

RECYCLED POLYPROPYLENE RAFFIA WASTE FOR INJECTION MOLDING: PROCESSABILITY AND LIFE-CYCLE IMPACT

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Abstract

This study examines the utilization of polypropylene raffia (RPP) waste from the shrimp industry as a viable feedstock for injection molding, addressing one of the most abundant post-consumer residues in Ecuador's coastal sector. Ecuador is the world's leading shrimp exporter, with over 120 million polypropylene sacks distributed annually across agribusiness, aquaculture, food, and construction sectors, making the shrimp industry the most significant consumer. Blends of post-consumer raffia polypropylene sacks with virgin polypropylene (PP), recycled low-density polyethylene (rLDPE) sacks, and isotactic polypropylene-based additives (IPE, Vistamaxx 8880 and 6502) were compounded using a torque rheometer. These blends were then characterized through melt flow index measurements, tensile testing, and life cycle assessment (LCA). Incorporating 5–10 wt% IPE significantly reduced peak torque and specific energy consumption by over 40%, stabilized fusion behavior, and lowered processing temperatures and fusion time. These improvements would facilitate faster melt flow, shorter cycle times, and enhanced processability of heterogeneous waste-derived inputs. Compatibilization with IPE enhanced the homogeneity of the material and partially restored tensile strength that had been compromised due to contamination. The maximum tensile strength improved to values ranging from 8 to 10 MPa, and elongation values between 0.8 and 1.4% were achieved as reported in the recycled raffia composites. By integrating transportation, end-of-life scenarios, and Ecuador's specific electricity mix, the assessment would provide a robust benchmark for circular economy strategies. In fact, embodied energy was reduced by up to 22% and carbon footprint by 32% for a representative drawer case study. The dominant contributions to impact reduction stem from decreasing virgin resin production, lower processing demands, and closed-loop substitution potential at end-of-life. These findings provide scientific and industrial evidence that shrimp raffia waste can be transformed into sustainable, cost-efficient injection-molding feedstock, contributing to circular economy strategies in Ecuador and similar contexts. The inspiring environmental benefits of this research underscore its potential to impact sustainability and resource conservation significantly.

Introduction and Motivation

Global plastic production continues to increase annually, driven by industrial demand and consumer use. In 2022, global output reached about 400 million metric tons (Mt), with polypropylene (PP) representing around 19% of this total[1]. In Ecuador, millions of polypropylene sacks are distributed each year in sectors such as agribusiness, aquaculture, food, and construction, with the shrimp industry being the largest consumer. A report by the Inter-American Development Bank (IADB) for Ecuador highlights that within the plastics and rubber sector, there are identified opportunities such as polypropylene sacks, containers for domestic use, construction materials, and coolers for shrimp[2]. As plastic production grows, the environmental burden of plastic waste is also intensifying, with mismanaged plastic waste reported at 267.7 Mt in 2023[1]. A significant portion of this waste can end up in marine environments, including polypropylene raffia sacks widely used in shrimp farming.

Currently, recycled polypropylene is mainly applied in low-engineering products[3] such as plastic lumber, which in Ecuador has been used to fabricate parks and other outdoor furniture. Polypropylene raffia is an extruded material typically exhibiting melt flow indices between 2 and 6 g/10 min[4], depending on whether mechanical strength or processability is prioritized. These grades were originally designed for woven sack production, not for injection molding. However, there is an increasing industrial and environmental interest in upgrading the value of recycled raffia through the development of products that meet higher performance and design requirements, such as injection-molded parts[5] for packaging, furniture, domestic, and industrial components. The key challenge lies in converting recycled polypropylene into injection-grade feedstock without inducing excessive material degradation from shear/friction or requiring high energy consumption[6].

A potential alternative explored in this study is the production of a recycled polymeric compound suitable for injection molding (e.g., industrial crates and drawers) using shrimp-industry polypropylene raffia (60 wt%), virgin polypropylene, recycled low-density polyethylene (rLDPE), and an isotactic polypropylene-based additive with random ethylene distribution (IPE). These additives are intended to improve flow behavior and compounding during injection processing and enhance mechanical properties (e.g., stiffness and strength), which are often compromised during recycling[7]. The main motivation is to demonstrate that locally available raffia waste can be transformed into an injection-molding feedstock that is technically viable, energy-efficient, and environmentally advantageous for non-critical applications. To this end, the work evaluates the effect of IPE content on fusion behavior, torque, specific energy consumption and rheological response of polypropylene raffia-based blends and links these processing changes to potential reductions in embodied energy and carbon footprint through a screening life cycle assessment.

