CAN THE FROG BECOME A PRINCE? A HIERARCHICAL MODEL FOR ADVANCING CIRCULARITY IN PLASTICS PACKAGING

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Abstract

The environmental impact of plastic waste has triggered an urgent call for sustainable solutions that minimize waste and optimize resource use, aiming to establish a closed-loop system where materials are continually reused, recycled, and repurposed. Transitioning to a circular economy (CE) requires effective frameworks and reliable indicators to monitor progress and guide improvements. The development and standardization of these metrics are crucial to align academic research with regulatory and practical applications, driving more sustainable practices in the industry. The circularity of plastics packaging is a critical issue, as this sector represents the largest share of global plastic consumption, yet its recycling rates remain low. In response, this study proposes a hierarchical model designed to monitor and enhance the circularity of plastics packaging. This model incorporates the lifecycle phases of plastics packaging while considering key stakeholders and the broader context of national (Colombian) and international factors such as market dynamics and legislation. This work used a mixed-methods approach, including bibliometric and content analysis. The research uncovers the diverse concepts and challenges the plastics packaging industry faces. The proposed model presents a novel, scalable tool that integrates these lifecycle phases and the main actors in the CE. It offers a practical framework for organizations to improve their circularity efforts. By bridging the gap between theoretical frameworks and industry application, this work contributes to developing actionable tools to drive systemic change in the plastics packaging sector (PPS), moving it closer to a truly CE.

Introduction and Motivation

The global plastic waste crisis is one of the most significant environmental challenges of our time. In 2024, the global production of plastics exceeded 460 million metric tons -Mt- (United Nations, 2024), of which about 38% went to packaging (174.8 Mt approx.), and less than 10% of this waste was successfully recycled (15.9Mt) (Melo, 2024). The situation is exacerbated by the disclosure that, out of 220 Mt of plastic waste generated worldwide in 2024, the IUCN (2024) estimates that 20 Mt end up in the environment yearly (EA, 2024). From this quantity, there could be more than 4.9 Mt in the ocean (Eriksen et al., 2023). This situation highlights the problems associated with plastics, "the frog of this story", underlining the urgency of moving towards a circular economy (CE), "the kiss transforming the frog into a prince", which promotes, among others, reduction, reuse and continuous recycling of materials, especially in high consumption sectors such as plastics packaging. Implementing effective frameworks and measurement tools adapted to the life cycle of these products is essential to overcome current constraints and transform the sector.

In terms of volume and scope, this industry segment occupies a central place in the transition to sustainability. Considering the wide variety of plastic materials available to manufacture packaging (Piergiovanni & Limbo, 2016), this sector faces significant challenges, including easily recyclable designs, efficient collection systems and secondary markets for recycled raw materials. These challenges emphasize the need for tools that enable industry players to understand and optimize each plastic packaging life cycle stage, enhancing its circularity. Despite the large body of literature on CE principles in recent years, applying them to a given sector or a set of stakeholders is still necessary, as the impact area and the actors may vary from sector to sector. In particular, the circularity of plastics packaging stands out as a pressing issue because, in addition to being the most significant plastic used and having low recycling rates (Pathak et al., 2023), it has become critical because of its relationship with international commitments adopted by countries such as the Paris Agreement, the Basel Convention, the European Green Pact and the European Strategy for Plastics in a Circular Economy (A European Strategy for Plastics in a Circular Economy, 2018).

Currently, a wide number of tools, methods, frameworks/models, approaches and indicators (TMFAIC) are available in CE and have been developed using pioneering concepts of material flow analysis (MFA), life cycle assessment (LCA), and R-Strategies, explored and proposed under the umbrella of sustainable development (Matschewsky et al., 2024; Vysochan et al., 2024). An effective circularity metric for a product should incorporate closed-loop material flows, support restoration through design decisions, enable regeneration through material selection, and result in long-term economic and environmental benefits (Ko et al., 2024), along with a holistic

perspective that connects the various stakeholders involved, from manufacturers and designers to collectors and recyclers. However, among the main barriers to advancing circularity in plastic packaging are the lack of a unified methodology, standardized data collection, and clear indicators to measure progress and guide improvements.

Having variety in the TMFAICs available and each country or organization being free to select among them limits the ability to generate systemic changes and makes it difficult to compare products, organizations and regions. It has been found that TMFAIC selection depends primarily on data availability (Corona et al., 2019; Khedmati-Morasae et al., 2024; Matos et al., 2023), and computational requirements, but the classifications typically used are not necessarily aligned with the 10R strategies or the product life cycle (Sierra-Fontalvo et al., 2024). In this context, developing systemically designed tools that integrate these complexities and promote cooperation between the different links in the value chain is essential.

