Uday Choudhary, 2024, 12:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

A Review on Sustainable Packaging and Printing Ecosystem

Uday Choudhary, Associate Professor Srivani Thadepalli
Department of Fashion Technology,
National Institute of Fashion Technology, Hyderabad, India

Abstract- In response to the growing global emphasis on sustainability, the packaging and printing ecosystem has witnessed a remarkable shift towards more eco-conscious practices. This comprehensive review paper, titled "A Review on Sustainable Packaging and Printing Ecosystem: A Study on Design, Materials, and Economical and Operational Aspects," provides a thorough examination of the multifaceted dimensions shaping the sustainable evolution of packaging and printing industries. At its core, this review paper delves into the intricate relationship between design, materials, and the economic and operational aspects of these industries. It draws upon insights from selected studies to offer a holistic understanding of the key components driving sustainability in packaging and printing. One pivotal aspect explored in this review is the concept of "Design for Sustainability." It illuminates innovative design strategies that prioritise reducing environmental impact, minimizing waste, and embracing the principles of a circular economy. Furthermore, the paper underscores the importance of user-friendly design approaches that align with eco-conscious practices. Materials play a central role in the pursuit of sustainability, and this review scrutinizes the adoption of sustainable alternatives. It sheds light on materials such as biodegradable polymers, cellulose nanofibers, and natural fibers, examining their environmental benefits and challenges in detail. Economic considerations are another critical facet discussed within the paper. It delves into the economic implications of sustainable packaging and printing, addressing issues of cost-effectiveness, resource conservation, and the competitive advantages that sustainability can confer in the market. Operational efficiency is also a key focus of this review, offering insights into how sustainable practices impact the day-to-day operations of packaging and printing industries. This includes discussions on efficiency gains, reduced energy consumption, and effective waste management. Technological advancements are highlighted as well, with an emphasis on cutting-edge innovations such as smart packaging and 3D printing. These technologies are shown to contribute significantly to sustainability efforts by enhancing product monitoring, traceability, and the development of intelligent materials. In essence, this review paper presents a comprehensive and cohesive perspective on the journey towards sustainability within the packaging and printing ecosystem. By synthesizing insights from diverse research areas, it aims to provide a roadmap for industry stakeholders to navigate the evolving landscape of environmentally responsible and economically viable solutions.

Keywords- Sustainable packaging, Waste management, intelligent materials, Printing ecosystem

I. INTRODUCTION

Packaging serves as an essential component in the logistics and supply chain, profoundly impacting various industries. Despite significant technological progress, the expansion of global supply chains has resulted in an escalating reliance on multilayered packaging and an associated surge in waste throughout the supply chain.

Many businesses continue to employ packaging solutions that are harmful to the environment, like single-use plastics and complex multilayered materials. Simultaneously, unsustainable consumer packaging disposal practices put further stress on the environment. The development of advanced technology and the emergence of global supply chains has led to the production, assembly, packaging, and distribution of products across different regions worldwide, consequently increasing the demand for packaging materials to facilitate the handling of raw materials, product components, and, ultimately, the delivery to end consumers, thus escalating packaging waste generation at each stage.

The demand for the exploration of advanced, environmentally sustainable packaging materials possessing superior physical, mechanical, and barrier properties is steadily increasing. The materials currently employed for packaging, particularly in the domains of food, beverages, pharmaceuticals, medical products, and industrial applications, are primarily non-degradable. Consequently, these materials have elicited concerns regarding environmental pollution.

The paradigm of sustainable packaging pivots upon three core principles (Abdul Khalil, H.P.S. et al., 2016):

1. Functionality of Materials
Packaging materials must serve the dual purpose of supporting sustainable development while ensuring the effective preservation of product quality. The design commences with material selection, predicated on an in-depth comprehension of material performance concerning product quality and its implications on material life cycles.

2. Material Recovery
The effective recovery of packaging materials stands as a pivotal challenge in fostering sustainable packaging. Effective recovery implies the economically viable collection of packaging materials. Various methods for potential collection and recovery encompass biological recovery (composting), technical recovery (recycling), and energy recovery (waste to energy).

3. Continuous Material Cycling
Sustainable packaging necessitates the unceasing cycling of materials with minimal degradation. Notably, packaging possesses a relatively brief lifespan. Consequently, the volume of packaging waste roughly parallels the volume of packaging in the market. In Europe, packaging waste constitutes approximately 17% of municipal solid waste by weight and 3% of the entire waste stream. Furthermore, packaging waste exerts a notable impact on specific materials, accounting for approximately 70% of glass wastage, 60% of plastic wastage, and 40% of paper and cardboard wastage (Huang, C. and Ma, H., 2004) .

