Review of Life Cycle Cost Analysis for Reusable Packaging for the Retail Industrial

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Abstract. This review comprehensively evaluates research on the lifecycle cost analysis (LCCA) of reusable packaging systems in the retail sectors of fruits and vegetables, automotive parts, etc. It categorizes researchers by product types and thoroughly analyzed the various models used by these studies to conduct LCCA of reusable packaging. This article provided extensive analyses of cost categorization frameworks, covering raw materials, transportation, maintenance, and end-of-life expenses, thereby providing profound insights into the economic and sustainability benefits of packaging logistics. Key findings indicate that, with effective logistics management, reusable packaging typically achieves significant long-term cost savings. The review also points out that future research should focus on the economic benefits of different types of reusable packaging, examining the impacts of reverse logistics management and packaging design on costs, and the development of more precise LCCA models. Such research will provide effective decision-making support for businesses promoting the transition of sup-ply chains towards sustainable development.

Keywords: Reusable Packaging, Reusable Plastic Crates, Life Cycle Cost, Retail

1 Introduction

As one of the largest sectors of the global economy[1], the retail industry spans a comprehensive distribution chain of goods and services, from production to final consumption, and holds a crucial and unique role in national economies. As Sustainable Development Goals (SDGs) advance, the retail sector, serving as a key bridge between producers and consumers, has become essential in promoting sustainable production, encouraging green consumption, and driving low-carbon development across the entire supply chain[2]. In this context, retailers are challenged to balance economic profitability with reducing operational costs, minimizing environmental impact, and meeting increasingly stringent sustainability standards[3].

Within this extensive and complex distribution chain, packaging and logistics are not only vital for ensuring the smooth flow of products from production to consumers but also key factors influencing a company's economic performance, environmental impact, and market competitiveness. Reusable packaging solutions, such as reusable plastic crates (PRCs), play a particularly important role in logistics[4]. These PRCs can reduce the use of single-use packaging materials, thereby minimizing resource waste and lowering packaging costs[5]. Their standardized design allows for strong stacking capabilities and durability, optimizing storage space, enhancing transportation efficiency, and reducing shipment frequency, which in turn significantly lowers logistics costs and positively impacts a company's sustainability efforts[6]. Moreover, the durability and reusability of turnover crates make them more cost-effective over their lifecycle compared to single-use packaging[7]. By adopting more sustainable packaging and logistics strategies, retail companies can not only reduce their environmental impact but also improve overall supply chain efficiency[8-10]. Life Cycle Cost Analysis (LCCA) serves as a comprehensive tool to help the retail industry assess the costs and benefits of packaging solutions like turnover crates throughout their entire lifecycle, enabling the optimization of packaging logistics strategies and the achievement of sustainability goals.

The purpose of this study is to review the existing research on the LCCA of RPCs in the retail industry, categorizing and summarizing the relevant literature. By identifying key findings, uncovering existing research gaps, and proposing future research directions, this review aims to provide valuable insights for both academic researchers and industry practitioners.

2 LCCA

Life Cycle Cost Analysis (LCCA) is an economic evaluation tool used to quantify all costs associated with a project or product over its entire life cycle, from planning, design, and construction to operation, maintenance, updating, and eventual decommissioning[11-13]. The definition of Life Cycle Costing (LCC) that is widely recognized internationally comes from the National Institute of Standards and Technology (NIST)[14]. According to this definition, LCC represents the total sum of all relevant economic costs throughout the life cycle of a product or system. This includes the initial purchase cost, operational and maintenance costs, and the residual or salvage value at the end of the product's life[15-17]. The LCC calculation typically considers the time value of money, discounting all future costs and revenues to the present to facilitate accurate economic comparisons and decision-making[18].

Life cycle costs can be categorized in various ways depending on the perspective and classification method. From the perspective of cost ownership, LCC can be divided into external and internal costs[19, 20]. When considering the source of costs, LCC can include manufacturer costs, user costs, and societal costs[21]. Manufacturer costs include expenses related to research and development, production, and marketing of new products. User costs cover expenses from the product's use until its final disposal. Societal costs involve costs borne by society throughout the product's lifecycle, including environmental management and pollution control[22, 23].