These actions need to propose a model for the circularity of plastic packaging that responds to this need. This research presents a hierarchical model that integrates different levels, such as product life cycle phases, including the particularities of production and actors, and the 10-R strategy. This approach can help the actors evaluate its performance in the sector and can be used to generate a database to create a circularity index. This index can be used to compare processes, identify opportunities for continuous improvement, and formulate evidence-based public policies with technical and quantitative support. The model presented here has been structured using international parameters and particularities of the Colombian context, incorporating variables such as collection informality and evolving national regulations. The design of this model is not an isolated effort but the result of a holistic vision that seeks to close the gap between theory and practice in the CE.

Review of Related Work

As part of the research methodology to propose a hierarchical model of circularity for plastics containers and packaging, the researchers conducted a bibliometric analysis of articles published in databases and a technology review of sources reporting TMFAIC in the CE. Between 2005 and 2024, 147 papers published in the Scopus database were analyzed. The results show the influence of the CE today, in addition to its increasing publication rate, citations (average of 67.89 citations per paper) and references (7,329). The most predominant increase in publications was from 2023 to 2024, suggesting a critical phase in advancing the field, marking a shift towards more specific, measurable and impactful research on CE and circularity indicators. Table 1 shows the evolution of the terms associated with bibliometric and technological analysis in CE.

Table 1. TMFAIC reported from literature and technological review

TMFAICC	2005-2016	2017-2022	2023-2024
Approach	1	14	13
Certificate		1	1
Framework	2	3	13
Indicator	2	20	40
Method		4	4
Methodology		2	3
Model	1	6	9
Tool		5	3
Total	6	55	86

Note: Tools, methods, frameworks/models, approaches and indicators (TMFAIC) reported from literature and technological reviews. The search equation was broad and not limited to the plastic sector, but it excluded articles on thermal or chemical treatments, microplastics, and non-recoverable waste treatment. The search was conducted in English and was not geographically restricted.

Based on the data and literature analysis, a knowledge tree was constructed to recognize how the concept has evolved towards creating indicators applied to the PPS. Figure 1 shows two seminal works in the CE: the Cradle-to-Cradle design (Braungart & McDonough, 2002) followed by the CE construct (Ellen MacArthur Foundation, 2013). The latter construct presents a technological and biological nutrient-based products and materials cycle through the economic system. It proposes that products and materials be kept in circulation at their highest value. This model, known as the butterfly diagram, evidences that the industrial system is restorative by design, eliminating waste and pollution, circulating products and materials, regenerating nature, using finite resources effectively, and enhancing the utility of raw materials.

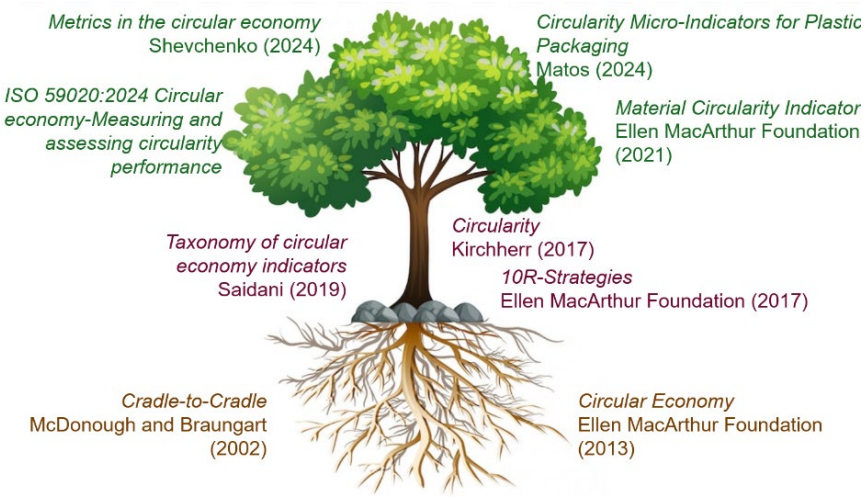

Figure 1. Tree of knowledge for CE metrics.

Subsequently, Kirchherr et al. (2017), Saidani et al. (2019) and Webster & Ellen MacArthur Foundation (2017) were pioneers in proposing definitions such as the term "circularity", 17 coding dimensions for the definition of CE and the first taxonomy of circularity indicators, the 10R strategies, respectively. In the period of greatest scientific production on the subject of research, the work of Shevchenko et al. (2024) stands out, which evidenced the following four clusters in the TMFAIC: CE-metrics-based tools for circularity assessment, Circular design intended tools built on CE-metrics, CE-metrics-based tools for monitoring the progress and Database related tools built on CE-metrics. Likewise, Matos et al. (2024) made an important contribution to films in the PPS, highlighting the three most relevant micro-level indicators for calculating their circularity. These three composite indicators are the Material Circularity Indicator (MCI), Value-Based Resource Efficiency Indicator (VRE), and CE Indicator Prototype (CEIP). It should be noted that this research considers the CE micro-indicators, CE guiding principles and Design for X (DfX) approaches in the literature and proposes eight actions that promote circularity in the sector. With the introduction of the ISO Family for circularity (International Organization for Standardization, 2024), there is now a set of definitions and base indicators to consider in measuring circularity in a benchmark context.