It is essential to underscore that packaging not only safeguards products but also serves a pivotal role in marketing, enabling brand owners and stakeholders to establish a distinctive presence in the marketplace. In the pursuit of sustainable packaging solutions, it is imperative to balance environmental concerns with the marketing and branding potential of packaging materials (James, F. and Kurian, A., 2021).

Definitions of Sustainability in Packaging

Due to the constant evolution of sustainable practices and a growing emphasis on eco-conscious solutions, the definitions of sustainability in packaging have evolved over time. These definitions have become more comprehensive and multifaceted, reflecting the intricate relationship between packaging and environmental, social, and economic considerations. Sustainability, in the context of packaging, is defined by two primary standards that encompass multifaceted principles (Wever, R. and Vogtländer, J., 2012).

Definition 1: Australian Sustainable Packaging Alliance

- **Effective:** Sustainable packaging fulfils its functional requirements with minimal environmental and social impact.
- **Efficient:** It minimises material and energy use throughout the product's life cycle.
- **Cyclic:** It reduces reliance on non-renewable resources and encourages the recovery of materials for reuse or recycling.
- **Safe:** All packaging materials and components, including inks and finishes, pose no risks to humans or ecosystems as presented in figure 1.

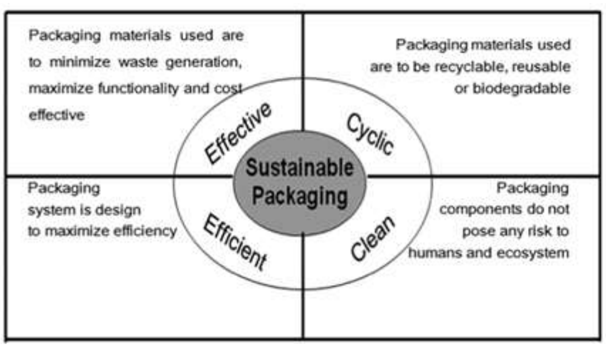

Fig. 1: Sustainable Packaging Alliance (SPA)

Definition 2: Sustainable Packaging Coalition

- Beneficial, Safe, and Healthy: It benefits individuals and communities while maintaining safety and health throughout its life cycle.
- **Performance and Cost:** It meets market criteria for both performance and cost.
- **Renewable Energy:** It is sourced, manufactured, transported, and recycled using renewable energy.
- **Optimised Materials:** It maximises the use of renewable or recycled materials.
- Clean Production Technologies: It employs clean production technologies and best practices.
- **End-of-Life Scenarios:** Materials are safe in all probable end-of-life scenarios.
- **Material and Energy Optimization:** The design optimises materials and energy use.
- **Closed-Loop Cycles:** Sustainable packaging is effectively recovered and used in closed-loop cycles.

These definitions establish the framework for evaluating the sustainability of packaging solutions, emphasising their holistic approach and the reduction of environmental and social impacts throughout the product life cycle.

II. METHODS FOR ASSESSING SUSTAINABILITY IN PRODUCT AND PACKAGING LIFE CYCLES

The assessment of sustainability is a pivotal process aimed at ensuring that products and their associated packaging adhere to environmental and social objectives. Evaluating sustainability within the life cycles of products and packaging entails the utilisation of various methodologies and frameworks. In this discussion, we delve into a range of techniques and approaches employed to assess sustainability and its far-reaching impact, emphasising the significance of a comprehensive and formal perspective.

Life Cycle Assessment (LCA): The Life Cycle Assessment stands as a widely embraced method for scrutinising the environmental repercussions of a product or process. It comprehensively examines all facets of the product's life cycle, spanning from the extraction of raw materials to its eventual disposal. The LCA method quantifies resource consumption, emissions, and environmental consequences, rendering it an exhaustive tool for evaluating sustainability (Dominic, C.A.S. et al., 2014).

Australian Packaging Evaluation Tool (PIQET): PIQET is an Australian tool used for assessing the environmental impacts of packaging. It takes into account several key environmental factors, including global warming/climate change, cumulative energy demand, photochemical oxidation, water use, solid waste, and land use. Additionally, PIQET evaluates other aspects such as product protection, shelf-life, and consumer knowledge/labelling (Svanes, E. et al., 2010).