According to ISO 56868, the LCC analysis method can forecast initial and future operational costs over a specified period and provide a comprehensive analysis of economic cost-benefit trends[24]. It enables the comparison of multiple solutions to determine the most effective one. Moreover, LCCA highlights the importance of sustainability and environmental impact, as environmentally friendly designs can reduce energy consumption and emissions over the product's lifecycle, thereby lowering long-term costs. By using LCCA, decision-makers can gain a better understanding of the long-term economic and environmental impacts of different options and translate these effects into monetary terms, leading to more informed and responsible decisions[25].

3 LCCA of reusable packaging

Research on Life Cycle Cost Analysis (LCCA) began as early as 1979[25], but studies specifically focusing on packaging LCCA remain limited. We have searched and categorized the relevant research into four main areas based on application: general studying, fruit and vegetable packaging, automotive parts packaging, and other categories. A summary of these studies is presented in Table 1.

Table 1. Focus of articles in the literature review.

Packaging System	References
Generic Containers	[26]
Reusable containers for vegetables and fruits.	[4, 27-31]
Reusable containers for automotive parts	[32-36]
Others	
Sustainable packaging system for a regional pork meat company	[37]
Reusable containers for LCD panel	[38]
Bucket for cut flowers	[39]
Reusable containers for luxury goods	[40]

Through a comparative analysis of the packaging LCC structures across studies above, it is found that, although definitions of packaging cost components may vary, purchase costs, transportation costs, management costs (cleaning or handling), and end-of-life disposal costs are consistently included (Table 2). In most cases, reusable packaging is cheaper than single-use packaging, with production costs, transportation costs, and the number of reuse cycles being the primary influencing factors.

Table 2. Summary Table of Cost Structures and Key Findings for Various Packaging Systems

References	Cost structure	Key finding
[26]	1.Material Cost 2.Production Cost 3.Transport Cost 4.Storage Cost 5.Cost for Buildings 6.Handling Cost	An idea on how to calculate the costs have been given in this study.

References	Cost structure	Key finding
	7.Cost for Losses, Redelivery, Repair, Etc. 8.Disposal/Recycling Cost 9.Cleaning Cost 10.Capital Lockup Cost	
[27]	1.Production Cost 2.Transport Cost 3.Cleaning Cost 4.Disposal/Recycling Cost 5.Other Cost	The re-usable system has economic advantages over the single-use systems. The number of circulations is the main cost driver.
[4]	1. Purchasing Costs 2.Transport Cost 3.Labor/Handling Costs 4.Management Costs 5.Other Costs 6. Earnings	The total cost of reusable plastic container is higher compared to disposable packaging due to higher transport and maintenance costs.
[28]	1.Production Cost 2.Disposal/Recycling Cost 3.Transport Cost 4.Cleaning Cost 5. Handling Costs	Fiberboard boxes with removable plastic films are consistently found to be the best choice, reducing manufacturing costs and environmental impact.
[29]	/	Compared to road transport, shipping by sea results in an 11.7% reduction in total transport costs.
[30]	1.Material Cost 2.Transport Cost 3.Storage Cost 4.Cleaning Cost	A linear programming model is constructed to minimize the costs of the packaging pooling service while meeting the demands and service requirements of food suppliers and retailers.
[31]	1.Purchase Cost 2.Transport Cost 3.Handling Cost 4.Disposal Cost Depreciation Cost	A multi-objective optimization model was proposed to simultaneously evaluate the economic and environmental impacts of RPC. The study results indicate that although RPC may have higher initial costs, they can achieve economic benefits in the long term by reducing waste and lowering disposal costs.
[37]	1. Container Cost 2.Transport Cost 3.Handling Cost 4.Cleaning Cost 5.Assembling Cost 6.Maintenance Cost	By designing a more sustainable model for box allocation, both the economic and environmental impacts associated with the packaging strategy can be reduced.

