Challenges on life cycle assessment of Polylactic Acid based products

Helena Monteiro[1], Bruna Moura[1], Joana Almeida[1], Ana Carneiro[1]

[1]Low Carbon & Resource Efficiency, R&Di, Instituto de Soldadura e Qualidade, R. do Mirante 258, 4415-491 Grijó, Portugal
Keywords: Life cycle assessment; Sustainability; Polylactic acid; Global warming potential
Presenting author email: himonteiro@isq.pt

Plastic is one of the most important materials in modern society due to its versatility and durability properties. More than 99% of plastics are produced from chemicals derived from non-renewable sources (European Environment Agency et al., 2021) and almost all petroleum-based plastics are non-biodegradable. These characteristics, combined with the throw-away culture that is lived nowadays – 40% of the plastics produced are single-use plastics (Chen et al., 2021) – and the insufficient and ineffective waste management of plastics, have been leading to serious environmental problems. In this context, bioplastics are now potential substitutes to petroleum-based plastics.

Bioplastics are polymers that are either produced (wholly or in part) from biological material or renewable feedstocks, and are commonly biodegradable, being already applied in industries related to agriculture, consumer goods, transportation, and textile (Atiwesh et al., 2021). Overall, Figure 1 shows the relation between different plastics, their biodegradability properties and raw materials involved (*i.e.*, biomaterial or fossil fuel), that are frequently used to obtain these resins. Among bioplastics, polylactic acid (PLA) outstands as one of the most used bioplastics, with an estimated production of 0.3 million tons in 2019 (Rezvani Ghomi et al., 2021). PLA is a biodegradable thermoplastic polyester produced from renewable sources (McGrath et al., 2012), that is currently applied in several sectors, such as packaging, biomedical, environmental remediation, agriculture, 3D printing and textile (Maga et al., 2019). PLA exhibits unique physical and mechanical properties, and it is expected to be a more environmentally friendly option than the petroleum-based polymers (Jem & Tan, 2020).

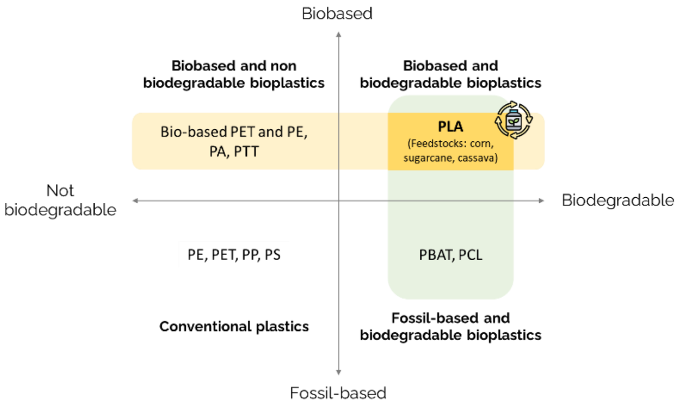

Figure 1. Classification of different plastic types, their biodegradability and raw materials involved during plastic production.

To understand the environmental impact of PLA, life cycle assessment (LCA), a methodology internationally accepted, has been widely applied during the past decade (Hottle et al., 2017; Leejarkpai et al., 2016; Moretti et al., 2021; Tamburini et al., 2021; van der Harst et al., 2014). However, there are still controversial results on the environmental impact of PLA (Hottle et al., 2017; Leejarkpai et al., 2016). Therefore, this study presents a comprehensive literature review on LCA studies for PLA products, aiming to identify the critical issues that affect the environmental performance of PLA production, use, and end-of-life. Herein, the main hotspots for improvement, and the existing challenges or gaps for further research, were identified and analyzed. Based on the data collected from the literature, four analyses are presented:

(1) From a "cradle-to-grave" approach, the importance of each life cycle phase of PLA on global warming potential (GWP) category is analyzed for a functional unit of 1kg of resin (Leejarkpai et al., 2016; van der Harst et al., 2014). The results show that the dominant terms are usually the resin production or the end-of-life stage. In both cases, assumptions on the LCA should be pointed out. Regarding biomass production, categories such as land-use change and energy demand demonstrated the highest environmental burdens. On the other hand, the end-of-life impact seemed to differ significantly according to the waste management scenario considered.

(2) A detailed analysis is presented on the environmental impact categories – GWP, acidification (AP), and freshwater eutrophication potential (EP) – of alternative end-of-life scenarios (Leejarkpai et al., 2016; Moretti et al., 2021; van der Harst et al., 2014).

(3) PLA is compared with petroleum-based plastics (PET, PP, and PS) from two different approaches: (i) “cradle-to-gate”, and (ii) “cradle-to-grave”. Considering the system boundary and the GWP, the production of 1kg of PLA appears to be a more sustainable alternative than 1kg of any conventional plastics. However, regarding other environmental impact categories, contradictory results were obtained. For instance, PLA underperforms conventional plastics in EP and AP, due to the agricultural feedstock production (Hottle et al., 2017; Moretti et al., 2021; van der Harst et al., 2014). These results highlight the importance of analyzing the considerations pointed out by each author. Given the importance of the end-of-life stage in PLA’s life cycle, the comparison between bioplastics and conventional plastics were also carried out from a “cradle-to-grave” approach, by comparing the life cycle of different plastics with the same waste management scenario. Landfilling represents the most critical end-of-life for PLA, increasing the environmental impact in relation to petroleum-based plastics. On the other hand, recycling revealed to grant benefits to PLA’s cradle-to-grave environmental performance (Leejarkpai et al., 2016; Moretti et al., 2021; van der Harst et al., 2014).