Cradle-to-Cradle Design (C2C): The C2C framework underscores the design of products and packaging to be eco-effective, aiming to maximise ecological and economic benefits. It focuses on principles such as "waste equals food" and "using current solar income," and assesses products based on five criteria: material health, material reutilization, renewable energy and carbon management, water stewardship, and social fairness.

Material Circularity Indicator (MCI): Developed by the Ellen MacArthur Foundation and Grants, the MCI evaluates the alignment of a product with a circular economy, calculating the restorative nature of material flows. This encompasses indicators related to risks and impacts. The MCI is an invaluable tool for promoting circularity in product design.

Life Cycle Sustainability Assessment (LCSA): LCSA combines three pillars of sustainability: environmental, economic, and social. It entails the application of Life Cycle Assessment (LCA) for environmental impact analysis, Environmental Life Cycle Costing (ELCC) for accounting costs incurred by stakeholders, and Social Life Cycle Assessment (SLCA) for evaluating social and socio-economic impacts. This comprehensive framework aids in the evaluation of sustainability throughout the entire life cycle of a product (Wever, R. and Vogtländer, J., 2012)..

Svanes Model: The Svanes model amalgamates eco-burden aspects with functionality, encompassing five key categories: environmental sustainability, distribution costs, product protection, market acceptance, and user-friendliness. By considering both value creation and environmental impact, it offers a holistic perspective on sustainability in product and packaging design (Svanes, E. et al., 2010).

These methodologies provide varied vantage points for the assessment of sustainability. Each approach carries its own set of strengths and weaknesses, and the choice of a specific method hinges on the precise objectives and context of the sustainability evaluation. The amalgamation of multiple methods can offer a more comprehensive comprehension of sustainability within the life cycles of products and packaging.

III. DESIGN PROCESS FOR SUSTAINABLE PACKAGING

An effective design process is essential for producing innovative and sustainable packaging materials. This process involves collaboration among scientists, designers, and engineers to address existing packaging issues and define the best manufacturing processes and technologies (Abdul Khalil, H.P.S. et al., 2016). Packaging designers confront a multifaceted challenge: achieving product protection, optimising material efficiency, and minimising environmental impact throughout the supply chain. To address this challenge, a Sustainable Packaging Development (SPD) model has been established (Dominic, C.A.S. et al., 2014), focusing on three key variables:

1. Technical Design
This centres on optimising packaging structure and materials, with an emphasis on material avoidance to reduce usage.

2. Supply Chain Design
Extending technical design principles throughout the supply chain, aiming to minimise waste and ensure product integrity.

3. Environmental Design
Emphasising material reuse, waste reduction, and CO2 emission mitigation in the supply chain.

Life cycle assessments (LCA) analyze packaging's environmental impact, including materials like expanded polystyrene and various packaging types, along with greenhouse gas emissions and energy use. Innovative recycling, like using limonene orange oil for expanded polystyrene recycling, reduces emissions and energy consumption (Lee & Xu, 2005). These assessments address direct and indirect impacts on the entire packaging system, guiding product design decisions to balance sustainability with practicality. Sustainable packaging reduces its environmental impact through material selection, design, and consumer communication (Steenis et al., 2017).

To achieve sustainable packaging, a comprehensive approach is essential. Engineered sustainable packaging optimizes bio-based materials while considering factors such as availability, pricing, manufacturing processes, and performance. Quality standards for recycled materials are pivotal in this regard (Abdul Khalil, H.P.S. et al., 2016). This approach aligns with principles akin to the European Waste Hierarchy Directive, emphasizing the minimization of material usage, the assessment of carbon footprints, and the balance between material avoidance and disposal, ultimately reducing damage, waste, and CO2 emissions (Dominic, C.A.S. et al., 2014).

Design for the Environment (DfE) plays a crucial role by encompassing functionality, maintainability, affordability, and environmental impact. Sustainable development, as defined by the World Commission for the Environment and Development, seeks to meet current needs without compromising the ability of future generations to do the same (Lee, S.G. and Xu, X., 2005). Innovative materials and technologies, including biodegradable options and smart packaging, are integral components of this sustainable approach. Furthermore, the reduction of CO2 emissions from transport packaging through lighter materials and reusability is a paramount sustainability goal (Lee, S.G. and Xu, X., 2005).

