Optimization of Processing Routes and Sustainability of Banana-Fibre-Based Biocomposites

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Introduction

Banana pseudostems represent a significant lignocellulosic biomass in tropical countries, yet they remain largely underutilized, often treated as agricultural waste (Azriena et al., 2025; Zhang et al., 2021). Their high fibre and cellulose content makes them a promising feedstock for bio-based composites, offering a partial substitution to fossil-based materials (Cabrera et al., 2023). Developing sustainable industrial processes for transforming this biomass requires the early consideration of environmental performance. Life Cycle Assessment (LCA) provides a robust framework to quantify and mitigate impacts across the production chain, linking material properties with associated mass and energy flows (ISO, 2006a; ISO, 2006b; Rodríguez et al., 2020; Gorrepotu et al., 2025).

Objectives

The main objective of this study is to develop an integrated ecodesign approach for bio-based composites reinforced with banana pseudostem fibres. Specifically, it aims to :

- Define the composite formulation through a structured brainstorming process followed by a multicriteria analysis to select the most relevant fibre–matrix combination (PLA/HDPE)
- Model the complete transformation chain from cradle to gate.
- Quantify material and energy use and associated emissions.
- Identify processing steps with the highest environmental impact.
- Guide technological choices towards lower energy and environnemental impact.

Methodology

The approach relies on process modelling using functional block diagrams, decomposing the chain into unit operations: fibre extraction, carding, drying, extrusion-compounding, and shaping via injection moulding or thermoforming (Rodríguez et al., 2020). Detailed mass and energy balances are established for each step, accounting for yields, material losses, electrical and thermal energy consumption, and mechanical energy requirements. The inventory data then feed an LCA conducted according to ISO 14040 and ISO 14044, enabling comparison of alternative fibre preparation and composite processing scenarios (ISO, 2006a; ISO, 2006b).

Results

Thermal operations, notably fibre drying and polymer melting during extrusion, emerge as the primary contributors to energy use and CO_2 emissions. Shaping processes, including injection moulding and thermoforming, also contribute significantly. These results emphasize the importance

of optimizing processing parameters: lowering thermal inputs, improving yields, and reducing material losses. Integrating LCA into the design process allows the identification of environmentally favorable scenarios and supports the development of bio-composites with reduced ecological impacts. Overall, this approach strengthens the sustainability of banana pseudostem valorization, turning agricultural residues into a strategic resource for low-carbon, bio-based materials.

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