Review of Related Work

Recycling of polypropylene packaging and raffia sacks has traditionally targeted low-engineering applications, where dimensional stability and surface quality requirements are less stringent. In a study on recycled polypropylene, it was found that incorporating recycled material in low-to-moderate proportions into virgin polypropylene allows for a good balance of properties such as improved crystallinity, yield strength, and thermal stability[1]. In contrast, a higher recycled content would indicate the need to reintroduce stabilizers. Stoian et al [5] propose that the most suitable strategy for reintegrating raffia-grade recycled polypropylene into engineering applications is to use blends containing about 30–50% virgin PP, since this proportion significantly enhances mechanical properties, melt flow index, crystallinity, and thermal stability, without causing severe structural or thermal degradation, thus enabling its use in high-performance applications. Bernagozzi et al. [3] reported that repair additives can improve flow characteristics and processability of degraded PP. These additives can partially recover the viscosity and extend the useful life of recycled streams. Additionally, blends containing up to 70 wt% recycled PP can retain properties similar to those of virgin materials.

Polyolefins such as polyethylene (PE) and polypropylene (PP) are the two most widely used plastics across industries, and cross-contamination between them is a common issue in recycling streams[8]. Formulations containing around 87.5 wt% PP and 12.5 wt% PE have been reported[1] to improve mechanical strength, UV resistance and barrier performance. Accurate determination of PP and PE content in polyolefin blends, using techniques such as DSC combined with advanced data analysis, has also been highlighted as essential for process control and quality assurance in recycled compounds [8]. These findings suggest that carefully designed PP/PE blends could be a viable route for valorizing mixed polyolefin waste if phase separation and degradation are controlled[9].

From a packaging perspective, both PP raffia and LDPE sacks are short-lived industrial products (service lives ≤ 6 months), which makes their effective incorporation into recycling schemes particularly relevant [10]. Design-for-recycling guidelines—such as those from RecyClass, the Association of Plastic Recyclers (APR), and the Golden Design Rules—converge on promoting mono-material structures with high polymer purity (>80 – 90 wt%) and the use of recycling-compatible components[11]. For woven PP bags and flexible films, these frameworks emphasize minimizing incompatible layers, inks, and additives to ensure compatibility with established polyolefin recycling streams and to improve their reintegration into circular value chains[8], [11].

Among isotactic polypropylene-based elastomeric (IPE) modifiers, Vistamaxx™ 6502 and Vistamaxx™ 8880 are particularly relevant for the present work. Both are metallocene-based propylene elastomers with random ethylene distribution, showing good compatibility with PP and PE and acting as efficient flow and toughness modifiers.

Vistamaxx 6502[7] combines low density with very high melt flow (≈ 45 g/10 min at 230 °C/2.16 kg) and elastomeric behavior, making it suitable for compounding and injection molding, while Vistamaxx 8880[7] is a very low-viscosity grade widely used in hot-melt adhesives and polyolefin modification. The rheological profile of IPE grades like Vistamaxx 6502 and 8880 can reduce melt viscosity, torque, and specific energy consumption while improving ductility in recycled PP raffia/PP/rLDPE blends. However, most data refer to virgin or lightly contaminated polyolefins with limited evidence for high-content post-consumer raffia blends. Additionally, there is a lack of studies connecting torque rheometry, melt flow behavior, and specific energy consumption with the mechanical performance and environmental indicators of injection-molded parts made from these compounds, which are addressed in this work.

The present work builds on this body of literature by focusing specifically on shrimp-industry raffia waste and by coupling processing and rheological analysis of RPP/PP/rLDPE/IPE blends with a screening life cycle assessment. This approach seeks to close existing gaps regarding the simultaneous optimization of processability, mechanical performance and environmental impact in recycled polypropylene raffia compounds for injection molding.

Technology Approach

Materials

Post-consumer raffia polypropylene sacks with a melt flow index (MFI) of 8.351 g/10 min (230°C/2.16 kg) were donated by Nicovita S.A. This company uses raffia sacks to store balanced feed for shrimp and fish in Guayaquil, Ecuador. The compatibilizer VISTAMAXX 8880 (density: 0.879 g/cm³; melt flow rate [230 °C/2.16 kg]: 10–60 g/10 min) and VISTAMAXX 6502 (density: 0.865 g/cm³; melt index [190 °C/2.16 kg]: 21g/10 min) (IPE) was supplied by ExxonMobil. Virgin polypropylene PP COPO AI MI LOTTE CHEMICAL JM-375 with an MFI of 45 g/10 min to stabilize melt flow behavior during processing, was donated by Pycca S.A. Additionally, recycled low-density polyethylene (rLDPE) sacks (MFI: 2.7 g/10 min). The recycled LDPE material was used to package the pellets from which the PP was obtained. The formulations used are detailed in Table 1.