In consumer packaged goods (CPG) markets, packaging serves multiple functions, maintaining product quality, preventing losses, and aiding transportation and storage (Steenis, N.D. et al., 2017). However, traditional practices often come with environmental drawbacks. Notably, despite comprehensive Life Cycle Assessments (LCAs), consumer awareness of packaging sustainability lags, leading to disparities between consumer beliefs and actual outcomes. Sustainable packaging, when viewed from a consumer standpoint, conveys eco-friendliness through its design, choice of materials, and the information it provides (Steenis, N.D. et al., 2017).

In summary, the quest for sustainable packaging is characterised by a holistic approach that encompasses design, material selection, environmental impact assessments, and the influence of consumer perceptions. This approach acknowledges the entire packaging life cycle and its interaction with the products it safeguards and showcases. The key connections between these elements create a cohesive and integrated framework for sustainable packaging practices.

IV. SUSTAINABLE PACKAGING MATERIALS

The pursuit of sustainable packaging solutions has gained remarkable traction in recent years. This endeavour has given rise to innovative biodegradable packaging materials that offer promising alternatives to traditional packaging. These biodegradable materials encompass a wide range of options, including synthetic and agricultural (compostable) polymers. Extensive research has revealed that these bio-degradable polymers can substantially lower both regional and global environmental footprints in comparison to conventional packaging materials. This paradigm shift towards bio-degradable materials holds immense potential for reducing the environmental impact of packaging (Lee, S.G. and Xu, X., 2005).

However, a significant challenge in the packaging industry lies in the issue of excessive packaging. Nowadays, consumers often make their choices based on the visual appeal and quality of a product's packaging, leading to the problem of over-packaging. This overuse of materials raises serious environmental concerns. As an integral part of manufacturing, the packaging industry has a pivotal role to play in addressing these issues. One significant focus has been on paper packaging materials, which have historically accounted for over 40% of packaging materials. Nevertheless, challenges related to the production and recycling of paper packaging materials threaten the environment and the social economy. In response to these challenges, the development of edible paper packaging has emerged as an innovative solution. Made from edible materials such as starch, protein, and plant fibre as shown in figure 2, this type of packaging material has seen successful development in Japan. For instance, the Sakai Ri Institute of Chemistry has successfully extracted pure food fibre from bean dregs and processed it into edible packaging paper. This edible paper is primarily used for the inner packaging of food and disposable beverage cups, significantly reducing environmental pollution and waste. Another notable stride towards sustainable packaging is the development of foam paper as a replacement for foamed plastic. This environmentally friendly alternative was pioneered by the German Bremen Paspa (PSP) Company. The production process of foam paper is not only simpler than that of foamed plastic but also minimises resource waste. It uses old scrap paper and flour as raw materials, thus reducing environmental pollution. Importantly, foam paper production is economically advantageous, being about 10% cheaper than producing the same amount of packaging materials using foamed plastic (Huang, J., 2017) .

Biodegradable plastics have also entered the market, offering an eco-friendly alternative to conventional plastics. These biodegradable plastics are made from renewable sources such as corn, sugar beets, and other agricultural materials. They have the potential to replace traditional plastics in various applications, effectively reducing environmental impact and energy consumption (Davis, G. and Song, J.H., 2006).

Fig. 2: Classifications of Polymers

Advances in nanocomposites have shown great potential in enhancing the quality and properties of biodegradable packaging materials, particularly in terms of heat resistance, gas barrier properties, and mechanical characteristics. By incorporating natural antioxidants and antimicrobial agents into polymeric matrices, these materials can extend shelf life and improve the quality of packaged food. Recent advances in nanotechnology have given rise to antimicrobial packaging to combat food spoilage and losses, demonstrating the continued progress in sustainable packaging (Thulasi Singh, A. et al., 2021).

Another facet of sustainable packaging is the utilisation of natural green packaging materials, sourced from renewable resources such as bamboo, wood, hemp, and crop straws. These materials are eco-friendly alternatives that do not contribute to pollution. They are characterised by less energy-intensive processing, quick recyclability, and minimal waste. Moreover, sustainable packaging doesn't only encompass the materials used but also focuses on efficient resource utilisation in the printing and packaging industry. Reducing waste and maximising efficiency is critical in this endeavour. High-performance printing processes suitable for mass production, such as high-speed gravure processes, can be taken to increase efficiency. The promotion of digital printing technology, characterised by reduced environmental impact and efficiency, has been a key area of focus. (Qu, Z.C., 2013)

