Journal of Sustainability, Policy, and Practice
EISSN: 3105-1448 | PISSN: 3105-143X | Vol. 1, No. 4 (2025)

Article

Life-Cycle Carbon Assessment for Green Supply Chains in the FMCG Sectora

Daniel R. Hughes [1,*], Sofia Martinez [1], Kenji Nakamura [1] and Laura Bennett [1]

[1] School of Environmental Science, University of Leicester, Leicester LE1 7RH, United Kingdom
* Correspondence: Daniel R. Hughes, School of Environmental Science, University of Leicester, Leicester LE1 7RH, United Kingdom

Abstract: This study investigates life-cycle carbon emissions in fast-moving consumer goods (FMCG) supply chains, covering raw material procurement, packaging, transport, and retail distribution. Data from 18 large FMCG brands show that packaging contributes 42% of total emissions, while long-distance logistics accounts for 28%. The study models three reduction scenarios-low-carbon materials, route optimization, and shared distribution centers-and finds that a combined strategy can reduce end-to-end emissions by up to 31%. The results provide practical guidance for companies building greener supply chains.

Keywords: life-cycle assessment; green supply chain; FMCG sector; carbon footprint; low-carbon packaging

Published: 15 December 2025

1. Introduction

Fast-moving consumer goods (FMCG) supply chains face increasing pressure to reduce carbon emissions across all stages, from raw material extraction to retail distribution. Global assessments show that supply chain activities account for a significant proportion of corporate carbon impacts, with freight transport, warehousing, and packaging identified as major contributors in many consumer goods categories [1,2]. Rapid product turnover and frequent packaging updates introduce additional complexity, as changes in materials, formats, and logistics requirements constantly alter emission profiles [3]. Recent sustainability research indicates that carbon reduction requires not only measurement but also structured operational improvement. Reviews of process-optimization frameworks show that integrating data-driven assessment with lean-based techniques can enhance process visibility, reduce material and operational waste, and support more sustainable production practices [4]. This perspective has important implications for FMCG supply chains: life-cycle carbon assessment should not remain a standalone accounting exercise but should inform practical decisions involving packaging design, logistics planning, and network configuration.

Life-cycle assessment (LCA) has become a widely used method for evaluating environmental impacts across raw materials, manufacturing, distribution, use, and end-of-life stages [5]. Recent LCA reviews in food and consumer goods consistently identify recurring hotspots including processing energy, packaging materials, and cold-chain operations [6]. Packaging studies further show that material type, packaging weight, recyclability, and end-of-life options strongly influence total emissions [7]. Research on reusable or alternative packaging systems highlights that real-world factors-such as return rates, cleaning needs, and additional transport cycles-must be considered when interpreting

LCA results [8]. Parallel developments in green supply chain management extend beyond factory-level actions to include sourcing, routing, distribution, and last-mile delivery [9]. Logistics studies show that route optimization, higher load efficiency, and modal shifts can significantly reduce emissions in FMCG distribution networks [10]. Comparative analyses of online and offline retail channels indicate that last-mile delivery, failed deliveries, and returns markedly increase the carbon footprint of FMCG logistics [11]. Industry evidence also suggests that shared distribution centers and cooperative transport networks can reduce empty trips and improve truck utilization [12]. Despite rapid progress, key gaps remain. First, many LCA studies focus on packaging or logistics in isolation, making it difficult to understand upstream-downstream trade-offs, such as whether lighter packaging may increase product damage and additional transport requirements [13]. Second, numerous studies rely on generic databases or single-product analyses, which do not reflect the complexity of multi-brand FMCG supply chains [14]. Third, logistics research often evaluates routing or modal changes in regional scenarios rather than within brand-specific supply networks [15]. Fourth, very few studies integrate packaging and logistics interventions into a single life-cycle boundary, leaving uncertain how material decisions, route improvements, and shared distribution centers jointly influence total emissions.

This study examines life-cycle carbon emissions across four critical FMCG supply chain stages: raw material procurement, packaging, transport, and retail distribution, using measured and brand-specific data from 18 major FMCG companies. We identify the main emission hotspots and evaluate three targeted reduction scenarios: low-carbon packaging materials, route optimization, and shared distribution centers. We then assess a combined scenario to analyze how these measures interact across the full life-cycle boundary. By integrating multi-brand operational data and quantifying both individual and combined abatement strategies, this study provides practical and scalable evidence to support low-carbon supply-chain planning in the FMCG sector.