SAMPLE	RPP [%]	PP [%]	RLDPE [%]	IPE [wt%]
RPP	100	0	0	0
RPP + PP	60	40	0	0
COMPOSITE	60	40	15	0
	85			
COMPOSITE + IPE 8880	60	40	15	5
	85			
COMPOSITE + IPE 8880	60	40	15	10
	85			
COMPOSITE + IPE 6502	60	40	15	5
	85			
COMPOSITE + IPE 6502	60	40	15	10
	85			

RPP, raffia sacks: intertwined plastic fibers; PP, polypropylene; IPE, isotactic polypropylene with random ethylene distribution; RLDPE, post-consumer sacks low-density polyethylene.

Table 1. Recycled Polypropylene Raffia Sacks with additive composite formulations

Torque Rheometry

The composites were prepared using a Brabender Plastograph EC torque rheometer, as seen in Figure 1, operating at a processing temperature of 190 °C and a rotor speed of 90 rpm. The equipment Mixer Program measured loading torque, maximum torque, and specific energy consumption (SEC) for each blend. Shear viscosity and shear rate were calculated empirically, following previously described methods. All experiments were carried out in triplicate to ensure repeatability, and the values reported correspond to the mean of the obtained data.

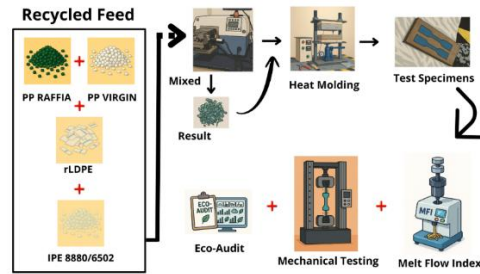


Figure 1. Scheme of experimental processing

Melt Flow Index

The rheological melt index test was performed using an XNR-400 JINJIAN MELT FLOW INDEXER. 10g of the extruded materials were prepared for each sample. The runs were conducted at 230°C and a piston load of 2.16kg, parameters standardized by the ASTM D1238 standard.

Mechanical Testing

Tensile properties were assessed following ASTM D638 in Shimadzu AG-IS (10 kN) universal test frame. Data was collected and processed through TRAPEZIUM2 V2.24 software, applying a test speed of 50mm/min.

Eco-Audit

Ashby [12] provides a straightforward methodology for evaluating energy demand and carbon emissions throughout a product's life cycle. The analysis phases include material, manufacturing, transportation, use, and end-of-life disposal, based on the equations presented by Loo et al. [13]. These equations serve to standardize the calculations within the eco-audit, ensuring comparability across scenarios and providing a simplified framework for translating material and process data into consistent energy and carbon indicators. Ashby's eco-audit methodology was adopted as a screening LCA to ensure consistency and comparability when local primary data are incomplete; however, we acknowledge limitations in applying this approach to the Ecuadorian context, particularly differences in the electricity mix, transport distances, end-of-life practices, and plant efficiencies, which means results should be interpreted as relative trends rather than absolute values.

Discussion

Table 2 presents the results of the rheological analyses for each blend. As shown in Figure 2 a), the torque peak decreases in the blends containing both IPE. This reduction is attributed to the low viscosity of the additives. When added in small amounts to extrusion-grade polypropylene, IPE results in a significant decrease in the initial torque[14]. IPE 8880 has been observed to homogenize the temperature during extrusion processing[15], as observed in the stock temperature (Figure 2) b) at the end of processing. This effect reached its minimum value of 12.725 Nm by adding

10% of the additive. Figure 2 a) illustrates how the stability of the compounds improves with the incorporation of the additive 8880 at both 5% and 10%, compared to the raffia polypropylene blends and the blends with IPE 6502. This improvement in processability is attributed to the 8880 additive's ability to dampen the effects of temperature fluctuations, allowing for a flatter and more stable melting profile throughout the mixing process[16]. It is important to note that the composite made from polypropylene raffia and recycled LDPE achieves torque stabilization that is comparable to blends containing additive percentages. Huiying Jin [17] detailed that the branched chain structure of LDPE promotes crosslinking mechanisms during the recycling process, thereby increasing viscosity with successive extrusion cycles. IPE 6502 and 8880 work well with polypropylene and polyethylene. This compatibility helps prevent phase separation issues when rLDPE is added to the blends[9]. As a result, both IPE promoted a more homogeneous matrix. This led to better processability behavior IPE reduced the torque during melt blending, which means lower temperatures are needed. This happens because it lessens the heat created by mixing processes, making manufacturing more efficient and enhancing the material.