Based on these studies, other authors have further developed the proposal of circularity indicators for plastics packaging, as shown in Table 2 below. These studies showed different criteria for embracing CE. Some of these frameworks offer well-developed methods and tools for measuring circularity; however, they often require highly specialized information, which can limit the data-gathering process within companies. Additionally, there is the challenge of complexity, both in modelling data for the construction of metrics and interpreting the results to develop effective strategies and tactics for the industry. This complexity can hinder the practical implementation of circularity measures within businesses.

Table 2. Categorization alternatives for circularity indicators.

Criteria	Reference
Levels of CE implementation	(Arbolino et al., 2022; De Pascale et al., 2021; dos Santos Goncalves & Campos, 2022; Harris et al., 2021; Saidani et al., 2019)
Sustainability	(Barros et al., 2024; Baumer-Cardoso et al., 2021; Ferronato et al., 2023; Kristensen & Mosgaard, 2020)
CE loops	(De Pascale et al., 2021; Kristensen & Mosgaard, 2020; Matos et al., 2023)
Design for X	(Matos et al., 2024; Mesa et al., 2018; Ruiz-Pastor et al., 2024)
Performance, Perspective, Dimensionality, Transversality, Format	(Saidani et al., 2017)

Technology Approach

While working within the PPS, it is important to consider the variations of material, usage, and limitations, which are significant for an accurate selection of metrics and in the application of said metrics. Defining the system boundaries of the PPS helps to identify the material flows, actors and data sources. As shown in Table 2, distinguishing the specificities and technicalities also helps correctly encompass the products that should be considered for analysis. This paper considers all types of plastic packaging available in the market, not just single-use items. The design of a plastic product—whether intended for single-use, durability, or recyclability—is a key factor in determining its circularity potential. Moreover, how consumers use and dispose of these products dramatically influences their lifecycle and the feasibility of closing the material loop. Therefore, the analysis comprehensively encompasses a broad spectrum of plastic packaging to understand its circularity.

This research proposes a product-based CE model associated with indicators. It was necessary to have a systemic vision and be clear about the system's limits to create the model. A computational tool for calculating indicators associated with product circularity is being created with the model results (the indicators and the computer tool are not covered in this document because they are part of a work in revision for publication). In coherence with the principles of cradle-to-cradle and the CE, we started from the premise that the packaging sector's influence extends far beyond the materials used; it encompasses the entire supply chain and lifecycle of plastic packaging products. Thus, the first level considered was the product life cycle phases. Figure 3 shows the plastic packaging system; with this system, the following eight phases were defined for the model: 1. design, 2. raw material supply, 3. production process, 4. distribution, 5. use, 6. collection and separation, 7. recovery and 8. final disposal.

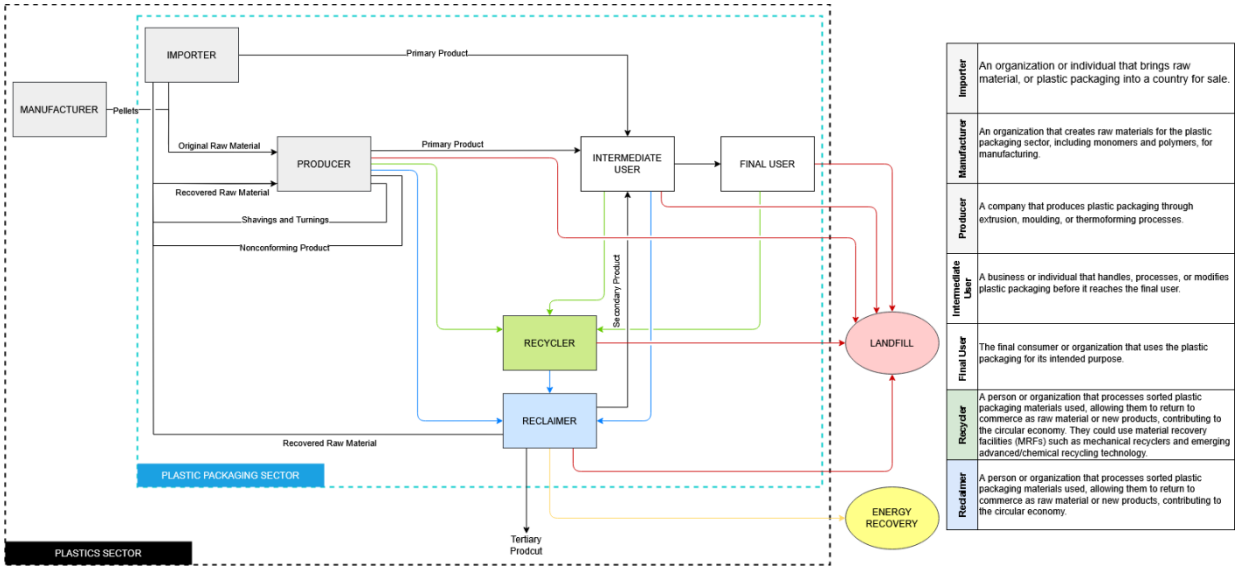

Figure 2. Plastic packaging system and stakeholders.

