SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2025
ORGANIZATION AND MANAGEMENT SERIES NO. 230

FOOD PACKAGING EVOLUTION IN THE CONTEXT OF ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY

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Purpose: This scientific study investigates the transformation of food packaging systems over time with a focus on ecological implications. By tracing the evolution from traditional biodegradable materials to synthetic polymers and back toward eco-friendly innovations, the study identifies key environmental challenges and sustainable packaging trends shaping modern food systems.

Design/methodology/approach: The research applies a multidisciplinary approach combining historical review, environmental impact assessment, and market trend analysis. It utilizes data from Statista, FAOSTAT, and EU environmental agencies (2010-2023) to evaluate material flows, carbon footprints, and policy shifts affecting packaging choices.

Findings: Modern food packaging has moved from convenience-driven plastic dominance to sustainability-centered innovation. Compostable biopolymers, edible films, and smart packaging solutions now gain traction. Consumer awareness and EU regulations have driven demand for circular economy-based models. Despite progress, challenges remain in scalability, waste management infrastructure, and cost competitiveness.

Research limitations/implications: This study is based on secondary data and literature, which may be subject to reporting biases and variations in methodological quality. Differences in life-cycle assessment boundaries, geographic contexts, and timeframes limit direct comparability between sources. Market figures are projections and may change due to economic fluctuations, policy shifts, or technological breakthroughs. Future research should incorporate primary data collection, harmonised LCA methodologies, and region-specific analyses to validate and refine the findings.

Originality/value: The study provides a comparative framework for understanding the ecological consequences of different packaging materials. It highlights the crucial role of innovation, consumer behaviore, and policy in transitioning to sustainable packaging systems. These results could be especially interesting for researchers whose studies are interdisciplinary.

Keywords: eco-packaging, sustainable development, food industry, plastic alternatives, circular economy.

Category of the paper: Research paper.

JEL: Q56, O13, A10, D62.

http://dx.doi.org/10.29119/1641-3466.2025.230.36

1. Introduction

Food packaging plays a pivotal role in modern supply chains – extending shelf life, ensuring food safety, and enabling global distribution. However, its evolution reflects a tension between functionality and environmental responsibility. From clay pots and leaves to multilayer plastic films and aluminum composites, packaging materials have transformed dramatically.

Today, food packaging is under scrutiny for its contribution to plastic pollution, carbon emissions, and resource consumption. The European Union's "Green Deal" and "Circular Economy Action Plan" have accelerated the shift toward sustainable packaging systems. This article explores this evolution and evaluates the ecological footprint of various packaging types.

Food packaging sits at the intersection of public health, supply-chain efficiency, consumer preference, and environmental stewardship. Over the past century packaging has shifted from simple, often reusable materials (glass, metal, wood) to single-use polymeric materials that enabled dramatic improvements in food safety, shelf life, and transport efficiency. This same shift, however, created large-scale waste-management and environmental challenges. In response, researchers, industry and policymakers are re-evaluating packaging solutions through the twin lenses of environmental sustainability (including circular economy principles and lifecycle impacts) and economic sustainability (costs across the supply chain, affordability, and market feasibility). This review synthesises major themes and findings in the literature on the historical evolution of food packaging, the environmental and economic trade-offs among material choices, methodological approaches used to evaluate those trade-offs, policy and market drivers shaping transitions, and promising technological and systemic innovations.

The historical literature frames packaging evolution as a sequence of technological advances responding to industrialisation, urbanisation and global trade. Early packaging – plant leaves, woven fibers, ceramic vessels, and wooden crates – was local, low-tech and often reusable. With industrialisation came glass, tinplate and paperboard, which combined preservation, stackability and mechanical protection. The mid-20th century plastic revolution (polyethylene, polypropylene, PET, PVC) introduced lightweight, low-cost, highly adaptable packages and transformed logistics by reducing breakage and transport energy per unit of product.

Academic accounts emphasise that plastics solved critical economic and functional problems – reduced weight, improved barrier properties, flexibility, and economies of scale – thereby lowering food spoilage and enabling longer supply chains. However, by the late 20th and early 21st centuries, the environmental externalities of persistent polymer waste, litter, microplastics, and resource dependence led to intense scrutiny and the search for alternatives and systemic responses.