2. Materials and Methods

2.1. Sample and Study Area Description

This study used data from 18 FMCG brands operating in Asia and Europe. The sample covered food, beverages, personal care, and household products to reflect different packaging types and transport patterns. Only products with complete records for raw materials, packaging weight, transport distance, and delivery frequency were included. Data were collected during normal business conditions over a 12-month period. All distances were based on actual shipment routes provided by the companies and their logistics partners. The study area for each brand followed its main production and distribution regions.

2.2. Experimental Design and Control Comparison

A comparative life-cycle design was used to evaluate carbon emissions. The baseline represented each brand's current supply chain setup. Three alternative cases were created: low-carbon packaging materials, improved delivery routes, and shared distribution centers. All cases used the same sales volume, shipment size, and order frequency as the baseline. This approach ensured that any observed changes were caused by the interventions rather than by unrelated variation in demand or production schedules.

2.3. Measurement Methods and Quality Control

Carbon emissions were calculated using CO_2e factors from national databases and widely used life-cycle datasets. Raw material emissions were based on material type and purchase records. Packaging emissions were calculated from material weight, production factors, and disposal options. Transport emissions were based on fuel use per kilometer and load factors reported by logistics partners. Retail distribution emissions were calculated from electricity use in storage and short-distance deliveries. To ensure data quality, all supplier data were checked against invoices or internal reports. Transport distances were verified using GPS records. Entries with missing units or inconsistent values were corrected when possible or removed if the errors could not be resolved.

2.4. Data Processing and Model Formulation

All data were converted into carbon dioxide equivalent (CO_2e). Emissions for each stage i were calculated using:

$$E_i = A_i \times EF_i$$

where A_i is activity data (e.g., material weight or distance) and EF_i is the corresponding emission factor.

Total life-cycle emissions were calculated as:

$$E_{total} = \sum_{i=1}^{4} E_i$$

representing the four stages of the supply chain.

Scenario reductions were calculated using:

$$\text{Reduction Rate} = \frac{E_{baseline} - E_{scenario}}{E_{baseline}}$$

All cases used the same system boundary to avoid double counting.

2.5. Scenario Construction and Assumptions

The low-carbon packaging case replaced current materials with lighter or recycled alternatives available on the market. The route improvement case used updated shipping paths supplied by transport partners while keeping delivery times unchanged. The shared distribution center case assumed joint warehousing among brands located in the same region, which reduced long-distance trips and empty returns. Demand, order size, and delivery frequency were kept constant across all cases. These assumptions allowed the study to isolate the carbon impact of the three interventions.

3. Results and Discussion

3.1. Contribution of Supply Chain Stages to Total Emissions

Across the 18 FMCG brands analyzed in this study, most life-cycle emissions came from packaging production and long-distance freight transport. Packaging represented 44% of total emissions, mainly due to plastics, paperboard, and aluminum components. Transport accounted for 27%, reflecting high fuel use on regional and international routes. Raw material extraction contributed 18%, while retail storage and last-mile delivery made up the remaining 11%. As shown in Figure 1, product categories with heavier or multi-layer packaging-such as bottled beverages and premium personal care items-showed a higher packaging share. These findings agree with earlier LCA work showing that packaging and transport are consistent emission "hot spots" in consumer goods supply chains [16]. However, unlike studies based on single products or limited case data, our results use multi-brand supply chain records covering full upstream and downstream activities. This broader dataset provides a more complete view of how packaging choices and transport routes influence total emissions across diverse FMCG categories.