Melt viscosity is directly related to the stabilization temperature[6]. Higher viscosity results in higher composite temperature during processing. It is well-known that in the melt processing of thermoplastics/composites, higher melt viscosity under shear leads to increased heat generation (via viscous dissipation) and thus increased melt temperature[18], [19]. Accordingly, the blend composite, which exhibits the highest viscosity of 559.83 Pa·s, reaches the highest processing temperature of 196.8 °C, which corresponds to the blend with 10% of IPE 6502. In contrast, the blend composite with 10% of IPE 8880 shows a lower viscosity of 489.20 Pa·s and a processing temperature of 190.2 °C. In line with literature evidence on recycled polypropylene, viscosity in recycled-rich PP blends can be lower than expected despite elevated processing temperatures, due to chain-scission and lower molecular weight after reprocessing[20]. In our study, the RPP 100 and RPP 60 + PP 40 formulations exhibited comparatively low melt viscosities (401.93 Pa·s and 370.65 Pa·s, respectively) despite being processed at elevated temperatures. This behavior suggests that factors other than thermal input—such as chain scission, reduced molecular weight, or compositional effects associated with recycled PP—may govern the rheological response of these PP blends. Bichler [21] illustrated the effect of washing and hot air devolatilization as essential preliminary steps in recycling post-consumer polypropylene. However, he demonstrates that even after 7 and 22 hours of decontamination, substances such as ethyl-dodecanoate and ethyl-hexadecanoate (fatty acid esters: by-products of animal and vegetable oil residues used in shrimp feed) can still be detected in the polymer. Therefore, these compounds may participate in and contribute to the degradation of raffia polypropylene. As shown in Table 2, the blend RPP 100 exhibits an MFI of 59.62 g/10 min, which confirms that thermo-mechanical degradation results in shorter chains and degradation of the organic residues from the shrimp feed; consequently, a higher flow rate at low shear rate, such as in the MFI test.

Table 2 also compares the specific energy consumption and the viscosity of the blends. The RPP 100 material exhibits the highest energy consumption, at 9.56×10^{-2} kWh/kg, corresponding to the high initial force required to maintain the same processing torque. In contrast, the compounds containing the additives show a reduction in energy consumption between 42% and 44%. This is attributed to the additive's role IPE 8880 as a flow modifier within the blend, enhancing processability at lower temperatures[7].

SAMPLE	LOADING PEAK [Nm]	FINAL TORQUE [Nm]	FINAL TEMPERATURE [°C]	MELT FLOW INDEX [g/10min]	ENERGY CONSUMPTION [kWh/kg]	SHEAR VISCOSITY [Pa.s]
RPP 100	46.66	3.36	194.6	59.62	9.56×10^{-2}	401.93
RPP 60 + PP 40	27.49	3.36	194.6	57.52	5.98×10^{-2}	370.65
COMPOSITE	19.87	4.96	190.6	52.82	5.49×10^{-2}	510.50
COMPOSITE + IPE 6502 5	21.545	3.345	196.6	35.804	4.87×10^{-2}	559.84
COMPOSITE + IPE 6502 10	27.36	4.41	196.8	20.944	5.92×10^{-2}	559.83
COMPOSITE + IPE 8880 5	18.33	4.85	189.3	36.58	5.35×10^{-2}	501.99

COMPOSITE + IPE 8880 10	12.725	4.78	190.2	43.21	5.50×10^{-2}	489.20
COMPOSITE + IPE 6502 8880 5	26.27	3.38	195.0	70.656	4.96×10^{-2}	536.19

Table 2. Fusion behavior for raffia polypropylene and composites with IPE at 90 rpm: specific energy, shear viscosity and melt flow index.

