluating quantitative results in the application of LCA, in biodegradable and conventional polymers. The results, based on comparisons between extraction and production of biodegradable polymers in relation to conventional polymers, indicate greater environmental benefits related to the use of biodegradable polymers.

Keywords: renewable source polymer; biopolymer production; LCA method

1. Introduction

With the excessive growth of the population, combined with the progress of industry, the rapid increase in consumption and generation of waste from disposable materials, the use of methods that are environmentally friendly, it has become indispensable and of extreme importance to society. The development of products from greener materials and processes is a way to contribute to global sustainability. The fast pace of the economy forces companies to remain competitive in the market and to overcome these challenges, products must be increasingly innovative and constantly improved, always meeting consumer demands.

According to ISO 14040 [1–4], Life Cycle Assessment (LCA) is a technique that allows identifying opportunities for product improvement at various points in their life cycles; can assist in decision-making in integrated management; environmental performance indicators; and; can provide input for the environmental marketing of the product.

The use of the LCA technique can help in identifying opportunities for improving products and processes, in decision-making, in the selection of indicators, as LCA is applied to quantify impacts generated during the life cycle of products and also helps in comparing the LCA of similar products [5].

The National Solid Waste Policy (PNRS), established by Law No. 12,305 of 2 August 2010 and regulated by Decree No. 7404 of 23 December 2010, provides for the integrated management and administration of solid waste. This policy outlines the responsibilities regarding what is generated, including the product life cycle from obtaining raw materials and inputs, its production process, its development, consumption until its environmentally appropriate final disposal, adhering to standards in order to minimize social and environmental impacts.

Polymers are widely used materials today and account for 15% to 20% of urban solid waste (MSW), with per capita consumption in Brazil being around 35 kg/inhabitant [6]. The environmental impacts of polymeric waste are due to its long useful life, low degradability, and improper disposal [7]. For these reasons, recognizing the influence of polymeric materials on the environment is essential, since their chemical and biological resistance makes their disposal increasingly difficult. The degradation of polymeric materials from petrochemical sources is a slow process that involves environmental factors and the action of microorganisms [7].

Conventional polymers take a long time to decompose, such as polyester, which takes up to 100 years [8]. We are experiencing a crisis caused by the environmental imbalance between population, natural resources, and pollution. The excessive use of resources, such as oil, is one of the factors that can be pointed out as the cause of the crisis. In addition, industrial waste exposed to nature causes pollution and can compromise the existence of living and non-living forms, through negative impacts such as: depletion of resources; global warming, depletion of the ozone layer, human toxicity, ecotoxicity, acidification, among other harmful effects [9].

Thus, there is a demand for biodegradable materials or materials with pro-degradant additives so that this decomposition process is facilitated and accelerated [7]. Environmental characteristics, as well as concerns about the effectiveness of actions and products, are gaining ground within the polymeric materials industries, especially in the effectiveness of biodegradable polymers in relation to conventional ones. Recognizing through the comparison between the production processes of petroleum-derived polymers and biodegradable polymers the advantages and disadvantages of the process for the environment. To this end, it is necessary to understand and improve the life cycle of products in order to minimize their environmental impacts in search of a sustainable culture.

The concept of sustainable development emerged from studies by the United Nations on climate change, as a response to the social and environmental crisis arising from the second half of the 20th century, with the inclusion and maturation of environmental movements and debates about eco-development. To this end, Loureiro [10] defines the concept of sustainable development as "meeting human needs without compromising the ecological context and, from an ethical point of view, respecting other species".

Sustainability, however, has become a marketing strategy in contemporary times, but there are no major commitments related to reducing environmental impacts or limiting the use of natural resources, which should be established in order to reconcile economic growth and sustainable development [11,12].

To this end, in the sustainable development process, actions are linked to technical, financial, managerial and, in particular, strategic strategies to achieve sustainability, and this reflection is consistent with Dempsey et al. [13]. Therefore, sustainable development seeks to maintain a balance between industrialization, consumption and the environment, and sustainability aims at social satisfaction.