Figure 2 shows the relation among actors. Each actor within this system carries specific responsibilities that collectively determine the environmental impact and circularity of packaging. Designers and producers play a crucial role in selecting materials and creating products that embrace one or more of the 10-R strategies, such as recycling or reusing. The second level was to identify the key players in each phase and their interconnectedness; distributors and retailers influence packaging decisions through demand and supply practices, often determining the types of packaging that reach consumers. Finally, consumers and waste management entities are responsible for the proper disposal, guiding recycling, reuse of packaging materials, and final disposal when the other alternatives are not viable.

Due to the importance of designers and producers in the product's life cycle and the integration of CE strategies, both would shape how plastic packaging interacts with the environment. Therefore, the third level considered the type of packaging amongst primary, secondary or tertiary packaging. Primary packaging is the one that has direct contact with the product; its primary purpose is to contain, preserve, and present the product. It features a design that allows for the identification of the contained product. The packaging is designed and sold individually,

oriented towards the quality and properties of the product (e.g. Bottles, food containers). Secondary packaging is responsible for containing the primary packaging; its goal is to protect this packaging and ensure it arrives in perfect condition. It can also be used as a promotional tool and is mainly oriented towards marketing (e.g. Boxes, baskets). Tertiary packaging encompasses everything that wraps around, contains, and protects the packaging and container. Its main objective is to facilitate storage and distribution in large quantities, protecting the product from impacts and falls during distribution, thus oriented towards logistics (e.g., adhesive tapes and strapping).

The compilation of the circularity indicators and the different specifications and guidelines proposed by the authors analyzed, as well as their recommendations for future research, allowed the creation of the model proposal for the visualization and proposal of circularity indicators for plastic packaging presented below. Some graphical-theoretical proposals became references for this research and inspired the creation of a hierarchical model. Among the main references are the Multi-Hierarchical Theoretical Framework by (Pieroni et al. (2022), the Material Circularity Indicator developed by Ellen MacArthur Foundation (2019) with the approach by Sazdovski et al. (2024), the method by Martinho et al., (2017) for the performance and operation analysis in the recycling sector, and the EoL approach for reuse and remanufacture by Favi et al. (2017) and Sierra-Fontalvo et al. (2024).