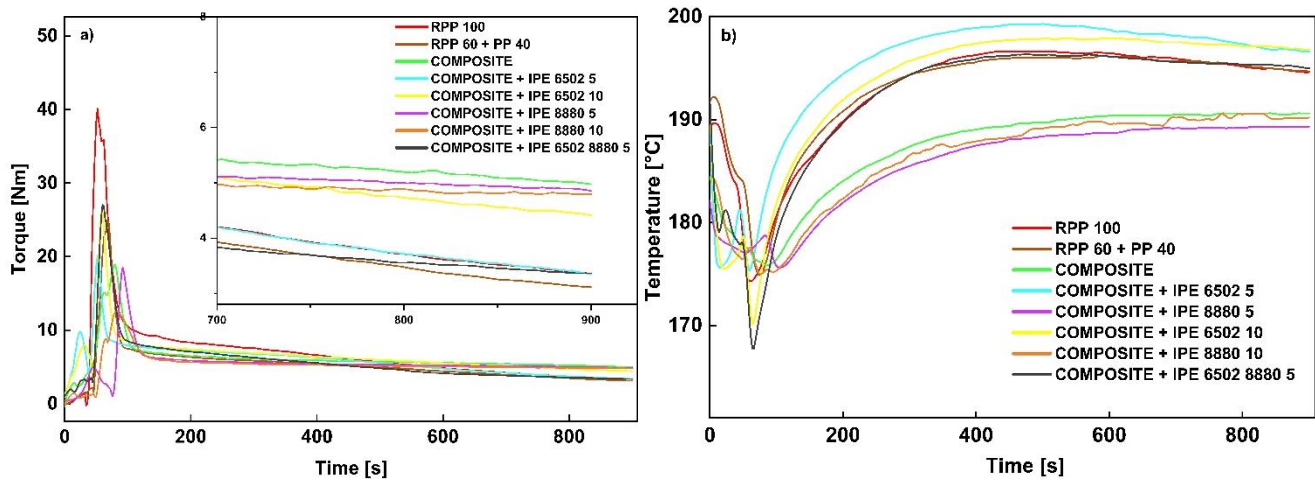


Figure 2. Fusion curves: (a) torque (Nm) versus time (s), (b) Fusion curves: temperature (°C) versus time (s)

In Figure 3, the tensile mechanical properties of the blends are presented. The maximum tensile strength (Figure 3) a) values range between 8 MPa and 14 MPa. Arnold's study [22] demonstrated that composites produced from recycled raffia and recycled polyethylene films, processed through shredding machines—similar to the present investigation, in which post-consumer raffia was shredded and pelletized—achieved tensile strength values of approximately 10 MPa. RPP 100 exhibits the highest strength due to its highly crystalline structure and the stiffness of the isotactic PP matrix. When rLDPE is added, the tensile strength decreases while the elongation at break increases up to $\approx 1.5\%$. This is due to LDPE being less crystalline and more ductile, acting as a flexible phase that facilitates plastic deformation of the blend[23]. In the absence of the compatibilizer, the COMPOSITE blend remains immiscible; LDPE tends to form dispersed droplets within the PP-rich matrix, giving rise to weak interfacial adhesion and inefficient stress transfer[24]. Thus, the lower tensile strength of the COMPOSITE compared to the neat rPP100. The composite with 10% IPE 8880 additive reaches a higher tensile strength than the other compatibilized blends. This indicates that this IPE content effectively fulfills its compatibilizing role: its PP-like segments interact with the PP matrix, while its PE segments interact with the rLDPE, improving interfacial adhesion and enabling better stress transfer[25].

These findings suggest that the developed compounds are suitable for “light-duty” injection applications, i.e., products that do not require high mechanical performance, such as rigid injected parts and components.

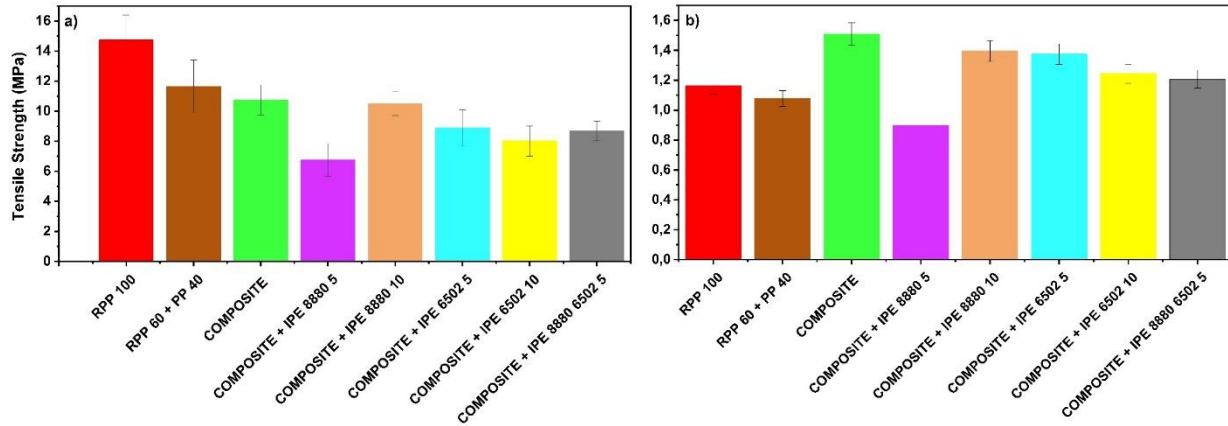


Figure 3. Comparison of the mechanical properties of all blends and composites.