Using the SLR (Systematic Literature Review) method, this article illustrates the current panorama of efforts aimed at applying LCA (Life Cycle Analysis) in production chains. It also demonstrates results obtained from these applications, mainly pointing out the impacts caused by the production and use of conventional "plastic" and biodegradable "plastic". This, to contemplate the objective of this work which is to "evaluate how much the biodegradable polymer contributes to the environment in relation to the conventional polymer considering the application of LCA in the production mode".

2. Material and methods

The research was conducted through the analysis of articles, which we describe as SLR (Systematic Literature Review), and is characterized, in relation to its objectives, as descriptive research [14,15]. Regarding the procedures adopted for this review, it is expressed as bibliographic research [16]. The SLR was prepared according to the step-by-step systematized in **Figure 1**.

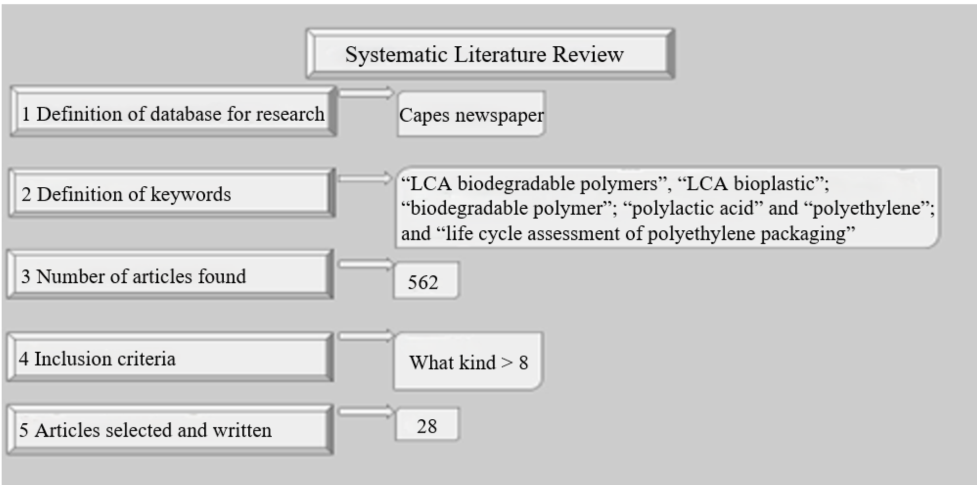

Figure 1. Steps used in RSL (Source: Prepared by the authors).

The first definitions for the RSL were: the CAPES journal as a research database, followed by the definitions of the keywords and search strings, which were: "LCA biodegradable polymers", "LCA bioplastic"; "biodegradable polymer", polylactic acid, "polyethylene" and "life cycle assessment of polyethylene package". From this, the academic works were selected in the Capes Periodicals Portal database, using the advanced search with definition of the last 10 years. The research covered both scientific articles and monographs, dissertations and theses. For this work, national and international literature was selected. To filter the most important works for this study, some inclusion criteria were used, which were: being published in a journal with a qualis concept higher than B2 and having been peer-reviewed, except for thesis and dissertation works, thus ensuring data quality.

Subsequently, **Table 1** was prepared, which refers to the results obtained through the search performed. It describes the keywords and the results obtained after being entered into the CAPES platform, as well as the number of articles selected by the abstract; those discarded by complete analysis, based on the complete reading of the work; and the list of articles fixed for support. The table ends with the works obtained by "snowball" selection, which are the works found from the references indicated in the selected articles themselves.

Subsequently, writing began based on the data available in the works (books, theses, dissertations and articles).

Table 1. Summary of articles selected for systematic literature review (Source: Prepared by the authors).

Systematic Literature Review				
Words	**Results**	**Selected by summary**	**Discarded by full analysis**	**Total per search**
"LCA biodegradable polymers"	394	24	17	7
"LCA bioplastic"	97	13	9	4
"Biodegradable polymer"	61	5	4	1
"Polylactic acid" and "Polyethylene"	8	4	1	3
"Life cycle assemssment of polietileno package"	2	2	0	2
Snowball selection				
Theses, dissertations, standards and articles collected from the readings	11			Grand Sum: Total per search + snowball: 28

During the readings, the focus was on the aspects of applying AVC to polymer-based products, especially the steps required for effective application as per the guidelines of ISO 14040 of 2006. The studies also elucidated issues such as: concept of LCA, concept of sustainability; characterization of polymers; history of LCA, current legislation, among other aspects.