Once different plastics (*i.e.* PP, PET, PS, and PLA) have densities ranging from 0.8 g/cm^3 to 1.4 g/cm^3 (Leejarkpai et al., 2016; Moretti et al., 2021), when the product manufacturing takes place, different mass amounts are required, which can result in environmental impacts’ fluctuations. Thus, to understand which parameters may affect more significantly the object of study (product molding), the analysis is repeated for different functional units (FU) – one cup or bottle product – which are the most reported FU in the literature analyzed.

Summing up, this overview highlights not only the possible conditions that turn PLA a more sustainable alternative, but also the bioplastic life cycle parameters that require additional attention and further developments. This study demonstrated the importance of the LCA studies to support further improvements on the PLA sustainability along its life cycle.

Acknowledgments
The project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under Grant Agreement No. 952941.

References

Atiwesh, G., Mikhael, A., Parrish, C. C., Banoub, J., & Le, T. A. T. (2021). Environmental impact of bioplastic use: A review. *Heliyon*, *7*(9). https://doi.org/10.1016/J.HELIYON.2021.E07918

Chen, Y., Awasthi, A. K., Wei, F., Tan, Q., & Li, J. (2021). Single-use plastics: Production, usage, disposal, and adverse impacts. *Science of The Total Environment*, *752*, 141772. https://doi.org/10.1016/J.SCITOTENV.2020.141772

European Environment Agency, Reichel, A., Trier, X., Fernandez, R., Bakas, I., & Zeiger, B. (2021). *Plastics, the circular economy and Europe’s environment : a priority for action*. Publications Office. https://doi.org/doi/10.2800/119700

Hottle, T. A., Bilec, M. M., & Landis, A. E. (2017). Biopolymer production and end of life comparisons using life cycle assessment. *Resources, Conservation and Recycling*, *122*, 295–306. https://doi.org/10.1016/J.RESCONREC.2017.03.002

Jem, K. J., & Tan, B. (2020). The development and challenges of poly (lactic acid) and poly (glycolic acid). *Advanced Industrial and Engineering Polymer Research*, *3*(2), 60–70. https://doi.org/10.1016/J.AIEPR.2020.01.002

Leejarkpai, T., Mungcharoen, T., & Suwanmanee, U. (2016). Comparative assessment of global warming impact and eco-efficiency of PS (polystyrene), PET (polyethylene terephthalate) and PLA (polylactic acid) boxes. *Journal of Cleaner Production*, *125*, 95–107. https://doi.org/10.1016/J.JCLEPRO.2016.03.029

Maga, D., Hiebel, M., & Thonemann, N. (2019). Life cycle assessment of recycling options for polylactic acid. *Resources, Conservation and Recycling*, *149*, 86–96. https://doi.org/10.1016/J.RESCONREC.2019.05.018

McGrath, J. E., Hickner, M. A., & Höfer, R. (2012). Introduction: Polymers for a Sustainable Environment and Green Energy. *Polymer Science: A Comprehensive Reference, 10 Volume Set*, *10*, 1–3. https://doi.org/10.1016/B978-0-444-53349-4.00301-0

Moretti, C., Hamelin, L., Jakobsen, L. G., Junginger, M. H., Steingrimsdottir, M. M., Høibye, L., & Shen, L. (2021). Cradle-to-grave life cycle assessment of single-use cups made from PLA, PP and PET. *Resources, Conservation and Recycling*, *169*, 105508. https://doi.org/10.1016/J.RESCONREC.2021.105508

Rezvani Ghomi, E., Khosravi, F., Saedi Ardahaei, A., Dai, Y., Neisiany, R. E., Foroughi, F., Wu, M., Das, O., & Ramakrishna, S. (2021). The Life Cycle Assessment for Polylactic Acid (PLA) to Make It a Low-Carbon Material. *Polymers 2021, Vol. 13, Page 1854*, *13*(11), 1854. https://doi.org/10.3390/POLYM13111854

Tamburini, E., Costa, S., Summa, D., Battistella, L., Fano, E. A., & Castaldelli, G. (2021). Plastic (PET) vs bioplastic (PLA) or refillable aluminium bottles – What is the most sustainable choice for drinking water? A life-cycle (LCA) analysis. *Environmental Research*, *196*, 110974. https://doi.org/10.1016/J.ENVRES.2021.110974

van der Harst, E., Potting, J., & Kroeze, C. (2014). Multiple data sets and modelling choices in a comparative LCA of disposable beverage cups. *Science of The Total Environment*, *494–495*, 129–143. https://doi.org/10.1016/J.SCITOTENV.2014.06.084