R. Geyer, J. Jambeck, and K. Law estimated the total amount of plastics ever produced (8.3 billion metric tonnes), highlighting that packaging is the dominant application sector. The authors demonstrate that the vast majority of plastic waste is landfilled or leaked into the environment, with only 9% recycled. Their analysis underscores that environmental sustainability of packaging requires a systemic approach, integrating material reduction, design for reuse/recycling, and infrastructure development (Geyer, Jambeck, Law, 2017). K. Marsh and B. Bugusu examine the functions of food packaging – protection, preservation, convenience, and communication – and link these to environmental and economic trade-offs. They emphasise functional-unit-based comparisons in LCA, warning against misleading conclusions based solely on material mass. The review also notes that while plastics offer superior performance in many applications, they pose significant end-of-life challenges (Marsh, Bugusu, 2007).

V. Siracusa et al. provide a comprehensive overview of biodegradable polymers for food packaging. The authors discuss PLA, PHA, starch-based and protein-based materials, analysing their physical properties, processing feasibility, and biodegradation profiles. They conclude that while bio-based packaging can reduce fossil-resource use, environmental benefits depend on production practices, composting infrastructure, and avoidance of food–fuel conflicts (Siracusa, et al., 2008). S. Spierling and colleagues conduct a meta-analysis of LCAs on bio-based plastics, focusing on environmental impact categories including GWP, eutrophication, and land use. Their findings reveal substantial variability in environmental performance, largely due to differences in feedstock, system boundaries, and assumed end-of-life scenarios. This variability calls for transparent and harmonised LCA methodologies (Spierling et al., 2018).

Ellen MacArthur Foundation (2016) in The New Plastics Economy report, the EMF frames packaging transformation through circular economy principles: eliminate problematic plastics, innovate for reuse (recyclability), and circulate materials effectively. The report integrates economic and environmental arguments, modelling the potential for $2-3 trillion in economic benefits globally if circularity principles are applied to plastics. So, EMF operationalised circular-economy principles for packaging: (1) eliminate problematic plastics, (2) innovate to ensure reuse/repair/recycling, and (3) circulate materials through effective collection and recycling. EMF places strong emphasis on design-for-circularity, industry collaboration, and policy-business instruments (e.g., EPR) to scale systemic change (Ellen MacArthur Foundation, 2016).

The purpose of this study is to investigate the transformation of food packaging systems over time with a focus on ecological implications. By tracing the evolution from traditional biodegradable materials to synthetic polymers and back toward eco-friendly innovations, the study identifies key environmental challenges and sustainable packaging trends shaping modern food systems.

2. Theoretical framework and methodology

This study adopts a mixed-methods research design, combining a systematic literature review (SLR) with comparative life-cycle assessment (LCA) meta-analysis and qualitative policy analysis. The methodological framework is grounded in sustainability science, integrating environmental, economic, and socio-technical perspectives to produce a holistic assessment of the evolution of food packaging. The aim is to synthesise existing empirical evidence, identify methodological convergences and divergences in prior studies, and develop context-sensitive recommendations for industry and policymakers.

The investigation is anchored in the Triple Bottom Line (TBL) paradigm, which evaluates sustainability across environmental (planet), economic (profit), and social (people) dimensions. Environmental performance is interpreted through the lens of circular economy principles, while economic viability is examined using total cost of ownership and externality internalisation models. Social aspects – although not the primary focus – are considered in terms of consumer acceptance and behavioural feasibility.

The study focuses on primary food packaging for perishable and non-perishable products, excluding tertiary (logistics) packaging unless explicitly linked to environmental or economic trade-offs. Geographical coverage includes global literature with emphasis on European Union, North America, and selected emerging economies, recognising the contextual dependence of both environmental and economic outcomes. The temporal scope captures literature from 2000 to 2024, a period marked by accelerated innovation in sustainable materials and regulatory activity.