References	Cost structure	Key finding
[32]	1.Initial Purchase Expense 2.Return Sorting Cost 3.Return Transport Cost 4.Cost Cleaning Cost 5.Tracking Cost 6.Replacement Cost 7. Disposal Cost 8. Damage Reduction 9. Expendable Package Savings	Returnable logistical packaging systems can offer significant financial and environmental benefits compared to traditional expendable packaging systems.
[33]	1.Container Cost 2. Transport Cost 3.Labor Cost 4.Disposal/Recycling Cost	The container cost ratio is the most important driver of cost differences between reusable containers and expendable containers, followed by average daily volume.
[34]	1.Production Cost 2.Transport Cost 3.Handling Cost 4.Waste Cost 5.Administration Cost	One-way packaging resulted in fewer economic and environmental impacts. The transport distance and packaging fill rate were the key factors influencing the economic costs and environmental impact of packaging
[35]	1. Holding costs 2.Transport Cost	Shared mode has lower transportation volume, lower pipeline inventory, and lower safety inventory, which means shared mode has a lower total cost compared with dedicated mode.
[36]	1.Container Cost 2. Importer Inland 3.Ocean Freight Cost, 4.Exporter Inland Cost 5. Packaging Cleaning and Repairing Cost 6.Depreciation Cost.	The multi-trip reverse logistics arrangement was most operationally and environmentally viable, with the largest total packaging cost reduction and packaging waste reduction of 61% and 68%, relative to the disposable packaging.
[38]	1.Material Cost 2. Shipping Cost 3. Recycling Cost	The total cost of the green logistics mode with reusable boxes is always lower than that of the traditional logistics mode with single-use boxes. And the material cost of reusable boxes is the most influential sector of the total cost.
[39]	1.Investment Costs 2.Administration Costs 3. Logistical Costs 4. Disposal Costs	The use of a reusable system, which ensures production with less waste and fewer environmental pressures, is also economically advantageous
[40]	1.Investment Costs 2.Transport Cost	The use of reusable containers is not always less expensive than the current

References	Cost structure	Key finding
		operation with cardboard ones, due to the high transportation costs imposed by the company.

3.1 LCCA of reusable packaging

In 1996, Martin Dubiel[26] identified a major reason why many companies were unaware of packaging costs and their economic significance: the challenge of accurately calculating these costs. He has studied the costing structure of reusable packaging system, categorizing packaging costs into 10 distinct categories: material cost, production cost, transport cost, storage cost, cost for buildings, handling cost, cost for losses and repair, disposal/recycling cost, cleaning cost and capital lockup cost. In addition, he compared the cost structures of one-way and reusable packaging, highlighting that recycling and waste disposal costs are predominantly incurred with one-way packaging. Dubiel emphasized the need to analyze packaging costs according to specific industry types. His study included a table to assist companies in calculating packaging system costs. The table consisted of 3 parts: (1) system parameters, (2) calculation of cost categories, and (3) cost comparisons. He called for manufacturers and consumers in the same type of industry to create a practical reusable system offering economic and ecological advantages to all participants. Dubiel's research not only provided a framework for cost analysis but also laid the groundwork for a paradigm shift towards more sustainable packaging solutions, highlighting the potential for long-term savings and environmental conservation.

3.2 LCCA of reusable packaging for vegetables and fruits

Reusable packaging systems for fruits and vegetables have been studied by research, with multiple methodologies applied to assess their economic and environmental impacts.

In 2013, life cycle analysis (LCA), LCC and Life Cycle Working Environment (LCWE) methodologies were used by Stefan Albrecht et al.[27] to assess and compare the environmental, economic, and social impacts of the most common fruit and vegetable transport packaging systems in Europe. These include single-use wooden and cardboard boxes as well as RPC. They categorized the costs of these packaging systems into five components: production cost, transport cost, cleaning cost, disposal/recycling cost, other cost. The largest portion of the LCC of wooden boxes and cardboard boxes occurs at the production stage. For RPC, the number of circulations is the main cost driver. Total costs decrease as the number of circulations increases. The result showed that the re-usable system is the most cost effective over its entire life cycle.

In 2014 Accorsi et al. [4] conducted an economic and environmental assessment of RPC used in the food supply chain, focusing on the transport of fresh fruits and vegetables from suppliers to final customers. They investigated various factors such as the lifespan of RPCs, washing rates, and waste disposal treatments, examining their impact on environmental and economic costs. The study found that, in their modeled scenario, the LCC of RPCs was higher compared to disposable packages with equivalent functionality. This was mainly due to the high maintenance cost and transport cost of reusable plastic container.

Daria Battini et al.' s analysis[28] further enriches this discussion by comparing corrugated fiberboard boxes with RPCs. An analytic model was developed to estimate the total cost of each packaging system. The study assessed the impact of three main processes—manufacturing (including disposal), transportation, and washing—on the total cost. It found that the primary cost for fiberboard boxes was associated with the production process. For RPCs, transportation and washing costs became more significant as the number of uses per container increased. The study proposed two packaging solutions: fiberboard boxes with removable plastic films and RPCs with a corrugated fiberboard bottom. The comparison revealed that fiberboard boxes with removable plastic films were the most cost-effective option, with lower manufacturing costs and environmental impact.