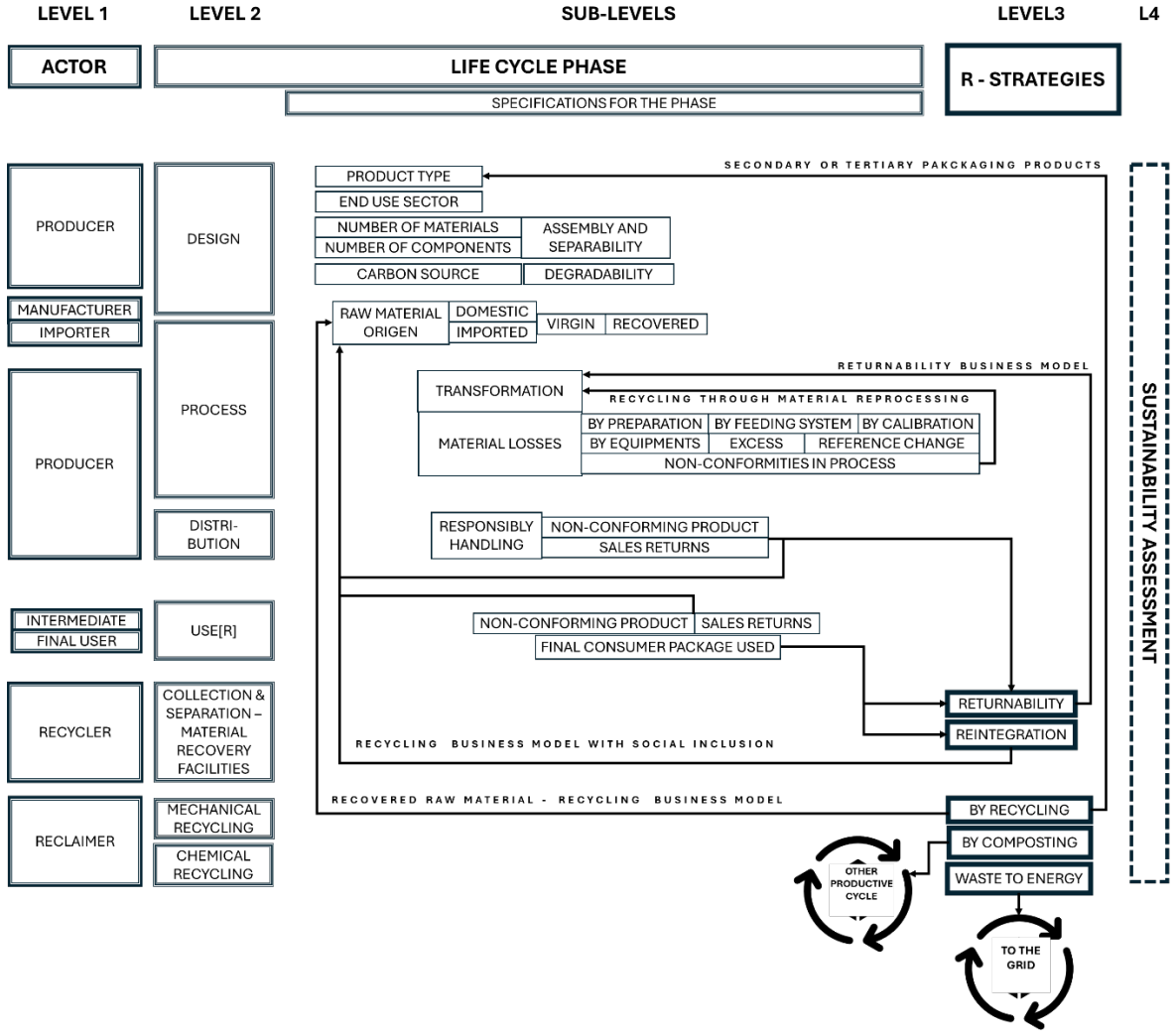

Figure 3. Hierarchical model for circularity measurement of plastic packaging

Notes: → Closing loops to increase CE. Sustainability assessment is transversal and could be applied to other levels. The model is comprised of indicators in levels 2, 3 and sublevels; however, they are not covered in this document because they are part of a work in revision for publication titled "Measuring Circularity: Applying Micro-Level Indicators in the Colombian Plastic Packaging Sector" by Hernandez-Diaz, Paula and Julio, Laura, expecting to be published in the Journal of Cleaner Production. The producer is the organization that produces the plastic packaging; it appears twice in level 1 because it participates in three stages of the life cycle (design, process and distribution). The final model and software version can be presented at the conference.

Discussion

The findings of this paper highlight the critical urgency of tackling the escalating plastic waste crisis and the pressing need for a comprehensive transition to a CE in the PPS. While there have been efforts for quantification, previous research has been hindered by the lack of a unified methodology to assess circularity; different metrics and frameworks used by various countries and organizations lead to inconsistencies, making it hard to compare. While the introduction of the ISO 59000 family of standards provides a common understanding of the CE, the use of metrics and indicators to evaluate the performance of selected circularity aspects, for the application of the standard, the company can choose which methods, approaches, guidelines or standards to use for the data acquisition, documentation and modelling, limiting the ability to benchmark progress, compare practices across regions, and develop cohesive policy alignment tools (Arana-Landin et al., 2023; Heras-Saizarbitoria et al., 2023). Addressing these gaps, the proposed model provides a pivotal framework for evaluating and advancing the sector, offering a foundation that aligns with CE principles and promotes systemic transformation (Ko et al., 2024).

The introduced model underscores the importance of sector characterization in the actors' delimitation and the product typology, which is essential for understanding industry dynamics and formulating effective regulations and strategies to guide sustainability transitions. By leveraging standardized metrics, such as material flow analysis and life cycle analysis, actors and stakeholders can gain critical insights into the environmental impacts of plastic packaging and identify actionable areas for improvement. These data-driven approaches enable informed decision-making, facilitating performance assessment reports, monitoring progress, and optimizing resource utilization (Khedmati-Morasae et al., 2024; Ko et al., 2024).

Integrating eco-design principles into production processes is crucial for developing functional and sustainable packaging. As highlighted previously, incorporating these principles ensures that packaging materials are designed for reuse and recycling from the outset, thereby contributing to the broader goals of a CE (Franco et al., 2021; Sala et al., 2013). This shift toward eco-design is foundational for advancing sustainability in the PPS (Cilleruelo Palomero et al., 2024; Ding & Zhu, 2023; Pathak et al., 2023) and is covered by the producer in the design phase.

The model’s alignment with international standards, while considering local factors such as the informality of waste collection systems in countries like Colombia, ensures that it is both globally relevant and adaptable to regional contexts (Farida et al., 2024; Martinho et al., 2017; Sazdovski et al., 2024). This adaptability highlights the importance of flexibility when implementing CE principles, recognizing that each region faces distinct challenges and opportunities during the transition to sustainable systems, where actors face different dynamics such as deregulation, lack of standard quality controls and vanguard technologies while making strategic decisions where complying with the environmental regulations may not be aligned with the economic sustainability of the organizations. In Colombia, collection and separation is a formal and informal sector called “recyclers”. Plastic packing industries could choose a collective or independent plan for returnability. In both, a business model considering social inclusion could be relevant to the local, regional, and national economies.