Cellulose nanofibers have emerged as a remarkable material for enhancing the mechanical and barrier properties of cellulosic fibre-based products, including papers and biocomposites. These nanofibers, derived from natural resources like wood or plants, are considered nearly inexhaustible, renewable, and globally abundant. Their utilisation in packaging offers significant benefits, enhancing properties such as biodegradability, transparency, gas barrier, specific surface area, and heat stability. The application of cellulose nanofibers in packaging not only benefits the environment but also minimises packaging costs and waste. An effective design process is essential for producing innovative and sustainable packaging materials. This process involves collaboration among scientists, designers, and engineers to address existing packaging issues and define the best manufacturing processes and technologies (Abdul Khalil, H.P.S. et al., 2016).

Table 1: Lignocelluloses fibres utilised in packaging of food and non-food materials

Cellulosic	Application
Cotton	Food packaging
Wood Pulp	Food packaging
Sago Starch	Pharmaceutical and Industrial Applications
Sterculia Uren	Food and medical applications
Wools	Agricultural Packaging
Cassava	Food packaging
Corn	Food packaging
Rice Straw	Industrial and Food Packaging
Sweet Potato	Food packaging
Mulberry	Food packaging
Wheat	Industrial Packaging

Furthermore, a new class of materials known as biomass-fungi composite materials has been reported. These materials, created through the growth of interconnecting fibrous filaments of fungi, provide an innovative approach to binding biomass materials. This method offers the potential for 3D printing, facilitating the manufacturing of complex shapes that are challenging to achieve using conventional moulding-based methods (Bhardwaj, A. et al., 2020).

V. SUSTAINABLE PRINTING ECO SYSTEM

In the printing and packaging industry, there is a growing emphasis on using non-fossil-based, fully renewable printing substrates. Raw materials used for paper and cardboard production must be sourced from sustainably managed industrial forests, with alternative renewable natural fibre sources also being considered. Even agro-food industry waste materials can be used for cellulosic pulp production. Forests with commercial and cultural tree species must be protected. Documentation of the fibre source is essential to ensure that the world's forest products are used correctly, and environmental inks and recycled papers should be preferred in line with social responsibility and environmental awareness (Aydemir, C., Yenidogan, S., and Tutak, D., 2023).

Understanding the composition of inks is crucial for developing alternatives that use renewable resources. All printing inks are composed of four main ingredients: colourant, vehicle or binder, solvent, and additives. Pigments and dyes are used as colourants, with pigments being the preferred choice in the printing process. Binders serve to disperse pigments in the support material and bind them to the printing stock, while solvents are employed to adjust ink viscosity for different printing processes. Lastly, additives are used to enhance various ink properties. In the realm of inks used for packaging materials, there has been a notable shift towards sustainability. A growing number of inks now partially consist of renewable resources. This shift aligns with efforts to reduce dependence on petrochemical resources and lessen the environmental impact. Water-based and UV-curing inks have gained popularity due to their ability to reduce solvent use, thus leading to lower volatile organic compound (VOC) emissions (Robert, T., 2015).

Table 2: Range of commercially available printing inks based renewable material

Brand Name	Company	Renewable Percentage
K+E Arrowstar, Starbase	Flint Group	Soy Based Binder (100% renewable)
SunLit Diamond	Sun Chemical	100% Vegetable Oil
Reflecta, Quickfast	Huber Group	80% renewable vegetable oil
Sicura Eco	Siegwerk	50% Renewable
Eco Set Series	American Offset printing ink	Vegetable Based, > 24% renewable

In summary, the quest for sustainable packaging solutions is driven by the urgent need to reduce environmental impact and promote responsible practices in the printing and packaging industry.

This evolution encompasses a range of innovative materials and approaches, with a common goal of minimising waste, reducing pollution, and conserving resources. It's a dynamic and ongoing journey toward a more eco-friendly future for packaging.

VI. SMART PACKAGING

Smart or intelligent packaging is an innovative development in food packaging. It senses environmental and content changes and communicates them, making it valuable in various applications. This packaging uses minimal material while fulfilling essential functions like product protection, quality preservation, security, and distribution. It's ideal for applications where close monitoring and control are needed (Lee & Xu, 2005). Intelligent packaging enhances standard communication functions by measuring and communicating specific product properties, internal conditions, and external factors. It offers significant potential to enhance safety, quality, traceability, and consumer interaction with products (Machiels, J. et al., 2021).