Quantitative synthesis was conducted on a subset of LCA studies that met comparability thresholds (aligned functional units, declared system boundaries, and compatible impact categories). Environmental indicators extracted included: Global Warming Potential (GWP, kg CO_2-eq); Cumulative Energy Demand (CED, MJ); Water footprint (m^3); Eutrophication potential (g PO_4^{3-}-eq); Recyclability and material recovery rates (%).

Economic indicators included unit packaging cost, transport cost implications (linked to mass and volume), and end-of-life management costs (collection, recycling, composting). Statistical aggregation applied random-effects modelling to account for inter-study heterogeneity.

A thematic analysis was performed on policy documents, industry roadmaps, and NGO reports to identify regulatory trends and market drivers influencing packaging evolution. Documents from the European Union, North America, and selected emerging markets were coded using NVivo software under categories: regulatory constraints, economic incentives, voluntary industry commitments, and infrastructure capacity.

Findings from the SLR, meta-analysis, and policy analysis were triangulated to strengthen internal validity. Cross-verification ensured that environmental and economic conclusions were consistent across methods and data sources. Sensitivity analysis tested the robustness of conclusions under different recycling rate assumptions and end-of-life scenarios.

Although the study is based on secondary data, academic integrity was maintained through accurate citation of all sources, transparent reporting of inclusion/exclusion criteria, and avoidance of selective reporting. Where institutional reports were used, provenance and potential biases (e.g., industry funding) were critically noted. So, historical analysis of packaging materials and technologies (1950-2023); Life Cycle Assessments (LCAs) comparing plastics, glass, paper, bioplastics, and aluminium; market research on sustainable packaging growth and consumer trends; policy review of EU directives on single-use plastics and eco-design standards were examined.

3. An overview of the literature

Scholars from multiple disciplines have framed the evolution of food packaging as a systemic challenge that balances functional performance, environmental burden and economic viability. The authors have summarised leading viewpoints and key works that shaped debate and research. The seminal work of Roland Geyer, Jenna R. Jambeck & Kara Lavender Law quantifies global plastic production and the cumulative fate of plastic waste, showing packaging as the single largest sector in plastic demand. The authors argue that technical improvements alone (e.g., higher recycling rates) will be insufficient without systemic shifts in design, consumption patterns and waste-management infrastructure. They foreground the magnitude of existing in-use plastic stocks and call for integrated solutions combining reduction, reuse, and improved circularity (Geyer, Jambeck, Law, 2017).

J.Jambeck et al. quantify mismanaged plastic waste entering marine systems and highlight the governance and infrastructure gaps – particularly in rapidly urbanising coastal regions. Their work catalysed policy attention on collection, proper disposal, and upstream reduction of single-use packaging (Jambeck, Law, 2015).

R.C. Thompson, et al. early papers on microplastics in marine ecosystems (2004-2010) provided important early evidence that microplastic pollution is pervasive and raises ecological and potential human-health concerns. Their research reframed single-use plastics not only as waste-management problems but as long-term contaminant issues, motivating research on packaging materials' fragmentation and persistence (Thompson et al., 2004).

Widely-cited review of K. Marsh and B. Bugusu links packaging functionality (barrier properties, mechanical protection, shelf-life) with environmental trade-offs. Marsh & Bugusu stress that decisions must be functional-unit driven: comparing materials per unit of food preserved, not per unit mass of packaging. They also highlight technological trade-offs (e.g., multi-layer laminates improve performance but impede recyclability) (Marsh, Bugusu, 2007).

V. Siracusa, P. Rocculi, S. Romani, Dalla Rosa review bio-based and biodegradable polymers, concluding that while these materials offer promise to reduce reliance on fossil resources, their environmental advantage depends on feedstock cultivation impacts, production energy, and end-of-life options (industrial composting vs. landfill). They emphasise rigorous LCA comparison and realistic scalability assessments (Siracusa, Rocculi, Romani, Dalla Rosa, 2008).

Research by various authors argue that technological innovations (time-temperature indicators, gas sensors, antimicrobial films) can reduce food loss – which often yields greater environmental returns than marginal improvements in packaging material alone. They stress techno-economic assessments to determine where such innovations are cost-effective (Yakymchuk, Valyukh et al., 2020). Economists highlight market failures-unpriced external costs of pollution and waste – and advocate for policy mixes (EPR, deposit-refund systems, recycled-content mandates) that alter producer incentives, drive eco-design, and finance collection/recycling infrastructure (European Parliament, 2021).