Scenarios should understand the model. Each scenario must have at least five actors. The producer defines the design specifications for the package, making important decisions such as the carbon source, which is directly attached to the degree of degradability. Each actor registers their indicator in mass units and gets the performance of their concerned responsibility in the value chain. The final calculations could give a systemic understanding of the circularity of the plastic package and the incidence of the absence or documentation of the process. The targeted indicators represent the intersection of three key models: MFA and the 10R-Strategies, evaluated in the phases considered in LCA methods, prioritizing primary data and avoiding composite models. Tracking the flow and transformation of materials within a system makes it possible to identify inefficiencies and optimize resource use. The real value of these indicators lies in their ability to locate action areas within the defined stages of the LCA method, providing a clear roadmap for developing effective strategies and tactics. This approach offers a holistic perspective on sustainability by integrating material flow, environmental impact, and CE principles. For the plastic packaging industry, these indicators serve as a practical tool to make informed decisions, minimize

environmental impact, and enhance resource efficiency while aligning with local regulations and international standards.

This research represents a meaningful advancement in addressing the challenges of transitioning the PPS into a CE system. By providing a robust framework for evaluating circularity, identifying areas for enhancement, and fostering collaboration among industry participants, the model presented in this paper lays a solid foundation for creating a more sustainable and efficient plastic packaging industry. It is essential to refine and apply these tools in close collaboration with stakeholders across the value chain, ensuring that the transition to a CE effectively mitigates the environmental impacts of plastic waste. The future applications of the circularity model outlined in this paper hold great potential for advancing sustainability in the PPS. By focusing on sector characterization, stakeholders can gain valuable insights that will support the development of more targeted and effective regulations and strategies. Compiling data according to established standards for LCA, carbon footprint, and water footprint will further strengthen the understanding of environmental impacts and provide a clear foundation for continuous improvement. Moreover, aligning data collection with regulations will enable actors to demonstrate compliance with legislation and facilitate participation in national grants, promoting the adoption of sustainable practices. Finally, the integration of an eco-design tool for producers will empower manufacturers to design packaging solutions that are both functional and sustainable, ensuring that the transition to a CE is achieved through informed, proactive decision-making. Together, these initiatives will foster a more coordinated, transparent, and effective path toward sustainability in the plastic packaging industry.

Conclusions & Recommendations

For the construction of a hierarchical model that has the capacity of being the "kiss transforming the frog into a prince", it needs to integrate the lifecycle phases of plastic packaging and consider key stakeholders, national and international factors, and legislation while being a scalable tool to enhance circularity efforts. Having input from different sources in the construction of the inventory of tools, methods, frameworks/models, approaches, indicators, and certifications (TMFAIC) provides flexibility when measuring the circularity of plastic packaging. Different categories were identified for the model: (1) sustainability alignment, (2) scope, (3) technical approach, (4) life cycle phases, and (5) 10R-Strategies; each one provides a particular diagnostic view that allows the selection of map work for the organization. The model bridges the gap between theoretical concepts and practical applications, offering a comprehensive framework that could guide industry actors and policymakers in driving sustainable practices. This work advances the CE by providing an actionable framework that helps identify metrics to optimize resource uses, minimize waste, and promote the continuous reuse and recycling of materials, specifically in the PPS. Mass indicators target the model in most stages of the lifecycle. Despite this paper, they are not developed; they are part of another work that will contribute to getting the mass balance in the PPS in Colombia and other regions that decided to use it. For sure, not all frogs could become princes. However, with the right conditions and tools, they could contribute to a healthy pond where we can hear it sing a hearty, resonating trill, reminding us that summer is here and every day is a new adventure waiting to be discovered.

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References

A European Strategy for Plastics in a Circular Economy (2018). https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:28:FIN

Arana-Landin, G., Sigüenza, W., Beñat Landeta-Manzano, |, & Laskurain-Iturbe, I. (2023). *Circular economy: On the road to ISO 59000 family of standards*. https://doi.org/10.1002/csr.2665

Arbolino, R., Boffardi, R., Ioppolo, G., Lantz, T. L., & Rosa, P. (2022). Evaluating industrial sustainability in OECD countries: A cross-country comparison. *Journal of Cleaner Production*, *331*, 129773. https://doi.org/10.1016/J.JCLEPRO.2021.129773

Barros, M. V., Salvador, R., Pieroni, M., & Piekarski, C. M. (2024). How to measure circularity? State-of-the-art and insights on positive impacts on businesses. *Environmental Development*, *50*, 100989. https://doi.org/10.1016/J.ENVDEV.2024.100989

Baumer-Cardoso, M. I., Campos, L. M. S., & Ashton, W. (2021). Circular Economy and Companies: Understanding the Characteristics and the Challenge of Measurement. *Springer Proceedings in Mathematics and Statistics*, *367*, 597–608. https://doi.org/10.1007/978-3-030-78570-3_46

Braungart, M., & McDonough, W. (2002). *Cradle to Cradle: Remaking the way we make things*.