3. Life cycle analysis: Brief history and application

Changes in production and consumption patterns are the main indicator of sustainable development. Thus, the first studies in which the life cycle analysis (LCA) method was used were during the first oil crisis in the 1960s. During the crisis, the need to optimize natural resources was awakened. The first studies to evaluate production processes focused on energy consumption and became known as Resource Environmental Profile Analysis (REPA).

Given the growing need, the approach and discussion on recycling and reverse logistics emerged. Thus, in 1965, Coca-Cola funded a study conducted by MRI (Midwest Research Institute) with the aim of identifying which packaging, whose life cycle would generate the lowest emissions and losses of natural resources in the built environment. This study became known as REPA and was improved in 1974 by MRI during a study for the EPA (Environmental Protection Agency). From this, this study introduced a method to normalize and aggregate emissions into air and water, thus gradually building what is now known as Life Cycle Assessment (LCA). In Brazil, the first formal activity related to LCA in Brazil was the creation, in 1994, of the Standardization Support Group (Ghana), whose objective was to enable Brazil's participation in the elaboration of environmental standards [17,18].

The first guide to LCA was published in 1993, and was called a "Code of Practice". The International Organization for Standardization (ISO) established a technical committee (TC 207/SC 5) in 1992 with a view to standardizing a number of environmental management approaches, including LCA. The Life Cycle Analysis (LCA) methodology is described by a series of ISO standards, of which two stand out, published in their Portuguese version by ABNT, the corresponding ISO standard in Brazil: ABNT NBR ISO 14040:2009, which addresses environmental management-Life cycle assessment-Principles and structure and ABNT NBR ISO 14044:2009 … (Environmental Management-Life cycle assessment-Requirements and guidelines) [1–4,19,20].

Thus, the standards presented by ISO define general requirements for conducting LCAs and disseminating results. Therefore, organizations are increasingly becoming aware of the importance of environmental aspects in their production by applying this methodology.

Application of LCA and detailing of phases

The applications of LCA involve the development and improvement of products, strategic planning, elaboration of public policies and promotion of the brand/organization. Although its application is not mandatory, some companies have used it as a business strategy for increasingly demanding markets. ISO 14040 [21] establishes that the LCA of products must include four stages for its application: definition of the objective, the scope of the project, the analysis of the inventory, the assessment of the impacts and the results. As illustrated in **Figure 2**.

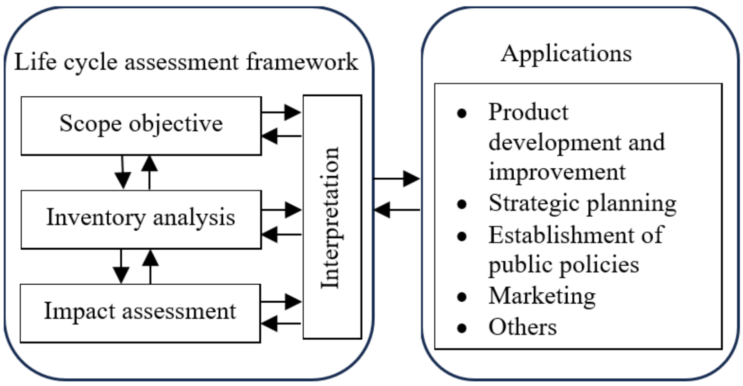

Figure 2. LCA phases and applications (Source: Adapted from ISO 14040:2006).

For better understanding, the respective phases were detailed, namely: a) definition of the objective and scope: in this stage the product, process, methodology and procedures necessary for carrying out the study are delimited; b) life cycle inventory analysis (LCI): this stage has as its objective the definition of data categories, preparation and collection of data and data validation; c) life cycle impact assessment (LCIA): where there is the selection and definition of environmental impact categories, including classification, characterization, standardization and weighting; d) interpretation of the life cycle, the fourth and final phase, in which the results are identified and evaluated regarding the integrity and consistency of the information, drawing conclusions in relation to the objective, showing the limitations of the processes and recommendations for future analyses, as well as exposing possible decision-making based on the data presented [1–4]. In an LCA, it is essential to pay attention to the generation of waste in each stage of the product's life cycle, from raw material, production, use and disposal.