Leading scholars converge on the idea that packaging sustainability is a system problem requiring design, infrastructure, policy and behaviour change – not merely material substitution. Comparative LCA must normalise by food preserved or spoilage avoided; packaging that reduces food waste can yield net environmental benefits even if material impacts are higher (Grainger et al., 2017). Many researchers (and EMF) prioritise mono-materials, recyclability, and reuse/refill systems as high-leverage strategies. Outcomes vary by geography – local waste-management infrastructure, energy mixes, and consumer behaviour decisively shape which interventions succeed. Robust, real-world LCA data for emerging materials, integrated food-waste/packaging models, and empirical studies on consumer behaviour and policy impacts (Yakymchuk, Halachenko, Irtyshcheva et al., 2021).

Contemporary literature typically clusters packaging materials into several classes – conventional fossil-based plastics, glass and metal, paperboard and fibre-based materials, and bio-based/biodegradable materials – and analyses their environmental and economic performance across functional metrics. Fossil-derived plastics (e.g., PET, HDPE, LDPE, PP) remain dominant due to low unit cost, light weight and resistance to breakage. Life cycle assessment (LCA) studies repeatedly show that, per unit mass, plastics can exhibit lower greenhouse gas emissions during transport compared with heavier alternatives such as glass. Nevertheless, the end-of-life impacts of mismanaged plastics – marine pollution, persistence in landfills, microplastic formation – raise long-term environmental concerns. Literature stresses that the overall footprint of plastics hinges on recycling rates, product design for recyclability and the existence of collection/sorting systems (Grainger et al., 2017).

Glass and metals (aluminium, steel/tinplate) score highly on material circularity: they are technically infinitely recyclable without loss of quality. However, they are energy-intensive to manufacture (particularly primary aluminium) and heavier, which can increase transport emissions. Economic analyses often show that in contexts where high recycling rates exist, metals and glass can perform well environmentally. Yet their suitability varies by product: fragile products or premium packaging may justify glass, while beverage cans align well with aluminium's lightness relative to glass and high recyclability (Yakymchuk, Valyukh, Poliakova, Skorokhod, Sak, 2023).

Paperboard and paper-based containers are renewable and readily recycled in many systems, and are often perceived favourably by consumers. However, achieving necessary barrier properties for many foods (moisture, oxygen, grease) commonly requires polymer or metallic coatings or laminates. Such multilayer constructions complicate recycling and may reduce environmental advantages. Additionally, pulp production has water- and chemical-use impacts that must be managed through sustainable forestry and modern pulping technologies (Agriculture and Food Security in Ukraine, 2023).

Bio-based polymers (PLA, PHA), edible films, and compostable blends have attracted strong academic and industry interest as potential substitutes for conventional plastics. Literature identifies several strengths-lower reliance on fossil feedstocks and potential biodegradability under suitable conditions – but also caveats: many require industrial composting conditions to degrade, may compete with food crops for land use if scaled without care, and currently incur higher production costs and limited material property parity for demanding barrier applications. Life cycle studies emphasise that the environmental advantage of bio-based materials is highly contingent on feedstock source, fertiliser and land-use change impacts, and end-of-life treatment (European Food Safety Authority, 2021).

4. Results of the investigation

The dominant methodological approach in the literature is life cycle assessment (LCA), which compares environmental impacts from "cradle to grave" (or cradle-to-cradle). LCA enables quantification of greenhouse gas emissions, energy use, water footprint, eutrophication potential and other impact categories for packaging options. Key findings across meta-analyses and comparative LCAs include (Canali et al., 2019):

- functional equivalence matters – comparisons must normalise to the same functional unit (e.g., protection of a defined quantity of food over a specific shelf life), because lighter packaging that reduces food waste often yields lower overall impacts even if the material itself is carbon-intensive;

- system boundaries and assumptions drive outcomes – differences in recycling rates, transport distances, and end-of-life fates can reverse apparent advantages between materials;
- multiple impact categories must be considered – solutions that lower greenhouse gas emissions may increase water use, land use or eutrophication-trade-offs require multi-criteria assessment;
- the role of food waste is critical – better packaging that reduces spoilage and food loss can deliver net environmental benefits that outweigh raw-material impacts.