The embodied energy and carbon footprint were evaluated for a commercial drawer with dimensions of 30 cm in height, 39 cm in width, 59.5 cm in length, and a weight of 2.2 kg. A comparative life cycle assessment was performed between the proposed composite material and the high-impact virgin polypropylene commonly used in industrial drawers, assuming injection molding as the manufacturing process in both cases. As shown in Figure 4, incorporating the composite with 5% IPE 8880 achieved a global reduction of 27.88% in embodied energy and 37.36% in carbon footprint. In comparison, the formulation with 10% IPE resulted in reductions of 22.60% and 32.08%, respectively. In the case of compounds with 5% and 10% of IPE 6502, the percentage of energy reduction and carbon footprint was very similar. These differences are not only descriptive of material substitutions but also reveal that the main drivers of environmental savings lie in the replacement of virgin resin and the enhanced processability of the composite. Similar trends were reported in recent LCAs of recycled polypropylene pellets, where avoiding extraction and polymerization processes was identified as the dominant contributor to impact reduction[26].

In the material phase, the use of recycled raw materials available at the national level eliminated the need for energy-intensive feedstock production, leading to reductions in embodied energy (34.87% and 28.95%) and carbon footprint (56.01% and 50.39%) for the 5% and 10% IPE composites, respectively. Similarly, Galve[27] in his study on the life cycle assessment of an injected part made from recycled polypropylene versus virgin alternatives, reported a 61% reduction in raw material manufacturing for the recycled option.

Manufacturing, end-of-life, and methodological considerations collectively highlight the environmental advantage of recycled PP routes over virgin inputs. Virgin PP exhibited higher energy demand, whereas IPE-containing composites benefited from lower torque, faster melt flow, and shorter cycle times, reinforcing process efficiency gains during injection molding and aligning with Mannheim [28], who showed that PP recycling pathways are environmentally preferable to incineration with energy recovery. At the end-of-life, composites with recycled fractions can generate positive credits by enabling closed-loop substitution in new products, while virgin PP typically offers benefits only through incineration with partial energy recovery, in line with global waste-management hierarchies that prioritize recycling and material separation over energy recovery [28]. Although Ashby’s methodology cannot fully capture country-specific conditions, the robustness of the outcomes is supported by convergence with previous LCA studies under comparable methodological frameworks [13], which reported similar impact hierarchies in other industrial contexts, strengthening the relevance of these findings for Ecuador’s plastics sector, where shifting from virgin to recycled PP can deliver measurable environmental benefits at both process and system levels.

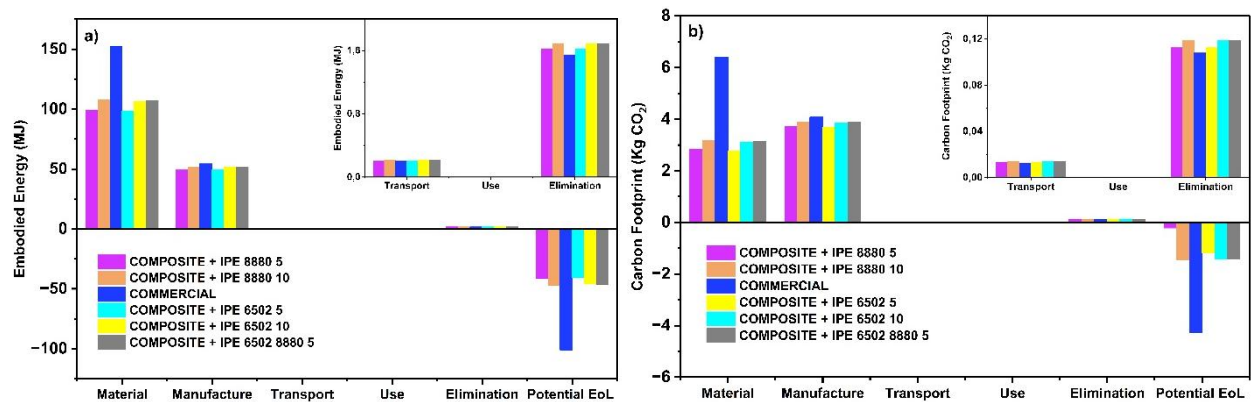


Figure 4. Eco-audit of a) Embodied Energy (MJ) and b) Carbon Footprint (Kg CO₂)