As for raw materials (natural resources), they are divided into two classes: renewable sources and non-renewable sources. Renewable resources are resources that regenerate at a rate that may be equivalent (or not) to consumption, therefore, attention must be paid to the equivalence rate. Non-renewable resources are not regenerated/or are not reused in a way that can sustain the consumption rate [9]. Therefore, priority should be given to the possibility of producing the raw material to be used, using renewable sources reduces environmental impacts. Considering, for example, that oil is not a renewable source, there is an intrinsic benefit to using polymers from materials such as sugarcane, which, in turn, are renewable.

Thus, it is understood that the life cycle of a product involves everything from the production/obtaining of raw materials, through production in the industry, then its release and destination to the consumer and, finally, the disposal of the product when it is no longer used.

There are organizations dedicated to developing and improving software for applying LCA in a thorough, effective, and practical manner. Kalakul et al. [22] point out that LCA software assists in executing the study and analyzing the inventory, thus allowing for agile data simulation, resulting in more reliable reports. These tools support industry managers and process engineers, professionals who are normally responsible for applying LCA. The authors indicate two of the main software models used, which are SimaPro and ecoinvent.

The first most recommended software is SimaPro: Launched in 1990, it has users in more than 80 countries. It is used to collect data and analyze the environmental performance of products and services. Model and analyze complex life cycles in a systematic and transparent way, following the recommendations of the ISO 14040 series. As for the software, a free trial version can be found.

The second is Ecoinvent: developed in 2003 by the Swiss Federal Institute for Materials Research and Testing—EMPA. There is a 2007 and 2013 version. Ecoinvent is a large library of inventories with values of environmental loads (inputs and outputs of materials, substances and energy) associated with the life cycle of a large number of products, processes, energy systems, transport systems, waste disposal systems, among others. According to the commercial website (www.acvbrasil.com) [18] and Kalakul et al. [22], these software programs have trial and student versions. Therefore, it is possible to download them and test them according to the purpose or even to test which one best suits the professional's needs. In addition to these, there are other programs that can be chosen according to the need or even adaptation.

4. Conventional polymers, biodegradable polymers and green biopolymer

Polymers are characterized as macromolecules composed of numerous repeating units called monomers. In general, monomers are organic units that, when linked, form distinct chains. Monomers are generally obtained from non-renewable sources, mainly petroleum. Polymers are divided into three main categories: thermoplastics (usually called plastics), thermosets and elastomers [23]. In other words, polymers are generated from the union of atoms, known as merons, through covalent bonds, which repeat themselves forming long polymer chains. Conventional polymers are characterized by high molar mass with extensive carbon chains, which are generally what causes resistance to biodegradation [24]. Petrochemical polymers also show high mechanical resistance and thermal characteristics; in addition to being stable against the action of microorganisms.

Conventional polymers come from petroleum and are identified according to their structural and mechanical characteristics. Each group of these materials has a numbering specified by ABNT, to facilitate the identification of the type of polymer used for manufacturing. According to ABIPLAST (Brazilian Association of the Plastics Industry), the most produced and consumed polymers are considered commodities, due to their wide application, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyethylene terephthalate (PET).

For Pires [25], polymeric materials have characteristics that justify their excessive and growing consumption in the market. These are: low weight, easy processing, malleability, mechanical resistance, electrical and thermal insulation. They also have high resistance to chemical substances such as acids, bases and even oxygen. They can be mixed with other substances, which give them other characteristics and properties, such as color, resistance, etc.

The high consumption of polymeric products has been generating a considerable amount of waste from this material, which accumulates in landfills and generates environmental impacts. These synthetic polymers contribute to these problems, since they are highly resistant to degradation and take years to decompose. In addition, they emit chemical substances onto the Earth's surface, causing problems with soil defertilization, erosion, leaching, infiltration of pollutants, among other damages [9].

On the other hand, new sources of monomers tend to emerge, creating materials capable of degrading naturally, minimizing these impacts. Thus, researchers and industry have been seeking alternatives to minimize environmental impacts and contribute to more effective decision-making when considering large-scale production, which are the so-called biodegradable polymers.