The literature also points to complementary tools such as material flow analysis, techno-economic assessment, and social life cycle assessment (S-LCA) to incorporate economic and social dimensions often omitted from conventional LCA. Economic analyses in the literature examine not only material costs but total cost of ownership across the supply chain. Important themes include (Vermeulen, Campbell, Ingram, 2012):

- upfront versus downstream costs – lightweight plastics often reduce transport and handling costs but may create higher waste-management expenses borne by municipalities or taxpayers;
- externalities and market failures – environmental externalities of packaging (pollution, climate impacts) are rarely fully priced into product costs, creating market incentives favouring cheap, single-use formats. Studies suggest that instruments such as extended producer responsibility (EPR), deposit-return systems, eco-taxes, or subsidies for recycling can realign incentives;
- economies of scale for alternatives – many bio-based or improved-recyclability designs remain more expensive at present; literature models sensitivity scenarios where costs fall with scale and policy support;
- consumer willingness to pay – behavioral and market research indicates heterogeneous consumer preferences: while many consumers express willingness to pay a premium for sustainable packaging, revealed behavior shows price sensitivity and trade-offs with convenience-implying that broader adoption requires cost-competitive solutions and clear, trustworthy labelling.

Policy research identifies regulatory frameworks as decisive levers. Examples commonly discussed include prohibitions or limits on single-use plastics, mandated recycled content, EPR schemes, landfill taxes, and support for circular-economy infrastructure. The literature stresses that effective policy mixes couple product standards (eco-design and recyclability requirements) with investments in collection and recycling infrastructure and consumer information campaigns. Comparative studies underscore that outcomes depend on national and local governance capacity: policies that work in well-developed waste-management systems may underperform where infrastructure is weak.

Industry responses-voluntary pledges, design-for-recycling commitments, and partnerships with waste management firms – are also analysed. Corporate and supply-chain pressures (e.g., retailer packaging targets) can accelerate change, but researchers caution against greenwashing and advocate for transparent metrics and third-party verification (Hwang et al., 2014; Food packaging market value, 2025).

Research highlights several promising directions:

- design for circularity – mono-material packaging, minimal use of adhesives and inks that complicate recycling, and modular formats that facilitate reuse or refill cycles,
- re-use and refill systems – studies show that for some product categories (e.g., beverages, detergents), reusable packaging systems can deliver lower lifecycle impacts when logistics and consumer behavior support returns and cleaning,
- advanced recycling technologies – chemical recycling and solvent-based depolymerisation can potentially handle mixed or contaminated streams, although energy intensity, scalability, and economics are active research areas,
- active and intelligent packaging – sensors, time-temperature indicators and freshness markers can reduce food waste by enabling better inventory management and more accurate shelf-life assessment; cost and integration challenges are subjects of techno-economic analyses,
- alternative feedstocks and materials science – research on PHA production from waste substrates, nanocellulose barriers, and protein-based films attempts to deliver materials that balance functional performance with environmental benefits (Kherchi, 2020).

A recurrent message is that sustainability outcomes are context-dependent. The same packaging solution may perform differently in systems with high recycling infrastructure versus regions lacking collection and sorting. Similarly, local energy mixes (coal-heavy versus renewables) alter cradle-to-grave impact profiles. Literature focusing on lower- and middle-income countries emphasises the importance of low-cost, locally appropriate solutions, informal waste sectors' role, and the need for capacity-building rather than transplanting high-income country policy models (Cannock, 2011; Bohn et al., 2018).

Key gaps identified across recent reviews include:

- real-world LCA data for emerging materials (particularly long-term studies that incorporate degradation pathways and real-world collection rates),
- integration of food-waste avoidance into packaging assessment-quantitatively linking packaging functions to food preservation and loss reduction across supply chains,
- economics of scaling novel materials-market models that couple policy scenarios (EPR, recycled-content mandates) with supply-chain dynamics to project price trajectories,
- behavioral dimensions-empirical studies on how labelling, deposit schemes, and design affect consumer sorting and return behavior,
- systemic assessments that combine environmental, economic and social indicators to guide policymakers and industry in choosing context-appropriate pathways.