Active packaging is typically initiated by a specific event, such as when a package is filled, pressure is released, or it's exposed to UV light. A prime example of active packaging is the innovative foam-producing 'widget' in a metal beer can, which enhances the consumer experience.

Radio frequency identification (RFID) technology has been of particular interest in intelligent packaging, providing enhanced capabilities for monitoring, detecting, sensing, recording, tracking, and communicating product information. Integrating screen-printed antennas and RFID chips in reusable cardboard packaging offers a sustainable and cost-efficient solution (Machiels, J. et al., 2021).

Recycling information can be integrated into intelligent packaging, aiding recyclers in more effective material sorting. The future of intelligent packaging might involve RFID technology for tracking. For example, Rawlplug, a UK hardware manufacturer, uses specialized equipment and software to monitor plastic bags for compliance with packaging waste regulations. Anticipated advancements in packaging technology aim to reduce CO2 emissions associated with transport packaging by about 40%. This projection doesn't consider potential improvements in energy efficiency during material production or changes in packaging demand. Using lighter or alternative materials can reduce CO2 emissions related to transport packaging by up to 12%. If these solutions are designed for reusability, an additional 16% reduction in CO2 emissions can be expected. Intelligent packaging technology has the potential to significantly enhance sustainability in packaging practices (Lee, S.G. and Xu, X., 2005).

VII. ECONOMIC AND OPERATIONAL ASPECTS

The global challenge of waste management has led to the development of numerous waste disposal and management programs, driven by government regulations aimed at reducing waste production. Businesses are adapting to these changes by adopting eco-friendly practices, particularly in response to evolving consumer preferences, especially in the e-commerce sector. E-commerce, in particular, has a keen interest in reducing packaging waste. This transformation towards sustainability is motivated by environmental concerns and strategic orientation within organisations, which involves using strategies to adapt and align with a more favourable environment, ultimately influencing business profitability and decision-making.

Green supply chain management (GSCM) plays a crucial role in these environmentally conscious efforts. GSCM encompasses green procurement, green manufacturing, and reverse logistics, aiming to minimise the environmental impact at each stage of the product life cycle (James, F. and Kurian, A., 2021).

Government regulations have been instrumental in compelling businesses to embrace green practices, covering various aspects like packaging, manufacturing, and logistics. Collaborating with suppliers and transitioning supply chains into green supply chains is essential for promoting environmental awareness. The role of packaging extends beyond protecting products; it is also integral to marketing. Effective packaging must attract buyers, convey messages, and enhance product desirability while optimising logistics and productivity as shown in fig-3. Eco-friendly packaging solutions include minimising packaging, using recyclable materials, and adopting biodegradable alternatives. The evaluation of current packaging systems takes into account the rise of e-commerce, the need for convenience, and the pressure to reduce waste and pollution (James, F. and Kurian, A., 2021).

Fig 3: Optimum packaging

The volume of shipped products has surged with the growth of e-commerce. Consequently, sustainability in logistics has emerged as a valuable tool for creating brand value and attracting a talented workforce, thereby boosting financial capabilities and innovation. Technology, such as 3D scanning and collaborative robots, has improved packaging optimization.

The replacement of plastic shrink wrap with alternatives like fibre-reinforced stretch films and biodegradable materials has become a notable trend. Closed loop logistics offers a sustainable solution for supply chains, even within the e-commerce sector (James, F. and Kurian, A., 2021). The closed loop model, as demonstrated by companies like RePack, encourages customers to return empty packaging, promoting recycling and reuse as given in figure 4.

Fig 4: Closed Loop Packaging in E-commerce, Source: DHL

Packaging's close connection with supply chains profoundly impacts the environment and cost efficiencies, from design to disposal (Morashti, J., An, Y., and Jang, H., 2022). Packaging and sustainability have a complex relationship. While essential for product protection and distribution, packaging often falls short of sustainability expectations due to its short lifespan compared to production energy.

The COVID-19 pandemic significantly affected the packaging industry, leading to increased demand for single-use products and excessive packaging waste. Industries face growing pressure to adopt sustainable packaging initiatives, aligning with Circular Economy (CE) and 4R principles (reuse, reduce, recycle, renew). Non-degradable plastic packaging in the environment poses a notable challenge (Morashti, J., An, Y., and Jang, H., 2022).

Businesses and organizations set goals to adopt sustainable practices and invest in packaging optimization to meet consumer demands. Sustainable packaging should use responsibly sourced materials with potential for resource recovery through recycling or compostable properties. Social and economic principles must align with sustainability guidelines (Morashti, J., An, Y., and Jang, H., 2022).