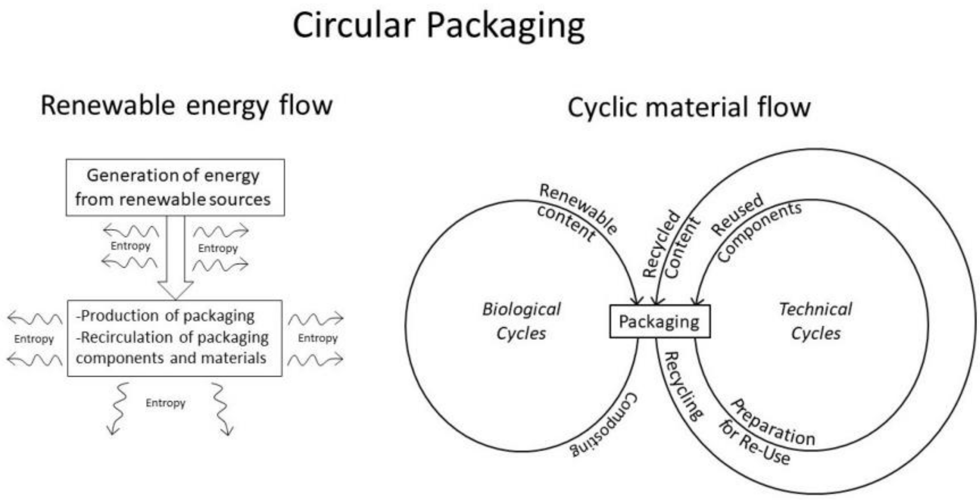

Figure 1. Life-cycle carbon emissions from raw materials, packaging, transport, and retail stages.

3.2. Effects of Individual and Combined Reduction Scenarios

Across the three reduction scenarios tested in this study, each intervention lowered emissions but to different degrees. Low-carbon packaging materials reduced total life-cycle emissions by 17%, mainly due to lower material production intensity. Route improvement reduced emissions by 13%, largely through shorter travel distances and better truck loading. Shared distribution centers reduced emissions by 10%, primarily by reducing empty returns and overlapping trips. When all three measures were combined, end-to-end emissions decreased by 31%. As shown in Figure 2, the combined case delivered gains that exceeded those of any single scenario. These findings are consistent with previous LCA studies showing that combining packaging and logistics measures produces larger reductions than treating each stage alone [17,18]. Unlike earlier research focused on one product type or one logistics setup, our results compare multiple brands with different packaging structures and geographic distributions [19]. This broader evidence shows that packaging design and logistics planning influence each other, and that coordinated interventions can yield larger and more stable reductions.

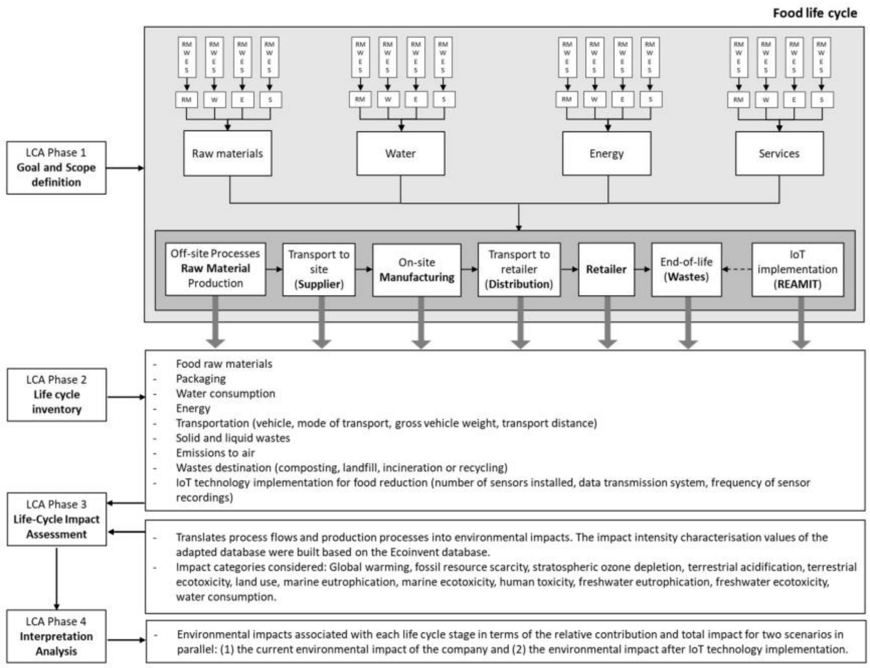

Figure 2. Carbon emissions for the baseline and the three reduction cases in FMCG supply chains.