Biopolymers are produced from renewable sources, such as corn, sugar cane, cellulose, chitin, and others. These sources are known to have a short life cycle compared to fossil sources [23].

Biodegradation consists of the physical or chemical modification of a polymer, in a process caused by microorganisms that colonize its surface and act under certain conditions of heat, pressure and humidity [26]. Therefore, biodegradable materials are those that, in contact with the environment, degrade, closing the life cycle of the chain

[23].

The most well-known and used biodegradable polymers have been: PLA (poly lactic acid), PGA (poly glycolic acid), PGLA (poly glycolic acid-lactic acid), PCL (poly ε-caprolactone), and PHAs (poly hydroxyalkanoates).

In addition to conventional polymers and biodegradable polymers, there is also the green biopolymer. This differs from the conventional polymer because it comes from a renewable source. However, it differs from the biodegradable polymer because it does not biodegrade, despite the raw material being renewable. For example, Braskem's green polyethylene, which has the same chemical, mechanical and process characteristics as the conventional polymer, is recyclable, but does not biodegrade. In 2010, Braskem announced a production capacity of 200,000 tons/year of Green Polyethylene, and considers recyclability to be the greatest benefit in using this material [27].

5. Life cycle analysis applied to conventional polymers and biodegradable polymers: Examples of applied studies and results

It was observed that there was a need to exemplify how the application of LCA occurs in practice, therefore, some application cases were sought that illustrate the process, each of the applications has different boundaries delimited by management.

Brito et al. [23] already explained that the use of biodegradable polymers would be more significant in the near future due to the fact that they generate short-lived waste. Almost 10 years later, Pires [25] evaluated the benefits and environmental damage caused by the production of High Density Biopolyethylene-BPEAD (biodegradable) and High Density Polyethylene-HDPE (conventional). The data indicate the capture of 2.5 tons of CO_2 (carbon dioxide) per ton of BPEAD (High Density Biopolymer) produced, while petroleum-derived polyethylene releases 2.5 tons of CO_2 per ton of polyethylene. Considering that the production of BPEAD captures and the production of HDPE releases, there is a gain in the production of Biopolymer, since this chemical compound, harmful to nature, is captured and not released. However, for the production of biopolymer, for every 1 million tons of this, more than 16 million hectares of plantation are required. This means that for Brazilian consumption, approximately 25% of its agricultural area would be required.

Table 2. Assessment of environmental impacts generated [28].

Indlce	Green PE (%)	Convenclonal PE (%)	Weight (weighting)
IAG	1.94×10^{-4}	69.86	0.56
ICRN	23	0	0.33
ICE	0	0	0.11
IPA	7.59	39.12	

In the study carried out by Matheus and Munhoz [28], the LCA results applied to conventional polyethylene film (polyethylene extracted from petroleum) and green polyethylene (polyethylene extracted from sugarcane) considered studying the Global Warming Index (GII), Natural Resource Consumption (NRCI) and Energy Consumption (ECI). Therefore, measuring the consumption of water, energy and fuel, to assess the environmental impact caused by both the extraction/production of conventional polymer and green polymer. These results are illustrated by the authors in **Table 2**.

For these aspects, the results were that Conventional PE has greater environmental impacts than Green PE. This is due to the Global Warming Index (GII), even though it has a lower Natural Resource Consumption Index (NRCI).

The evaluation carried out by Carvalho et al. [7] considered the characterization of biodegradable polymeric films for application in disposable bags. Films were developed using PBAT (polybutylene adipate coterephthalate), PLA (polylactic acid) and Calcium Carbonate ($CaCO_3$), in different compositions. These were subjected to mechanical tests and biodegradation evaluation. The environmental and economic performances throughout the life cycle of the prepared films were analyzed in relation to the usual bags available in supermarkets, such as kraft paper and HDPE (high-density polyethylene). It was concluded that biodegradable polymeric films present great advantages for replacing the pure biodegradable polymer, mainly from an economic point of view. It was observed that the high-density polyethylene bag, despite presenting the lowest economic impact, demonstrated greater environmental impacts than the bags manufactured with biodegradable polymers. Bags manufactured with biodegradable polymers have a high marketing cost, however, their environmental performance is superior to alternatives made of HDPE (High Density Polyethylene) and kraft paper.