Conclusion & Recommendations

Recycled polypropylene raffia (RPP) blended with virgin PP, rLDPE, and IPE additives can be processed efficiently, with improved melt flow, up to 40% lower energy consumption, and stable viscosity for injection molding. The findings advance knowledge on raffia recycling by demonstrating that compatibilized blends yield tensile strengths of 8–10 MPa, suitable for light-duty, non-structural parts such as pallets, crates, and housings. LCA results further highlight environmental benefits, with reductions of up to 22% in energy demand and 32% in carbon footprint, underscoring technical feasibility and sustainability. However, limitations remain in mechanical scope and long-term stability, requiring future studies on impact resistance, durability, odor removal, and cost–benefit evaluation. Overall, this research provides scientific and industrial evidence that raffia waste can be transformed into viable injection-molding feedstock while identifying clear directions for optimization and market integration.

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References

- [1] T. Zhiltsova and M. S. A. Oliveira, “Sustainable Polypropylene Blends: Balancing Recycled Content with Processability and Performance,” *Polymers (Basel)*, vol. 17, no. 11, Jun. 2025, doi: 10.3390/polym17111556.
- [2] Javier Beverinotti, Pablo García, Sebastian Gonzalez Saldarriaga, and Nicolás Grossman, “OPPORTUNITIES AND CHALLENGES OF PRODUCTIVE INTEGRATION AND DECARBONIZATION IN COLOMBIA, PERU, AND ECUADOR SUSTAINABLE VALUE CHAINS,” Inter-American Development Bank, 2023.
- [3] G. Bernagozzi, R. Arrigo, G. Ponzielli, and A. Frache, “Towards effective recycling routes for polypropylene: Influence of a repair additive on flow characteristics and processability,” *Polym Degrad Stab*, vol. 223, May 2024, doi: 10.1016/j.polymdegradstab.2024.110714.
- [4] HMEL POLYSURE, “Provisional Technical Datasheet,” 2021.
- [5] S. A. Stoian, A. R. Gabor, A. M. Albu, C. A. Nicolae, V. Raditoiu, and D. M. Panaitescu, “Recycled polypropylene with improved thermal stability and melt processability,” *J Therm Anal Calorim*, vol. 138, no. 4, pp. 2469–2480, Nov. 2019, doi: 10.1007/s10973-019-08824-2.