The literature converges on several actionable conclusions. First, material substitution alone will not automatically yield sustainability gains; functional performance, supply-chain impacts and end-of-life management must be considered jointly. Second, design-for-recyclability and reduction of multilayer laminates are high-leverage strategies in contexts with recycling infrastructure. Third, policy instruments that internalise environmental costs (EPR, landfill taxes, recycled-content mandates) can shift market incentives and make sustainable alternatives economically viable. Fourth, preventing food waste is often the single most important leverage point-packaging that reduces spoilage or extends shelf life can produce net environmental benefits even if its material footprint is larger. Finally, transitions will require coordinated action across industry, policymakers and consumers: technological innovation must be matched by investments in collection, sorting, recycling or composting infrastructures and by credible communication to consumers (Yakymchuk, Skomorovskyi, Pokusa, Pokusa, Łukawiecki, 2022).

This study analyzed the sources of fund healthy plant-based nutrition by countries.

Table 1.
Historical Evolution of Food Packaging

Period	Main Packaging Materials	Ecological Profile
Pre-Industrial Era	Leaves, animal skins, clay, glass	Biodegradable, local materials
Industrial Era	Tin cans, glass bottles, early plastics	Durable, but energy-intensive
Post-WWII (1950s)	PET, PVC, aluminum foil	Lightweight, but polluting
2000s–Today	Bioplastics, compostable films, cellulose	Greener, still limited by cost

Source: The data is based on the latest available statistics from FAOSTAT, 2023; Eurostat, 2022; International cooperation, 2021; European Commission, 2021, 12.08.2025.

Although lightweight and cheap, petroleum-based plastics (e.g., PET, HDPE) are major pollutants. Only 9% of all plastics ever produced have been recycled effectively (European Environment Agency, 2020). Microplastics increasingly infiltrate oceans and food chains, posing public health risks. Derived from renewable sources and biodegradable, paper is widely seen as eco-friendly. However, large-scale deforestation and high water usage undermine its sustainability unless sourced from certified forests.

Highly recyclable and chemically inert, glass and aluminum offer durability. Yet, their production is energy-intensive. Glass, in particular, has a high carbon footprint due to melting temperatures exceeding 1500°C. Innovative materials like PLA (polylactic acid), PHA, and edible coatings (e.g., from potato starch or seaweed) show promise. However, they require industrial composting facilities and remain niche due to cost barriers (Food packaging market value, 2025).

The EU generates over 75 million tonnes of packaging waste annually, with food packaging accounting for more than 35% (Eurostat, 2022). Landfill overflow, marine litter, and incineration-related emissions make packaging a central issue in environmental policy.

Table 1.

Average Carbon Footprint of Common Packaging Materials (kg CO_2 per kg of Material)

Material	Average Carbon Footprint (kg CO_2/kg)	Source	Notes / Context
PET plastic	3.2	European Commission, 2021	Common in beverage bottles and food packaging; recyclable but high footprint
Glass	1.5	European Commission, 2021	Heavy, reusable, recyclable; energy-intensive production
Aluminum	10.0	European Commission, 2021	Very high footprint due to mining and refining; highly recyclable
Paper	0.9	FAOSTAT, 2023	Often from renewable sources; recyclable, biodegradable
PLA (bio)	1.1	FAOSTAT, 2023	Biodegradable bioplastic from renewable sources; industrial composting required

Source: European Commission, 2021; FAOSTAT, 2023; Eurostat, 2022.

The data indicate substantial variability in the average carbon footprint among common packaging materials, ranging from 0.9 kg CO_2/kg for paper to 10.0 kg CO_2/kg for aluminum. While aluminum exhibits the highest emissions due to energy-intensive extraction and refining, its recyclability offers potential for significant footprint reduction over multiple life cycles. Biobased PLA and glass present intermediate values, suggesting that material choice in packaging design should balance production emissions, end-of-life management, and functional performance (Food packaging market value, 2025).