In the context of business strategies, understanding the eco-costs of a product is becoming increasingly important Companies are under societal pressure to internalize their products' external environmental damage, often by integrating these costs into pricing through taxes, tradable emission rights, regulations, or advanced technologies. While it poses challenges, it also presents opportunities for proactive strategies. Products with lower eco-costs can gain a competitive advantage, but businesses should also consider factors like the quality-cost ratio and the customer-perceived value, which is the price a customer is willing to pay. This customer-perceived value should align with the market price in a competitive market. Balancing eco-costs, quality, and value is essential for a comprehensive business strategy (Wever, R. and Vogtländer, J., 2012) as shown in figure 5.

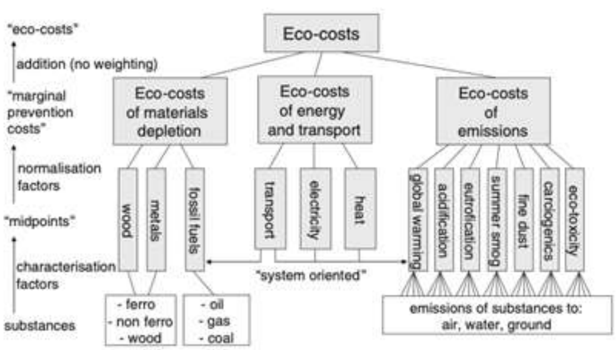

Fig. 5: Calculation structure of Eco-costs

VIII. CONSUMER BEHAVIOUR

Consumer understanding of sustainable packaging is often limited, leading to misconceptions. Despite detailed life-cycle assessments (LCAs) revealing packaging's environmental impact, consumers rely on personal beliefs that may not prioritise sustainability in their choices. This gap between beliefs and LCA results poses challenges for sustainable development (Steenis, N.D. et al., 2017).

Packaging influences brand image, product perception, and purchase intent. Consumers favour eco-friendly packaging and associate non-recyclable plastic packaging with negative product perceptions. Attitudes toward sustainable packaging strongly correlate with purchase intent. Factors like ease of use, willingness to pay, environmental concern, and attitude influence this intent. The shift toward sustainable packaging is driven by consumer preferences, regulation, e-commerce, and economics. However, challenges like inefficient packaging and waste management require supply chain collaboration (James, F. and Kurian, A., 2021).

Consumers are increasingly aware of wasteful e-commerce packaging, especially in fashion. Innovative approaches are needed to optimise packaging while maintaining product protection. Indian consumers show a growing environmental concern and willingness to pay for sustainable packaging, even from lesser-known brands (James, F. and Kurian, A., 2021).

The Theory of Reasoned Action (TRA) predicts consumer behaviour in green marketing. Environmental concern influences intentions, but trade-offs may be required, leading to an "attitude-behaviour" gap. Economic, socio-economic, or demographic factors can override sustainability preferences. Despite these challenges, category-wide shifts toward sustainable packaging are an effective but complex strategy (Boz, Z., Korhonen, V., and Koelsch Sand, C., 2020)

IX. CONCLUSION

The quest for sustainable packaging is complex and multifaceted, driven by evolving definitions and an ever-changing landscape. Sustainability in packaging is now defined by comprehensive principles that encompass environmental, social, and economic considerations.

To assess sustainability in product and packaging life cycles, various methodologies like Life Cycle Assessment (LCA) and Material Circularity Indicator (MCI) provide distinct vantage points for evaluation. Innovative design processes, integrating technical, supply chain, and environmental approaches, are essential. They optimize materials, minimize waste, and reduce environmental impacts, while sustainable materials like biodegradable options and nanocomposites enhance quality and properties.

Smart packaging and intelligent solutions are vital for product monitoring and safety. Economic and operational aspects are deeply intertwined with sustainability efforts, reflecting the global challenge of waste management and the shift toward green supply chain management.

Consumer behavior plays a pivotal role, though misconceptions and limited understanding exist. Still, consumer preferences, attitudes, and environmental concerns influence purchase intent. The shift toward sustainable packaging is driven by consumer demand, regulation, and economic considerations, especially in e-commerce.

In summary, the journey toward sustainable packaging involves collaboration, considers multiple dimensions, and seeks to bridge the gap between consumer beliefs and life-cycle assessments. It's a multifaceted endeavor propelled by environmental responsibility, consumer demand, and economic opportunities, all aimed at creating a more eco-friendly and responsible future for packaging practices.