In the study by Edwards and Parker [29], a life cycle assessment of compostable oxo-biodegradable bags and conventional bags is presented, in terms of functionality, weight, material content and production energy. The results of the LCA, in these terms, showed that the difference between oxo-biodegradable and conventional bags is insignificant, except in relation to waste when disposed of in the environment. The largest margin of difference was only 0.55% due to the similarity of the bags in weight, function, etc. However, the study shows that when the littering category is considered, the oxo-biodegradable bag has a significant advantage over the conventional bag through its ability to degrade in the open environment. Although only 0.75% of the bags enter the waste stream, this equates to over 48 million bags per year. The superior littering performance of the oxo-biodegradable bags offers real social benefits.

LCA has limitations when it comes to comparing different life cycle analyses. In other words, for each study, objectives and analysis focuses are defined. Thus, while the tool is flexible and dynamic, the comparison between methods results in complex understandings, since the aspects, perspectives and parameters change according to the purposes of the application.

In most of the articles studied in this work, they showed the results in environmental categories such as erosion, leaching, infiltration of pollutants, etc., which are effects caused by the production, use and incorrect disposal of conventional polymer-based materials [9]. Biodegradable polymers are more environmentally efficient when compared to conventional plastics, as they reduce greenhouse gases and do not compromise life and nature, as long as the resilience limit of renewable sources is observed [9]. However, this type of material is expensive from an economic point of view. This result was confirmed in most of the articles studied.

The comparative articles address legislation on reducing the use of plastics through recycling and reduced consumption; however, they highlight the lack of public policies that favor the replacement of plastic with non-plastic and biodegradable materials. However, economic viability is a limiting factor for the recycling, collection, separation, and transportation processes. Thus, biodegradable products are also expensive [7].

6. Conclusion

The study achieved its overall objective, "to assess how much biodegradable polymer contributes to the environment in relation to conventional polymers considering the application of LCA in production mode", identifying how the LCA method is applied and evaluating the results of the application of LCA in case studies that compare the benefits or losses caused by the production of conventional polymers and biodegradable (green) polymers. It is concluded that the use of biopolymers is less aggressive to the environment.

During the systematic review carried out, it was found that there is a wide variety of applications. This study prioritized works involving discussions about biodegradable polymers and conventional polymers.

Several categories of environmental impact were identified, ranging from the use of land area for the production of raw materials to the emission of gases. Studies involving LCA practices in polymers allowed the quantification of the environmental impacts of the production system at different stages of the life cycle of these products, from raw material selection, optimized production, efficient transportation, adequate distribution and waste management.

It is possible to observe, in this study, an effort towards reducing environmental impacts, continuous improvement of the process, in addition to innovation on the part of the organization, in order to be a competitive differentiator.

In this way, the article contributes to the current literature by providing satisfactory information on possible LCA practices in polymeric materials. Regarding the use or production of polymers, biodegradable polymers stand out positively in the parameters evaluated in the studies. These parameters indicate that they are the best production option for the environment, although there are limiting aspects described in each approach.

Conflict of interest: The authors declare no conflict of interest.

References

1. Brazilian Association of Technical Standards (ABNT). NBR ISO 14062: Environmental Management—Integrating Environmental Aspects into Product Design and Development. ABNT; 2004.
2. Brazilian Association of Technical Standards (ABNT). NBR ISO 14001: Environmental Management Systems—Requirements with Guidance for Use. ABNT; 2004.
3. Brazilian Association of Technical Standards (ABNT) NBR ISO 14040: Environmental Management—Life Cycle Assessment—Principles and Framework. ABNT; 2009.
4. Brazilian Association of Technical Standards (ABNT). NBR ISO 14042: Environmental Management—Life Cycle Assessment—Life Cycle Impact Assessment. ABNT; 2000.
5. Arduin RH. Life Cycle Assessment of Textile Products: Implications from Allocation [Master's thesis]. University of São Paulo; 2013. doi: 10.11606/D.18.2013.tde-07032014-130543