We have such a new trends and strategies in sustainable packaging:

- compostable films – used for fruits and baked goods; break down in under 90 days,
- edible packaging – made from protein or carbohydrate-based polymers; reduces waste completely,
- smart packaging – includes sensors to monitor freshness, reducing food waste,
- minimalist design – avoiding multilayer composites that hinder recycling.

Companies like Nestlé and Danone now target 100% recyclable or compostable packaging by 2030. EU directives such as the Single-Use Plastics Directive (2019/904) and the Packaging and Packaging Waste Directive (94/62/EC) have driven reform. Moreover, 71% of EU consumers prefer sustainable packaging, even at a premium (Statista, 2023).

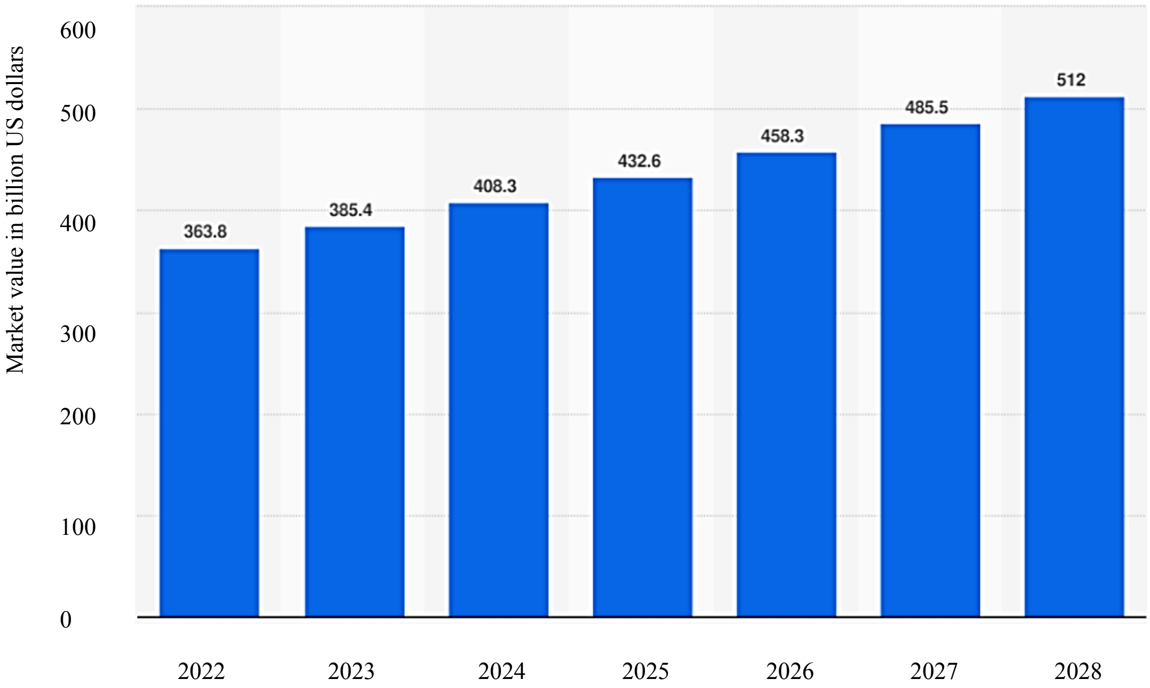

Figure 1. Estimated Growth in the Global Food Packaging Sector, 2022-2028 (USD billions).

Source: constructed by authors based on results of model development and Statista data (2025); FAOSTAT, 2023; Food packaging market value, 2025, 12.08.2025.

According to the data, food packaging encompasses a wide range of materials and formats, including plastic films, aluminum foil, paperboard, metal cans, glass containers, and numerous other solutions (Williams, Patel, 2017; Jones et al., 2017). The global food packaging market is experiencing steady growth and is projected to reach a value of approximately USD 512 billion by 2028. In 2022, the North American market alone was valued at over USD 100 billion, representing a substantial share of global demand.

