Global Discussion on Life Cycle Assessment Allocation Methods for Recycled Fibers

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On September 3rd, 2024, North Carolina State University, the University of British Columbia, Aalto University, the University of Chile, and the University of the Basque Country organized a global webinar on allocation methods for recycled fibers. The event focused on the challenges and complexities associated with allocation methods for open-loop recycling systems, focusing on bio-based fibers for packaging. The webinar featured three expert presentations by Dr. Tomas Ekvall, Dr. Caroline Gaudreault, and MSc. Ivana Azuaje, each offering valuable insights into the topic.

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The allocation of environmental impacts in recycled systems is a topic that remains at the forefront of discussions in the field of life cycle assessment (LCA). Over 14 different ways, including both official ISO methods and unofficial ones, can be applied to assign environmental impacts to recycled fibers and other recycled materials in open-loop systems. This leads to different conclusions and interpretations of the data. Working together, NC State University and The University of British Columbia invited scientists worldwide to discuss which methodology is most suitable for the recycled fibers scenario.

Allocation Methods Foundational Incentives

The implications of different allocation methods in life cycle assessments (LCA), particularly within the forest product sector, were brought to discussion by Dr. Caroline Gaudreault, director and global lead for LCA and impact metrics for North America at Anthesis Group. She aimed to illustrate the outcomes of applying various allocation methods and the types of incentives that these methods create. Dr. Gaudreault explored in her talk how different allocation methods can significantly alter the perceived environmental impacts of products, influencing which materials appear more sustainable. To illustrate this, she applied 12 different allocation methods across four case studies drawn from the literature, none of which was policy-oriented (Gaudreault 2012; Gaudreault et al. 2017). She highlighted the challenges in accounting for greenhouse gas (GHG) emissions for recycling fibers, emphasizing that fibers can be reused multiple times throughout their lifecycle. By presenting theoretical burden values for different recycling processes, she

demonstrated the variability and potential influence of each allocation method. Her analysis identified key hotspots and quantified their variations when different methodologies were applied.

Moreover, Dr. Gaudreault provided insights into how certain methods allocate the burden of virgin material production to recycled products. Although these values were illustrative, they underscored the critical influence that allocation choices play in shaping LCA outcomes. Dr. Gaudreault also evaluated different recycling rate scenarios and their impact on GHG emissions when using various allocation methods. The results revealed that, for most methodologies, a lower recovery rate correlates with increased GHG emissions, while a higher recovery rate leads to reductions in emissions.

She strongly emphasized the importance of understanding the values inherent to different allocation methods, as these methods not only affect the outcomes of LCAs but also shape the incentives for industries. For example, certain methods may favor the use of recycled content by allocating lower burdens to recycled materials, which could drive market preferences and policy decisions. Her talk was concluded by emphasizing the need for thoughtful selection of allocation methods in LCAs, aligned with the study objective, as the chosen method can significantly influence the perceived sustainability of products. In the case of carbon footprinting, she advocated for a balanced approach that considers the multifunctional nature of forest products and the complexities introduced by recycling while acknowledging that the cut-off methodology is still the most used due to its simplicity, even though ISO standards do not recognize it. The cut-off methodology, also known as the recycled content approach, assigns the environmental burdens of each material based on the flows and processes directly associated with its production. In the recycling context, this means that the burdens of producing the virgin material stay within the first production cycle, and the recycled material is free of this burden in the subsequent cycles (Gaudreault 2012).

Open-loop Recycling in LCA – Defining and Managing the Allocation Problem

Dr. Tomas Ekvall, an internationally recognized expert in allocation methods selection and decision-making within life cycle assessment, highlighted the importance of understanding allocation problems in material recycling. Dr. Ekvall emphasized that there is a wide range of available methods for handling these allocation issues and stressed the importance of thoughtful selection of the appropriate method based on specific circumstances. He explained that allocation problems in LCA occur whenever a process or system serves more than one product life cycle. In recycling, for instance, material recycling processes serve both as waste management for one product and as material for the production of another. The need for allocation arises because the impacts and benefits of processes such as recycling need to be fairly distributed among the involved life cycles. The lack of clear allocation rules can lead to significant variability in LCA results (Ekvall *et al.* 2020).

Nevertheless, Dr. Ekvall's talk emphasized that there are countless ways to define the allocation problem. To many LCA researchers, the allocation problem is broader than merely allocating the recycling process, with the definition of the allocation problem varying between attributional and consequential LCA.

-In an attributional LCA, the problem is to allocate the impacts of the recycling process (always), the primary material production (often), and the final waste disposal of the material (sometimes).

- In a consequential LCA, the problem is instead to allocate the net benefits of recycling, *i.e.*, the impacts of recycling (always) and the avoided impacts of primary production (always) and waste disposal (sometimes).

He argued that consequential approaches are particularly relevant for policy applications because they consider broader system changes and indirect effects. He suggested that attributional methods might be less suitable for policy-making due to their limited scope.

Dr. Tomas Ekvall concluded by reiterating that there is no single best allocation method for all applications of LCA. The choice of method should be guided by the specific goals of the LCA, the context of its application, and the intended audience. He encouraged LCA practitioners to consider the trade-offs between simplicity, robustness, and comprehensiveness when selecting allocation methods while highlighting the need for critical thinking during the process. His insights emphasized the complexity and variability inherent in LCA, particularly when dealing with multifunctional systems and recycling processes.