Giulia Baruffaldi et al.[29] present a methodology and a decision-support tool for quantifying the logistic and environmental impacts associated with packaging distribution in a closed-loop network among growers. Their analysis of reusable packaging for vegetables and fruits under different logistics scenarios showed that sea transport reduces total transportation costs by 11.7% compared to road transport. This study highlights the critical role of logistics management in the sustainability of packaging systems.

In the food industry, Accorsi Riccardo et al.[30] developed a linear programming model for reusable packaging to minimize the costs for packaging pool managers. The model included material costs, cleaning costs, storage costs, and transport costs, and included sensitivity analyses to assess how these factors influence the overall cost. In the study by Michele Ronzoni et al.[31], the use of RPCs in the Italian food catering supply chain was investigated. By employing a multi-objective optimization model, the study considers factors such as transportation, handling, procurement, and disposal costs, exploring the trade-offs between economic convenience and minimizing environmental impact. Through Pareto front analysis, the research reveals strategies for reducing environmental impacts across different scenarios. The results indicate that although the initial investment in RPCs may be higher, sustainable operational models can yield economic benefits in the long run by reducing waste and lowering disposal costs. These findings provide decision-makers with valuable insights to find the optimal balance between economic and environmental goals, thereby promoting the sustainable development of the food supply chain.

González-Boubeta, Iván et al.[37] studied the sustainable packaging system for a regional pork meat company, evaluating the total costs of three packaging types: purchased returnable plastic boxes, disposable cardboard boxes, and returnable plastic boxes rented from a logistics provider. They also proposed a new packaging allocation logic which had better economic and environmental performance. In this study the total cost was divided into container cost, transport cost, handling cost, cleaning cost, assembling cost, and maintenance cost. For long-distance transport, disposable cardboard boxes were used due to the complexities of reverse logistics. Firstly, economic and environmental impacts were calculated based on the company's 2015 sales data. Based on the calculations, the transport strategy was adjusted to get an optimized model and thus obtained the optimal strategy for the company's three packaging logistics systems. The optimized strategy involved expanding the use of purchased returnable plastic boxes, reducing the use of disposable cardboard boxes, and limiting rented returnable plastic boxes to trade partners. The results show that the optimal solution was strongly influenced by the geographical area and supply volume. The optimized logistics strategy led to a nearly 20% reduction in packaging costs and a significant 31% decrease in carbon footprint. The study highlights the importance of tailoring packaging logistics to specific regional and supply conditions to maximize both economic and environmental benefits.

3.3 LCCA of reusable packaging for automotive parts

The automotive industry has also explored the economic viability of reusable packaging, with studies focusing on cost comparisons between single-use and reusable systems.

In 1996, Wendee V. Rosenau et al.[32] investigated the investments in returnable containers by ten leading vehicle assembly companies and proposed a framework for evaluating packaging investment decisions. In this study, net present value was used to calculate the cost of returnable containers. It was found that the number of containers required depends on the circulation time of the crates and the daily crate requirements. Additionally, the lifespan of the containers is a critical factor in the NPV calculation. Longer lifespans make the investment more profitable. Compared to single-use containers, reusable containers reduce initial purchase and disposal costs but increase transportation and cleaning expenses. This study indicated that assembly companies could save $125 per vehicle by using reusable containers.

In 2005, Mollenkopf Diane et al.[33] compared the costs of single-use versus recyclable secondary packaging logistics systems in the automotive parts manufacturing industry. A generalizable cost model was developed to assess the economic viability of reusable packaging. Their analysis examined the relationship between the cost of reusable packaging and several factors such as its container unit cost, cycle time, pack quantity, delivery distance, daily volume. The analyses suggested that reusable packaging is more feasible for larger packages, while expendable containers are more economic for smaller packages. Average daily volume also appears to be a relatively important factor. However, the study's model simplified transport systems and overlooked considerations related to empty containers. In further study, dynamic simulation needs to be developed to provide a more realistic analysis of the complexities of a packaging system.