6. ABIPLAST. Plastic profile—Brazilian plastic material processing industry 2015. Available online: http://www.abiplast.org.br [accessed on 2 May 2025].
7. Carvalho JS, Oliveira SA, Rosa DS. Development of biodegradable polymeric films for disposable bags and their eco-efficiency analysis. In: Proceedings of the 5th Brazilian Congress on Life Cycle Management; 19–12 September 2016; Fortaleza, Brazil. pp. 763-770.
8. Amaral MC, Zonatti WF, Silva KL, et al. Industrial textile recycling and reuse in Brazil: case study and considerations concerning the circular economy. Gestão e Produção. 2018; 25(3): 431-443. doi: 10.1590/0104-530x3305
9. Silva DAL. Product life cycle management through environmental assessment and monitoring of manufacturing processes: Procedures and case studies [Master's thesis]. University of São Paulo; 2016.
10. Loureiro CFB. Sustainability and Education: A Perspective from Political Ecology. Cortez; 2012.
11. Cavalcanti C. Sustainability: mantra or moral choice? An ecological-economic approach. Estudos Avançados. 2012; 26(74): 35-50. doi: 10.1590/s0103-40142012000100004
12. Ferreira VF, da Rocha DR, da Silva FC. Green chemistry, sustainable economy and quality of life. Revista Virtual de Química. 2014; 6(1): 85. doi: 10.5935/1984-6835.20140008
13. Dempsey N, Bramley G, Power S, et al. The social dimension of sustainable development: defining urban social sustainability. Sustainable Development. 2011; 19(5): 289-300. doi: 10.1002/sd.417
14. Malhotra NK. Marketing Research: An Applied Orientation, 3rd ed. Bookman; 2001.
15. Lakatos EM, Marconi MA. Methodology of Scientific Work, 6th ed. Atlas; 2001.
16. Vergara SC. Research Methods in Administration. Atlas; 2005.
17. Silva GA, Kulay LA. Life cycle assessment. In: Junior AV, Demajorovic, J (editors). Models and Tools of Environmental Management: Challenges and Perspectives for Organizations. SENAC; 2010.
18. ACV BRASIL. Available online: https://acvbrasil.com.br/empresa [accessed on 2 May 2025].
19. Technical Committee ISO/TC. Environmental Management—Life Cycle Assessment—Life Cycle Impact Assessment. Technical Committee ISO/TC 207; 2004.
20. Brazilian Association of Technical Standards (ABNT). Environmental Management—Specifications and Guidelines for Use. ABNT; 2004.
21. International Organization for Standardization. ISO 14040: Environmental Management—Life cycle assessment—principles and framework. ISO; 2006.
22. Kalakul S, Malakul P, Siemanond K, et al. Integration of life cycle assessment software with tools for economic and sustainability analyses and process simulation for sustainable process design. Journal of Cleaner Production. 2014; 71: 98-109. doi: 10.1016/j.jclepro.2014.01.022
23. Brito GF, Agrawal P, Araújo EM, et al. Biopolymers, biodegradable polymers and green polymers. Revista Eletrônica de Materiais e Processos. 2011; 6(2): 127-139.
24. Muthukumar A, Eswaran A, Nakkeeran S, et al. Efficacy of plant extracts and biocontrol agents against Pythium aphanidermatum inciting chilli damping-off. Crop Protection. 2010; 29(12): 1483-1488. doi: 10.1016/j.cropro.2010.08.009
25. Pires RR. Evaluation of the Recycling Potential and Life Cycle of Blends Containing Polyethylene and Thermoplastic Starch [PhD thesis]. Universidade Federal de Minas Gerais; 2015.
26. Franchetti SMM, Marconato JC. Biodegradable polymers—A partial way for decreasing the amount of plastic waste. Quím. Nova. 2006; 29(4): 811-816. doi: 10.1590/S0100-40422006000400031
27. Belloli R. Green Polyethylene from Brazilian Sugarcane Ethanol: World-class biopolymer [Master's thesis]. Universidade Federal do Rio Grande do Sul; 2010.
28. Matheus JP, Munhoz PM. Life cycle evaluation of polyethylene (PE) films: a case study on the green PE alternative. I LCA Workshop: Social, Environmental and Economic Vision III LCA-Social Workshop. Universidade Federal do ABC (UFABC); 2017.
29. Edwards C, Parker G. A life cycle assessment of oxo-biodegradable, compostable and conventional bags. Intertek Expert Services; 2012.