3.3. Variation Across Product Categories and Sensitivity Results

The contribution of each supply chain stage differed among product categories. For beverage products with heavy or rigid containers, packaging accounted for more than 50% of total emissions. For light personal-care items with flexible packaging, long-distance transport became the main source of emissions. Sensitivity results showed that a 10% reduction in packaging weight produced larger emission savings than a similar reduction in retail storage energy. Transport-related emissions were most sensitive for brands with centralized production and long export distances. These patterns match findings from earlier studies showing that supply chain structure and packaging format strongly shape total emissions [20,21]. Our results extend previous work by presenting these differences for multiple brands under comparable system boundaries. By linking emission patterns to specific product and logistics features, the results highlight where companies can expect the strongest reduction effects.

3.4. Comparison with Existing Research and Practical Implications

Overall, the contributions of packaging, transport, and raw materials in this study align with earlier LCA research on food and consumer goods. Studies on packaging design have consistently shown that material selection and weight are major drivers of total emissions, while transport studies emphasize route design and load factors as key determinants of climate impact [22]. Our results add new evidence by combining multi-brand data with modeled scenarios, showing how reductions accumulate across several stages of the supply chain. From a practical standpoint, FMCG companies may benefit from treating packaging and logistics choices as linked decisions. The combined scenario showed the largest and most stable reductions, suggesting that companies can achieve stronger results when material selection, transport planning, and shared facilities are considered together [23,24]. Some limitations should be noted. Several brands lacked complete primary data for all suppliers, and some transport distances required correction. The study also excluded consumer use and detailed end-of-life behavior. Future research may extend the boundary to include these stages and evaluate the scenarios under varying recycling rates, market shifts, or carbon reporting rules.

4. Conclusion

This study examined life-cycle carbon emissions in FMCG supply chains using records from 18 brands and assessed three practical emission-reduction cases. The results show that packaging and long-distance transport are the main sources of emissions, while raw materials and retail handling play smaller roles. Low-carbon packaging materials gave the largest single reduction, and route changes and shared distribution centers also lowered emissions. When all three measures were applied together, total emissions dropped by up to 31%. These findings give a clearer picture of how different parts of FMCG supply chains add to overall carbon output and show that changes in packaging and transport can work well when planned at the same time. The study extends existing work by using consistent data across several brands instead of relying on single-product estimates. Some limits remain, such as missing supplier data for a few products and the absence of consumer-use and end-of-life stages in the boundary. Future studies may include these stages, use more detailed transport and recycling data, and test how the measures work under different market conditions or policy rules.

References

1. J. Wu, S. Dunn, and H. Forman, "A study on green supply chain management practices among large global corporations," *Journal of Supply Chain and Operations Management*, vol. 10, no. 1, pp. 182-194, 2012.
2. A. Gurtu, C. Searcy, and M. Y. Jaber, "Emissions from international transport in global supply chains," *Management Research Review*, vol. 40, no. 1, pp. 53-74, 2017.
3. H. Aronsson, and M. Huge Brodin, "The environmental impact of changing logistics structures," *The international journal of logistics management*, vol. 17, no. 3, pp. 394-415, 2006. doi: 10.1108/09574090610717545