Allocation Methods for Recycled Fibers- Containerboard Case

Using an industrial case, Ivana Azuaje, a PhD student from NC State University, focused the final webinar talk on explaining her findings when evaluating various allocation methods for recycled fibers in the production of containerboard made from both recycled and virgin fibers. The research aimed to understand how 14 allocation methods influence the assessment of environmental burdens associated with these materials, particularly in terms of GHG emissions, and to evaluate how accounting for losses in the recycling system influences the GHG values derived from each method (Azuaje *et al*. 2025).

To achieve this, Azuaje explained that a baseline GHG model was simulated to serve as a reference point for comparing the allocation methods and quantifying their differences. She also highlighted the use of sensitivity analyses by varying key factors, such as emissions associated with virgin fiber production, disposal, and recycling rates, to test the robustness of the results under different scenarios.

Her findings showed that the 14 allocation methods resulted in variations in GHG emission variations ranging from 4% to 19% compared to the baseline, with the 50/50 allocation method showing the highest deviation. When system losses were included, seven allocation methods produced results closer to the baseline, indicating the importance of considering losses in LCA models for recycled materials.

Additionally, when varying factors such as virgin fiber emissions and recycling rates, the system expansion, mass allocation, and cut-off methods exhibited the least variability, suggesting that these methods are more robust for this particular application. Azuaje concluded by emphasizing the critical need to carefully select allocation methods and the appropriate account and inclusion for losses and variability in the system to provide accurate environmental assessments as the most suitable methods for the containerboard case study. The cut-off method, in particular, was recommended when adjusted to include system losses due to its simplicity and less variation from the baseline under the different scenarios evaluated.

Key Messages and Final Discussion

The webinar's final discussion underscored a shared desire among speakers, organizers, and attendees to reach a consensus on a standardized methodology for specific applications, particularly in systems involving recycled fibers. Achieving a consensus would provide consistent and reliable guidance to the industry, helping to reduce variability in results across different studies. The discussion emphasized the need for a model that accurately accounts for emissions in systems using recycled fibers. Such a model would be instrumental in determining which allocation methodology best represents the actual emissions from these systems, providing a more precise and realistic assessment of their environmental impact.

Dr. Tomas Ekvall expressed that there is no single "best" allocation method, as the choice depends on the criteria and specific application of the LCA. He highlighted the limitation of the cut-off approach, which fails to account for the benefits of sending materials to recycling. This can be vital if the LCA aims to support policy-decisions or strategic decisions in industry. In such LCA applications, he advocated for a consequential perspective, citing the circular footprint formula, which attempts to model the effects of recycling. However, he noted that this approach remains incomplete and may require further refinement. Dr. Ekvall also emphasized that the value of LCA lies not only in delivering numerical results but in generating knowledge and insights about the systems being investigated.

Dr. Caroline Gaudreault, on the other hand, stressed that no allocation method can perfectly capture reality, as allocation is inherently a mental construct designed to assign burdens. She pointed out that while the circular footprint formula avoids some bias between different stakeholders in fiber systems and that number of uses method recognizes that recycled and virgin fibers are part of the same material cycle, both methods are relatively complex to apply. She suggested that the cutoff method might work well in North America due to the region's common disposal practices but may be less suitable for other regions, such as Europe, where fibers are often incinerated rather than landfilled. She concluded that if simplicity is the priority, the cutoff method might be appropriate for North American fiber systems for cases where the study objective is simply footprinting.

Based on her findings and comparing several allocation methods against a simplified model for recycled fibers, proxy to reality, Ivana Azuaje advocated for the cut-off method due to its simplicity and alignment with expected baseline outcomes. She noted that the cut-off method produced less variability in estimating GHG emissions when producing containerboard from a mix of recycled and virgin fibers, providing a reasonable and simplified reflection of reality.

References Cited

Azuaje, I., Forfora, N., Urdaneta, I., Ortega, R., Frazier, R., Vera, R., Vivas, K.A., Luana, D., Venditti, R., Jameel, H., Tu, Q., Lan, K., Marquez, R., Lizundia, E., and Kelley, S. (2025). "Reducing subjectivity when performing LCA for recycling systems in the paper industry through a comprehensive evaluation of different allocation methods," *Resour. Conserv. Recycl*. 215, article 108061. DOI: 10.1016/j.resconrec.2024.108061

Ekvall, T., Björklund, A., Sandin, G., Jelse, K., Lage, J., and Rydberg, M. (2020). *Modeling Recycling in Life Cycle Assessment*, Project Report. [WWW Document]. Swedish Environmental Research Institute. URL https://www.lifecyclecenter.se/wp-content/uploads/2020_05_Modeling-recyling-in-life-cycle-assessment-1.pdf

Gaudreault, C. (2012). "Methods for open-loop recycling allocation in life cycle assessment and carbon footprint studies of paper products," *NCASI Technical Bulletin* 1-109.

Gaudreault, C., Upton, B., and Vice, K. (2017). *2014 Life Cycle Assessment of U.S. Average Corrugated Product*, NCASI Project Report.