REFERENCES

1. Abdul Khalil, H.P.S. et al. (2016) 'A review on nanocellulosic fibres as new material for sustainable packaging: Process and applications', Renewable and Sustainable Energy Reviews, 64, pp. 823–836. doi:10.1016/j.rser.2016.06.072.
2. Aydemir, C., Yenidogan, S. and Tutak, D. (2023) 'Sustainability in the print and packaging industry', Cellulose Chemistry and Technology, 57(5–6), pp. 565–577. doi:10.35812/cellulosechemtechnol.2023.57.51.
3. Bhardwaj, A. et al. (2020) '3D printing of biomass-fungi composite material: A preliminary study', Manufacturing Letters, 24, pp. 96–99. doi:10.1016/j.mfglet.2020.04.005.
4. Boz, Z., Korhonen, V. and Koelsch Sand, C. (2020) 'Consumer considerations for the implementation of sustainable packaging: A Review', Sustainability, 12(6), p. 2192. doi:10.3390/su12062192.
5. Davis, G. and Song, J.H. (2006) 'Biodegradable packaging based on raw materials from crops and their impact on waste management', Industrial Crops and Products, 23(2), pp. 147–161. doi:10.1016/j.indcrop.2005.05.004.
6. Dominic, C.A.S. et al. (2014) 'Towards a conceptual sustainable packaging development model: A corrugated box case study', Packaging Technology and Science, 28(5), pp. 397–413. doi:10.1002/pts.2113.
7. Huang, C. and Ma, H. (2004) 'A multidimensional environmental evaluation of Packaging Materials', Science of The Total Environment, 324(1–3), pp. 161–172. doi:10.1016/j.scitotenv.2003.10.039.
8. Huang, J. (2017) 'Sustainable development of green paper packaging', Environment and Pollution, 6(2), p. 1. doi:10.5539/ep.v6n2p1.
9. James, F. and Kurian, A. (2021) 'Sustainable Packaging: A Study on Consumer Perception on Sustainable Packaging Options in E-Commerce Industry', Natural Volatile and Essential Oils, 8(5).
10. Lee, S.G. and Xu, X. (2005) 'Design for the environment: Life cycle assessment and sustainable packaging issues', International Journal of Environmental Technology and Management, 5(1), p. 14. doi:10.1504/ijetm.2005.006505.
11. Machiels, J. et al. (2021) 'Screen printed antennas on fiber-based substrates for sustainable HF RFID assisted E-Fulfilment Smart Packaging', Materials, 14(19), p. 5500. doi:10.3390/ma14195500.
12. Morashti, J., An, Y. and Jang, H. (2022) 'A systematic literature review of sustainable packaging in Supply Chain Management', Sustainability, 14(9), p. 4921. doi:10.3390/su14094921.
13. Niero, M. and Hauschild, M.Z. (2017) 'Closing the loop for packaging: Finding a framework to Operationalize Circular Economy Strategies', Procedia CIRP, 61, pp. 685–690. doi:10.1016/j.procir.2016.11.209.
14. Qu, Z.C. (2013) 'Innovation in low Carbon Printing & Packaging', Applied Mechanics and

Materials, 423–426, pp. 2257–2260. doi:10.4028/www.scientific.net/amm.423-426.2257.
15. Robert, T. (2015) "Green ink in all colors"—printing ink from renewable resources', Progress in Organic Coatings, 78, pp. 287–292. doi:10.1016/j.porgcoat.2014.08.007.
16. Steenis, N.D. et al. (2017) 'Consumer response to packaging design: The role of packaging materials and graphics in sustainability perceptions and product evaluations', Journal of Cleaner Production, 162, pp. 286–298. doi:10.1016/j.jclepro.2017.06.036.
17. Svanes, E. et al. (2010) 'Sustainable Packaging Design: A holistic methodology for packaging design', Packaging Technology and Science, 23(3), pp. 161–175. doi:10.1002/pts.887.
18. Thulasisingh, A. et al. (2021) 'Biodegradable packaging materials', Polymer Bulletin, 79(7), pp. 4467–4496. doi:10.1007/s00289-021-03767-x.
19. Wever, R. and Vogtländer, J. (2012) 'Eco-Efficient value creation: An alternative perspective on packaging and Sustainability', Packaging Technology and Science, 26(4), pp. 229–248. doi:10.1002/pts.1978.