Cilleruelo Palomero, J., Freboeuf, L., Ciroth, A., & Sonnemann, G. (2024). Integrating circularity into Life Cycle Assessment: Circularity with a life cycle perspective. *Cleaner Environmental Systems*, *12*, 100175. https://doi.org/10.1016/J.CESYS.2024.100175

Corona, B., Shen, L., Reike, D., Rosales Carreón, J., & Worrell, E. (2019). Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resources, Conservation and Recycling*, *151*, 104498. https://doi.org/10.1016/J.RESCONREC.2019.104498

De Pascale, A., Arbolino, R., Szopik-Depczyńska, K., Limosani, M., & Ioppolo, G. (2021). A systematic review for measuring circular economy: The 61 indicators. *Journal of Cleaner Production*, *281*, 124942. https://doi.org/10.1016/J.JCLEPRO.2020.124942

Ding, Q., & Zhu, H. (2023). The Key to Solving Plastic Packaging Wastes: Design for Recycling and Recycling Technology. *Polymers 2023, Vol. 15, Page 1485*, *15*(6), 1485. https://doi.org/10.3390/POLYM15061485

dos Santos Goncalves, P. V., & Campos, L. M. S. (2022). A systemic review for measuring circular economy with multi-criteria methods. *Environmental Science and Pollution Research*, *1*, 3. https://doi.org/10.1007/s11356-022-18580-w

EA. (2024). *plastic Overshooting Day 2024*. https://plasticovershoot.earth/wp-content/uploads/2024/04/EA_POD_report_2024.pdf

Ellen MacArthur Foundation. (2013). *Transitioning to a circular economy business*. https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

Ellen MacArthur Foundation. (2019). *Circular Indicator Methodology*.

Eriksen, M., Cowger, W., Erdle, L. M., Coffin, S., Villarrubia-Gómez, P., Moore, C. J., Carpenter, E. J., Day, R. H., Thiel, M., & Wilcox, C. (2023). A growing plastic smog, now estimated to be over 170 trillion plastic particles afloat in the world's oceans—Urgent solutions required. *PLoS ONE*, *18*(3 March). https://doi.org/10.1371/journal.pone.0281596

Favi, C., Germani, M., Luzi, A., Mandolini, M., & Marconi, M. (2017). A design for EoL approach and metrics to favour closed-loop scenarios for products. *International Journal of Sustainable Engineering*, *10*(3), 136–146. https://doi.org/10.1080/19397038.2016.1270369

Ferronato, N., Maalouf, A., Mertenat, A., Saini, A., Khanal, A., Copertaro, B., Yeo, D., Jalalipour, H., Raldúa Veuthey, J., Ulloa-Murillo, L. M., Thottathil, M. S., Shuaib, N. A. bin, Caplin, R., & Mohandas, V. J. (2023). A review of plastic waste circular actions in seven developing countries to achieve sustainable development goals. In *Waste Management and Research*. SAGE Publications Ltd. https://doi.org/10.1177/0734242X231188664

Franco, N. G., Almeida, M. F. L., & Calili, R. F. (2021). A strategic measurement framework to monitor and evaluate circularity performance in organizations from a transition perspective. *Sustainable Production and Consumption*, *27*, 1165–1182. https://doi.org/10.1016/j.spc.2021.02.017

Harris, S., Martin, M., & Diener, D. (2021). Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy. In *Sustainable Production and Consumption* (Vol. 26, pp. 172–186). Elsevier B.V. https://doi.org/10.1016/j.spc.2020.09.018

Heras-Saizarbitoria, I., Boiral, O., & Testa, F. (2023). ISO 59000 Standards for the Circular Economy: A Call for Accuracy. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4504702

International Organization for Standardization. (2024). *ISO 59020:2024Circular economy-Measuring and assessing circularity performance*.

IUCN. (2024). *Plastic Pollution*. www.iucn.org/issues-briefs

Khedmati-Morasae, E., Zils, M., Hopkinson, P., Nolan, R., Charnley, F., Okorie, O., & Abu-Bakar, H. (2024). Advancing the discourse: A next-generation value chain-based taxonomy for circular economy key performance indicators. *Sustainable Production and Consumption*, *48*, 219–234. https://doi.org/10.1016/J.SPC.2024.05.013

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/J.RESCONREC.2017.09.005

Ko, J., Guedes, G. B., Badurdeen, F., Jawahir, I. S., Morris, K. C., Ferrero, V., Hapuwatte, B., Bradley, R., & Raihanian, A. (2024). A critical analysis of circular product attributes and limitations of product circularity assessment methods. *Resources, Conservation & Recycling Advances*, *23*, 200219. https://doi.org/10.1016/J.RCRADV.2024.200219

Kristensen, H. S., & Mosgaard, M. A. (2020). A review of micro level indicators for a circular economy – moving away from the three dimensions of sustainability? *Journal of Cleaner Production*, *243*, 118531. https://doi.org/10.1016/J.JCLEPRO.2019.118531

Martinho, G., Gomes, A., Santos, P., Ramos, M., Cardoso, J., Silveira, A., & Pires, A. (2017). A case study of packaging waste collection systems in Portugal – Part I: Performance and operation analysis. *Waste Management*, *61*, 96–107. https://doi.org/10.1016/j.wasman.2017.01.030

