DOI: http://doi.org/10.21698/simi.2026.ab38

CLIMATE IMPACT AND ECOTOXICITY IN POLAR THERMOPLASTIC BIOCOMPOSITES

Marius Bumbac[1], Cristina Mihaela Nicolescu[1,*], Gabriela Zinca[1], Daniela Cristiana Alexandrescu[1], Costel Bumbac[2], Lidia Kim[2], Cosmin Stefan Gherghinoiu[3], Germano Craia[3], Bogdan Catalin Serban[4], Octavian Buiu[4]

[1]Valahia University of Targoviste, Aleea Sinaia Street, 13, 130004 Targoviste, Dambovita, marius.bumbac@valahia.ro, Romania
[2]National Institute for Research and Development in Industrial Ecology – ECOIND, Drumul Podu Dambovitei street, 57–73, 060652, Sector 6, Bucharest, Romania
[3]KIK Compounds SRL, Boerescu Zaharia Street, 6, 130059, Targoviste, Dambovita, Romania
[4]National Institute for Research and Development in Microtechnologies - IMT Bucharest, 126A, Erou Iancu Nicolae Street, 077190, Bucharest, Romania

**corresponding author: cristina.nicolescu@valahia.ro*

Keywords: *biocomposite, carbon footprint, cellulose, ecotoxicity, environmental life cycle costing, poly(lactic acid)*

Introduction

Natural-fiber thermoplastic composites generally show lower life-cycle impacts than glass-fiber ones, as the fibres have lower production impacts, replace part of the matrix and reduce mass [1]. For bio-based polymers such as poly(lactic acid) (PLA), reported climate impacts vary widely with end-of-life treatment, biogenic carbon credits and allocation [2]. This preliminary, literature-based study aimed to (i) estimate the cradle-to-gate climate impact of a polar PLA/cellulose biocomposite versus low-density polyethylene (LDPE) and neat PLA, (ii) calculate the material reduction needed to break even with PLA, and (iii) define the environmental life cycle costing (E-LCC) and ecotoxicity data required for validation. Its novelty is linking these elements to show that biomass need not lower per-kilogram climate impact.

Materials and methods

Materials. LDPE, neat PLA and a PLA/cellulose/maleic anhydride (MA, compatibiliser) biocomposite (nominal 69/30/1 wt%) were compared. *Method.* The cradle-to-gate carbon footprint (raw materials and processing electricity; transport, use and end-of-life excluded) was screened per 1 kg of processed material. Global warming potential was calculated as $GWP = \Sigma\, w_i \cdot EF_i + E \cdot EF_{el}$ (w, mass fraction; EF, emission factor; E, processing electricity). Assumed EF values were 1.93, 0.62 [3], 0.84 and 2.47 kg CO_2-eq/kg for LDPE, PLA, cellulose and MA, respectively. E was 4.0 (LDPE) and 4.5 kWh/kg (PLA-based systems), and EF_{el} 0.225 kg CO_2-eq/kWh. The break-even mass reduction versus PLA was $1 - GWP_{PLA}/GWP_{biocomposite}$, assuming linear scaling with mass. E-LCC maps acquisition, drying, conversion, quality-control and waste-management costs. The design combines USEtox characterization of quantified chemical emissions [4] with leachate and particle bioassays on fresh and aged materials, with pH, turbidity and nutrient controls; cost inventories, chemical-release measurements and bioassay results are the next, experimental stage.

Results and conclusions

Under these assumptions, the PLA/cellulose/MA biocomposite has approximately 39% lower climate impact per kilogram than LDPE, but 5.2% higher impact than neat PLA (Table 1), as cellulose and MA have higher emission factors than PLA.

Table 1 - Modelled cradle-to-gate GWP (kg CO_2-eq/kg; totals before rounding)

System	Materials	Processing	Total
LDPE	1.930	0.900	2.830
PLA	0.620	1.013	1.633
PLA/cellulose/MA	0.705	1.013	1.717

At equivalent function, the biocomposite would need about 4.9% less material than neat PLA to offset its higher impact per kilogram. The PLA factor includes biogenic carbon uptake [3], while equivalent accounting for cellulose remains unresolved; harmonized inventories and end-of-life scenarios are required for comparative claims. Published PLA-particle experiments report chronic effects on *Daphnia magna* [5], which cannot be assigned directly to untested biocomposites. In conclusion, climate benefits of PLA/cellulose biocomposites must be shown on a function-equivalent basis, with verified costs and ecotoxicity data rather than renewable content.

Acknowledgement

The research was funded by the Ministry of Education and Research – UEFISCDI, project PN-IV-P7.1-PTE-2024-0653 – contract no. 38PTE/2025.

References

[1] Joshi, S. V.; et al. Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Applied Science and Manufacturing* 35 (2004), 371–376. https://doi.org/10.1016/j.compositesa.2003.09.016.

[2] Walker, S.; et al. Life cycle assessment of bio-based and fossil-based plastic: A review. *Journal of Cleaner Production* 261 (2020), 121158. https://doi.org/10.1016/j.jclepro.2020.121158.

[3] Vink, E. T. H.; et al. Life Cycle Inventory and Impact Assessment Data for 2014 Ingeo™ Polylactide Production. *Industrial Biotechnology* 11 (2015), 167–180, https://doi.org/10.1089/ind.2015.0003.

[4] Rosenbaum, R. K.; et al. USEtox—the UNEP-SETAC toxicity model: Recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. *The International Journal of Life Cycle Assessment* 13 (2008), 532–546. https://doi.org/10.1007/s11367-008-0038-4.

[5] An, G.; et al. Chronic toxicity of biodegradable microplastic (polylactic acid) to Daphnia magna: A comparison with polyethylene terephthalate. *Aquatic Toxicology* 266 (2024), 106790. https://doi.org/10.1016/j.aquatox.2023.106790.