Pålsson Henrik et al.[34] also develop an evaluation model for selecting packaging systems in supply chains, considering both economic and environmental perspectives. Their study, which used Volvo as a case example, compared the sustainability of single-use and returnable packaging. The result showed that the transport distance and packaging fill rate were the key factors affecting the economic cost and environmental impact of packaging.

In 2015, Qinhong Zhang et al.[35] compared two different modes, i.e., dedicated mode and shared mode, in the context of automotive parts logistics. The total costs of the two modes were analyzed, focusing on transportation and inventory holding costs. The shared mode demonstrated significant advantages over the dedicated mode. Specifically, the shared mode replaces the long-distance return trips of empty containers with shorter-distance transportation of other goods. The result proved that the total costs, including transportation and inventory holding costs, were lower in the shared mode compared to the dedicated mode.

Nophanut Katephap and Sunpasit Limnararat[36] investigated the economic cost and environmental impact of disposable packaging and reusable packaging under three reverse logistics arrangements: the single-, round- and multi-trip arrangements. They proposed a mathematical model to calculate the total effective packaging cost, which consisted of six parts: container cost, importer inland, ocean freight cost, exporter inland cost, packaging cleaning and repairing cost, and depreciation cost. The study focused on a Thai manufacturer and exporter of automotive parts, with trading partners in the Philippines and Vietnam. The disposable packaging system used four carton pads, retained boxes, and a metallic frame, while the reusable packaging employed steel plates instead of carton pads. The findings indicated that the multi-trip reverse logistics arrangement achieved the greatest reductions in both total packaging cost and packaging waste, with reductions of 61% and 68%, respectively, compared to disposable packaging.

3.4 LCCA of reusable packaging for other products

Paolo Menesatt et al. [39] conducted a LCCA of disposable and reusable packaging in the floricultural sector. The cost was divided into four groups: purchasing, administration, logistical and disposal costs. The results show that reusable plastic packaging shows high economic benefits compared to traditional paper packaging. As reusable containers are part of a reverse logistics system, effective logistics management plays a crucial role in influencing their costs throughout their life cycle. Guillaume Goudenege[40] developed a generic model for reverse logistics management focusing on reusable packaging, mainly applied to a luxury goods company. The model was validated across various time horizons: from January to October (excluding the two months with the lowest sales) and for the entire year. Additionally, the model assessed the impact of different storage capacities and delivery times on the total cost of recyclable packaging. The result showed that the time horizons have a crucial influence on the total cost of containers, while storage capacity and delivery time have little impact. The analysis also revealed that reusable containers may not always be more cost-effective than cardboard ones due to higher transportation costs.

In 2019, Guo et al.[38] conducted a LCCA for a logistics system for reusable packaging in LCD panel industry, comparing the total costs of traditional disposable packaging with those of reusable packaging. The cost model of reusable packaging involves material cost, shipping cost, and recycling cost, while the model for traditional disposable packaging only included material cost and shipping cost. The results show that the total cost of the green logistics mode with reusable packaging is significantly lower than that of traditional logistics mode and the materials costs accounted for a major portion of the total. However, the study's calculation model was relatively simple and did not consider additional factors such as storage, handling, and cleaning costs.

4 Conclusion

This study provides a comprehensive overview of lifecycle cost analysis (LCCA) for reusable packaging in retailer industries, including fruits and vegetables, automotive parts, and other sectors, highlighting their significance in addressing economic sustainability, especially within the retail sector.

With the growing global focus on sustainable development, retailers must strike a balance between economic benefits and environmental impacts when selecting packaging logistics solution. Studies demonstrate that reusable packaging not only significantly reduces resource waste and operational costs but also enhances logistical efficiency, thereby boosting market competitiveness. The literature review highlighted the economic benefits of reusable packaging across various areas in retail. However, despite the advantages of reusable packaging in many cases, its cost-effectiveness is still influenced by factors such as transportation costs, reuse cycles, and logistics management efficiency. Therefore, enterprises formulating reusable packaging strategies should thoroughly consider these factors to optimize overall economic and environmental benefits. Future research should explore the application effectiveness of different types of reusable packaging across industries, particularly in reverse logistics management and packaging design innovation. With advancing technology and evolving market demands, continuous updates and enhancements to LCCA models will assist retailers in making informed decisions, driving the entire supply chain towards enhanced sustainability. In summary, LCCA serves as a powerful tool for assessing and refining packaging solutions, facilitating the attainment of sustainable development objectives.

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