Matos, J., Martins, C. I., & Simoes, R. (2024). *Circularity Micro-Indicators for Plastic Packaging and Their Relation to Circular Economy Principles and Design Tools*. https://doi.org/10.3390/su16052182

Matos, J., Martins, C., Simões, C. L., & Simoes, R. (2023). Comparative analysis of micro level indicators for evaluating the progress towards a circular economy. *Sustainable Production and Consumption*, *39*, 521–533. https://doi.org/10.1016/J.SPC.2023.06.002

Matschewsky, J., Lingegård, S., & Martin, M. A. (2024). Circular indicators for the design and procurement of plastic products in the healthcare sector - a review. *Procedia CIRP*, *122*, 891–896. https://doi.org/10.1016/J.PROCIR.2024.01.122

Melo, M. F. (2024). *El mundo está inundado de residuos plásticos*. https://es.statista.com/grafico/30051/produccion-mundial-de-residuos-plasticos-por-tipo/

Mesa, J., Esparragoza, I., & Maury, H. (2018). Developing a set of sustainability indicators for product families based on the circular economy model. *Journal of Cleaner Production*, *196*, 1429–1442. https://doi.org/10.1016/J.JCLEPRO.2018.06.131

Pathak, P., Sharma, S., & Ramakrishna, S. (2023). Circular transformation in plastic management lessens the carbon footprint of the plastic industry. *Materials Today Sustainability*, *22*, 100365. https://doi.org/10.1016/J.MTSUST.2023.100365

Piergiovanni, L., & Limbo, S. (2016). *Plastic Packaging Materials*. 33–49. https://doi.org/10.1007/978-3-319-24732-8_5

Pieroni, P., Kravchenko, M., Pigosso, D. C. A., Mcaloone, T. C., Franconi, A., Ceschin, F., & Peck, D. (2022). *Structuring Circular Objectives and Design Strategies for the Circular Economy: A Multi-Hierarchical Theoretical Framework*. https://doi.org/10.3390/su14159298

Ruiz-Pastor, L., Altavilla, S., & Borgianni, Y. (2024). Design issues concerning circular economy assessment methods at the product level: a comparative analysis through a case study of a mobile tiny house. *Design Science*, *10*, e12. https://doi.org/10.1017/DSJ.2024.12

Saidani, M., Yannou, B., Leroy, Y., & Cluzel, F. (2017). HYBRID TOP-DOWN AND BOTTOM-UP FRAMEWORK TO MEASURE PRODUCTS' CIRCULARITY PERFORMANCE. *Proceedings of the 21st International Conference on Engineering Design (ICED17), 1*.

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. In *Journal of Cleaner Production* (Vol. 207, pp. 542–559). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2018.10.014

Sala, S., Farioli, F., & Zamagni, A. (2013). Progress in sustainability science: Lessons learnt from current methodologies for sustainability assessment: Part 1. *International Journal of Life Cycle Assessment*, *18*(9), 1653–1672. https://doi.org/10.1007/S11367-012-0508-6/TABLES/2

Sazdovski, I., Batlle-Bayer, L., Bala, A., Margallo, M., Azarkamand, S., Aldaco, R., & Fullana-i-Palmer, P. (2024). Comparative assessment of two circularity indicators for the case of reusable versus single-use secondary packages for fresh foods in Spain. *Heliyon*, *10*(6). https://doi.org/10.1016/j.heliyon.2024.e27922

Shevchenko, T., Shams Esfandabadi, Z., Ranjbari, M., Saidani, M., Mesa, J., Shevchenko, S., Yannou, B., & Cluzel, F. (2024). Metrics in the circular economy: An inclusive research landscape of the thematic trends and future research agenda. *Ecological Indicators*, *165*, 112182. https://doi.org/10.1016/J.ECOLIND.2024.112182

Sierra-Fontalvo, L., Polo-Cardozo, J., Maury-Ramírez, H., & Mesa, J. A. (2024). Diagnosing remanufacture potential at product-component level: A disassemblability and integrity approach. *Resources, Conservation and Recycling*, *205*, 107529. https://doi.org/10.1016/J.RESCONREC.2024.107529

United Nations. (2024, November 21). Global plastics treaty: UN experts call for centrality of human rights. *UNNews-Global Perspective-Human Stories*. https://news.un.org/en/story/2024/11/1157326

Vysochan, O., Hyk, V., Vysochan, O., & Yasinska, A. (2024). Accounting in the Context of a Circular Economy for Sustainable Development: A Systematic Network Study. *Journal of Sustainability Research*, *6*(1), E240005. https://doi.org/10.20900/JSR20240005

Webster, K., & Ellen MacArthur Foundation. (2017). *The Circular Economy: A Wealth of Flows - 2nd Edition*. https://www.ellenmacarthurfoundation.org/the-circular-economy-a-wealth-of-flows-2nd-edition

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