Within the sector, the food service industry constitutes one of the largest end-use markets. In 2021, the global food service packaging segment was valued at USD 118 billion and is forecast to expand by more than 57 percent by 2030. Other key segments include packaging for dairy and meat products, both of which account for significant proportions of industry output. A notable player in this space is Tetra Pak, a Swiss multinational specialising in sustainable and safe food-packaging solutions, with operations in more than 160 countries. In 2022, Tetra Pak reported global net sales of approximately USD 12.5 billion.

Packaging within the global food system generates roughly one billion metric tonnes of greenhouse gas emissions annually. Although other stages of the food supply chain – such as agricultural production and land use – contribute a greater share of total emissions, packaging remains a focal point for sustainability initiatives aimed at reducing waste. At present, only about 25% of plastic packaging used in the food industry is recyclable, and less than 1% is designed for reuse (Statista, 2025).

The low proportion of recyclable packaging is notable given the substantial consumer interest in sustainable options. Surveys indicate that around half of U.S. consumers would accept a 1-3 percent price premium for sustainable packaging in fresh food products. In the United Kingdom, nearly three-quarters of consumers report a willingness to pay more for compostable packaging (Food packaging market value, 2025).

5. Conclusions

This study highlights that the evolution of food packaging is not merely a linear technological progression but a complex socio-technical transformation shaped by material science, regulatory frameworks, market dynamics, and consumer behaviour. The systematic review and synthesis of literature reveal several overarching conclusions:

1. Systemic nature of sustainability challenges – environmental and economic sustainability in packaging cannot be addressed through material substitution alone; integrated strategies combining design optimisation, infrastructure investment, and behavioural change are required. Critical role of functional performance – packaging's primary function-preserving food quality and reducing waste – often has a larger overall environmental impact than the packaging material itself. Life cycle assessments must therefore normalise impacts to a functional unit that incorporates food preservation outcomes.
2. Design-for-circularity as a high-impact pathway – strategies such as mono-material packaging, modular design, and refill/reuse systems can enhance recyclability and reduce environmental burdens, provided they are supported by appropriate collection and processing infrastructure. Economic viability as an adoption barrier – many sustainable alternatives face higher unit costs and limited economies of scale; policy instruments (e.g., Extended Producer Responsibility, deposit–refund systems, recycled-content mandates) are essential to correct market failures and accelerate uptake. Context-dependent outcomes – the same packaging innovation may produce markedly different environmental and economic results depending on local waste management capabilities, energy mixes, and consumer participation.
3. The authors also identified key research gaps that merit targeted investigation: harmonised LCA methodologies – future studies should apply standardised functional units, system boundaries, and end-of-life scenarios to improve comparability across packaging types and contexts; integration of food-waste prevention metrics – packaging evaluation should explicitly quantify the environmental and economic benefits of reduced food spoilage, especially for perishable goods; techno-economic modelling of scale-up – robust models are needed to assess the cost trajectories of bio-based and

advanced recyclable materials under varying policy and market conditions; real-world performance data for emerging materials – longitudinal studies tracking degradation, recyclability, and consumer acceptance of new materials in operational settings are critical for evidence-based decision-making; behavioural and social dimensions – empirical research should explore consumer willingness to adopt reuse/refill systems, the effectiveness of eco-labelling, and behavioural responses to economic incentives; systems-level policy impact assessment – cross-country comparative studies should evaluate how combinations of regulatory tools, infrastructure investment, and voluntary industry commitments influence both environmental outcomes and economic feasibility.

Future Research. Subsequent studies will focus on the cost-benefit analysis of biodegradable versus conventional packaging in emerging markets. The authors also propose developing a framework for integrating AI-driven waste sorting systems to improve recycling efficiency in food logistics. The evolution of food packaging reflects a continuing balancing act among functional performance, economic constraints, and environmental responsibilities. Contemporary research stresses that moving to sustainable packaging is a systems challenge: it demands careful functional assessments, transparent life-cycle accounting, supportive policy frameworks, and investment in end-of-life systems. Future progress lies less in seeking a single "best" material and more in deploying context-sensitive mixes of design innovation, circular business models (reuse, refill, recycled-content), and governance instruments that internalise environmental costs and scale viable alternatives.

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