- [6] H. S. Khabbaz *et al.*, “Rheological insights into the degradation behavior of PP/HDPE blends,” *Polym Degrad Stab*, vol. 225, Jul. 2024, doi: 10.1016/j.polymdegradstab.2024.110819.
- [7] ExxonMobil, “Low viscosity Vistamaxx™ 8880 for new possibilities in polymer modification. Compounding with Vistamaxx™ Performance Polymers. Vistamaxx™ Performance Polymer 6502,” 2020.
- [8] A. Bashirgonbadi, Y. Ureel, L. Delva, R. Fiorio, K. M. Van Geem, and K. Ragaert, “Accurate determination of polyethylene (PE) and polypropylene (PP) content in polyolefin blends using machine learning-assisted differential scanning calorimetry (DSC) analysis,” *Polym Test*, vol. 131, Feb. 2024, doi: 10.1016/j.polymertesting.2024.108353.
- [9] A. Rigail-Cedeño, J. Vera-Sorroche, G. García-Mejía, and R. Intriago, “Effect of the Intercalation and Dispersion of Organoclays on Energy Demand in the Extrusion of Recycled HDPE/PP Nanocomposites,” *Energies (Basel)*, vol. 15, no. 3, Feb. 2022, doi: 10.3390/en15030859.
- [10] R. Geyer, J. R. Jambeck, and K. L. Law, “Production, use, and fate of all plastics ever made,” *Sci Adv*, 2017, [Online]. Available: <http://advances.sciencemag.org/>
- [11] RecyClass, “Design for Recycling Guidelines.” [Online]. Available: <https://recyclclass.eu/recyclability/design-for-recycling-guidelines/>
- [12] M. Ashby, *Materials and the Environment: Eco-informed Material Choice*, Second Edition. Elsevier Inc., 2012.
- [13] J. S. Loor *et al.*, “Sustainable thermoplastic elastomers: valorization of waste tires, recycled HDPE, and recycled EVA,” *Frontiers in Sustainability*, vol. 6, Sep. 2025, doi: 10.3389/frsus.2025.1638375.
- [14] Delva L, De Tandt E, and Ragaert K, “Combining polymeric waste streams to improve functional properties of post-consumer mixed polyolefines,” 2018. Accessed: Sep. 21, 2025. [Online]. Available: https://core.ac.uk/outputs/188648509/?utm_source=pdf&utm_medium=banner&utm_campaign=pdf-decoration-v1
- [15] D. Cabrera-Álava, M. Lazo, E. Adrián, and A. F. Rigail-Cedeño, “Processability Characteristics of Biocomposite from Recycled High-Density Polyethylene and Brewers’ Spent Grain,” *Macromol Symp*, vol. 413, no. 4, Aug. 2024, doi: 10.1002/masy.202400017.
- [16] J. Czakaj, D. Pakuła, J. Głowacka, B. Sztorch, and R. E. Przekop, “Mechanical and Thermal Properties of Polypropylene, Polyoxymethylene and Poly (Methyl Methacrylate) Modified with Adhesive Resins,” *Journal of Composites Science*, vol. 8, no. 10, Oct. 2024, doi: 10.3390/jcs8100384.
- [17] J. Gonzalez-Gutierrez, P. Oblak, B. Zupančič, I. Emri, and H. Jin, “Effect of extensive recycling on flow properties of LDPE,” 2013. [Online]. Available: <https://www.researchgate.net/publication/259656619>
- [18] B. Cheng, C. Zhou, W. Yu, and X. Sun, “Evaluation of rheological parameters of polymer melts in torque rheometers,” *Polym Test*, vol. 20, pp. 811–818, 2001, [Online]. Available: www.elsevier.com/locate/polytestPropertyModelling
- [19] Cristiano Ribeiro Santi, Elias Hage Jr, Carlos Alberto Correa, and John Vlachopoulos, “Torque Viscometry of Molten Polymers and Composites,” *Applied Rheology*, vol. 19, p. 7, 2009.
- [20] H. M. Da Costa, V. D. Ramos, and M. C. G. Rocha, “Rheological properties of polypropylene during multiple extrusion,” *Polym Test*, vol. 24, no. 1, pp. 86–93, Feb. 2005, doi: 10.1016/j.polymertesting.2004.06.006.
- [21] L. P. Bichler, E. Pinter, M. P. Jones, T. Koch, N. Krempl, and V. M. Archodoulaki, “Impacts of washing and deodorization treatment on packaging-sourced post-consumer polypropylene,” *J Mater Cycles Waste Manag*, vol. 26, no. 6, pp. 3824–3837, Nov. 2024, doi: 10.1007/s10163-024-02085-4.

- [22] J. C. Arnold, F. O'Brien, and M. Moody, "All-polymer composites from recycled woven polypropylene fabrics and polyethylene film," *Polym Eng Sci*, vol. 46, no. 11, pp. 1523–1529, 2006, doi: 10.1002/pen.20614.
- [23] T. G. Mofokeng, V. Ojijo, and S. S. Ray, "The Influence of Blend Ratio on the Morphology, Mechanical, Thermal, and Rheological Properties of PP/LDPE Blends," *Macromol Mater Eng*, vol. 301, no. 10, pp. 1191–1201, Oct. 2016, doi: 10.1002/mame.201600166.
- [24] A. V. Van Belle *et al.*, "Microstructural contributions of different polyolefins to the deformation mechanisms of their binary blends," *Polymers (Basel)*, vol. 12, no. 5, May 2020, doi: 10.3390/POLYM12051171.
- [25] C. Rosales *et al.*, "Improving the Mechanical Performance of LDPE/PP Blends through Microfibrillation," *ACS Appl Polym Mater*, vol. 4, no. 5, pp. 3369–3379, May 2022, doi: 10.1021/acsapm.1c01932.
- [26] J. Saleem, F. Tahir, M. Z. K. Baig, T. Al-Ansari, and G. McKay, "Assessing the environmental footprint of recycled plastic pellets: A life-cycle assessment perspective," *Environ Technol Innov*, vol. 32, Nov. 2023, doi: 10.1016/j.eti.2023.103289.
- [27] J. E. Galve, D. Elduque, C. Pina, and C. Javierre, "Life Cycle Assessment of a Plastic Part Injected with Recycled Polypropylene: A Comparison with Alternative Virgin Materials," *International Journal of Precision Engineering and Manufacturing - Green Technology*, vol. 9, no. 3, pp. 919–932, May 2022, doi: 10.1007/s40684-021-00363-2.
- [28] V. Mannheim and Z. Simenfalvi, "Total life cycle of polypropylene products: Reducing environmental impacts in the manufacturing phase," *Polymers (Basel)*, vol. 12, no. 9, Sep. 2020, doi: 10.3390/POLYM12091901.

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