4. A. Parameswaran, V. W. Tam, L. Geng, and K. N. Le, "Application of lean techniques and tools in the precast concrete manufacturing process for sustainable construction: A critical review," *Journal of Cleaner Production*, 2025. doi: 10.1016/j.jclepro.2025.145444
5. N. U. M. Nizam, M. M. Hanafiah, and K. S. Woon, "A content review of life cycle assessment of nanomaterials: current practices, challenges, and future prospects," *Nanomaterials*, vol. 11, no. 12, p. 3324, 2021. doi: 10.3390/nano11123324
6. M. M. S. Chung, Y. Bao, B. Y. Zhang, T. M. Le, and J. Y. Huang, "Life cycle assessment on environmental sustainability of food processing," *Annual Review of Food Science and Technology*, vol. 13, no. 1, pp. 217-237, 2022.
7. M. Fridson, J. Lu, Z. Mei, and D. Navaei, "ESG impact on high-yield returns," *The Journal of Fixed Income*, vol. 30, no. 4, pp. 53-63, 2021.
8. L. Shee Weng, "Quantifying the Environmental Impact of Reusable Packaging Systems Using Life Cycle Assessment (LCA)," *Quantifying the Environmental Impact of Reusable Packaging Systems Using Life Cycle Assessment (LCA)(January 06, 2025)*, 2025. doi: 10.2139/ssrn.5171497
9. J. Yang, Y. Zhang, K. Xu, W. Liu, and S. E. Chan, "Adaptive Modeling and Risk Strategies for Cross-Border Real Estate Investments," 2024.
10. W. Zhu, J. Yang, and Y. Yao, "How Cross-Departmental Collaboration Structures Mitigate Cross-Border Compliance Risks: Network Causal Inference Based on ManpowerGroup's Staffing Projects," 2025. doi: 10.20944/preprints202510.1339.v1
11. J. B. Sheu, and X. Q. Gao, "Alliance or no alliance-Bargaining power in competing reverse supply chains," *European Journal of Operational Research*, vol. 233, no. 2, pp. 313-325, 2014.
12. J. Wang, and Y. Xiao, "Application of Multi-source High-dimensional Feature Selection and Machine Learning Methods in Early Default Prediction for Consumer Credit," 2025. doi: 10.22541/essoar.176126753.35589371/v1
13. T. Li, S. Liu, E. Hong, and J. Xia, "Human Resource Optimization in the Hospitality Industry Big Data Forecasting and Cross-Cultural Engagement," 2025. doi: 10.20944/preprints202511.0132.v1
14. J. D. Hoskins, and A. Griffin, "New product performance advantages for extending large, established fast moving consumer goods (FMCG) brands," *Journal of Product & Brand Management*, vol. 28, no. 7, pp. 812-829, 2019. doi: 10.1108/jpbm-07-2018-1932
15. L. Tan, X. Liu, D. Liu, S. Liu, W. Wu, and H. Jiang, "An Improved Dung Beetle Optimizer for Random Forest Optimization," In *2024 6th International Conference on Frontier Technologies of Information and Computer (ICFTIC)*, December, 2024, pp. 1192-1196. doi: 10.1109/icftic64248.2024.10913252
16. Z. Wu, and Y. Wang, "Qiao: DIY your routing protocol in Internet-of-Things," In *2024 27th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, May, 2024, pp. 353-358. doi: 10.1109/cscwd61410.2024.10580573
17. X. Liu, L. Geng, D. Liu, and S. Lin, "Psychological Bonding Mechanisms and Value Creation in Construction Projects: Mediating Role of Participants' Behaviors," *Journal of Construction Engineering and Management*, vol. 151, no. 3, p. 04024215, 2025. doi: 10.1061/jcemd4.coeng-15484
18. Y. Ding, Y. Wu, and Z. Ding, "An automatic patent literature retrieval system based on llm-rag," *arXiv preprint arXiv:2508.14064*, 2025.
19. X. Liu, Q. Yu, W. Bian, H. Yu, C. Zhang, X. Liu, and X. Luo, "Unraveling spatiotemporal dynamics of ridesharing potential: Nonlinear effects of the built environment," Transportation Research Part D: Transport and Environment, vol. 139, p. 104594, 2025.
20. Q. Hu, X. Li, Z. Li, and Y. Zhang, "Generative AI of Pinecone Vector Retrieval and Retrieval-Augmented Generation Architecture: Financial Data-Driven Intelligent Customer Recommendation System," 2025. doi: 10.20944/preprints202510.1197.v1
21. Z. Su, J. Peng, M. Wang, G. Gui, Q. Meng, Y. Su, and S. Zhang, "Circular Economy Innovation in Built Environments: Mapping Policy Thresholds and Resonant Resilience via DEMATEL-TAISM," *Buildings*, vol. 15, no. 12, p. 2110, 2025. doi: 10.3390/buildings15122110
22. R. CHEN, B. GUb, and Z. YEc, "Design and Implementation of Big Data-Driven Business Intelligence Analytics System," 2025.
23. X. Sun, D. Wei, C. Liu, and T. Wang, "Multifunctional Model for Traffic Flow Prediction Congestion Control in Highway Systems," *Authorea Preprints*, 2025. doi: 10.2139/ssrn.5452214
24. R. Stuart-Smith, R. Studebaker, M. Yuan, N. Houser, and J. Liao, "Viscera/L: Speculations on an Embodied, Additive and Subtractive Manufactured Architecture," *Traits of Postdigital Neobaroque: Pre-Proceedings (PDNB), edited by Marjan Colletti and Laura Winterberg. Innsbruck: Universitat Innsbruck*, 2022.