Integration of Artificial Intelligence in Biodegradable Plastic Packaging Design: Exploring Stakeholder Attitudes

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ABSTRACT

Biodegradable plastic or biopolymers from renewable resources have attracted growing interest from industries as well as individual consumers as a solution to the environmental problems and limited resources of petroleum-based polymers. This research aims to explore stakeholder attitudes towards the integration of artificial intelligence (AI) in biodegradable plastic packaging design, aiming to address gaps in sustainable packaging innovation. This study engaged 30 principal players, comprising packaging designers, sustainability officers, lawmakers, NGO representatives, and ecologically aware customers. The researchers employed a multi-method qualitative framework, encompassing comprehensive case studies of five organisations at various levels of AI deployment and a phenomenological analysis of stakeholder experiences. The data gathering encompassed semi-structured interviews, focus group discussions, and the analysis of business sustainability reports and policy documents. The results identified three major stakeholder groups: hopeful industrial pragmatists, cautious reformers, and sceptical consumers. Significant obstacles included knowledge disparities between technical and executive teams, regulatory ambiguities, and workforce transfer apprehensions. Consequences for practice include methods for implementing artificial intelligence in stages, open certification systems, and legislative subsidies for ethical innovations.

Keywords: Biodegradable Plastic Packaging, Artificial Intelligence, Stakeholders' Attitude, Packaging Design, Qualitative Research, Sustainable Packaging

INTRODUCTION

Pollution from plastic inflicts considerable environmental harm, with millions of tonnes of non-biodegradable garbage contaminating ecosystems each year (Rosenboom et al., 2022). Potential alternatives, biodegradable polymers, have recently emerged; nevertheless, they confront challenges including inconsistent decomposition rates, high production costs, and effectiveness limits (Wamba-Taguimdje et al., 2020). To improve substance compositions, predict the impact on the environment, and refine production methods, biodegradable package design could be revolutionised by artificial intelligence (AI) (De Meyer et al., 2024). But getting everyone on board and working together is key to an effective implementation. To provide knowledge on how to effectively employ artificial intelligence for eco-friendly packaging alternatives, this study explores stakeholder views on AI-driven biodegradable packaging, namely focusing on potential, difficulties, and regulatory implications.

The packaging business in Bangladesh is grappling with the enormous challenge of striking an appropriate balance between ecological consciousness and economic viability, as the country produces three thousand tonnes of plastic waste per day and only manages to recycle 36% of it (Bhatia et al., 2025). Plastics with single-use characteristics account for about half of Dhaka's municipal waste, making them a major source of both pollution in cities and monsoon floods (Alvarez-Miranda & Pereira, 2024). There are biodegradable alternatives; however, they aren't used much because of issues with efficacy, high costs, and manufacturing flaws. Bangladesh has its own set of problems, such as a lack of technological competence among SMEs,

unclear legislation, and distrustful customers, all of which might be solved by Artificial Intelligence (Kumar et al., 2024). Table 1 shows that Bangladesh's SME-driven, cost-sensitive approach contrasts with the systemic, policy-led strategies of developed economies (Reza et al., 2024).

Table 1: AI in Biodegradable Packaging- Global vs. Bangladesh

Aspect	Global Practices (EU/US/Japan)	Bangladesh Context
Regulatory Standards	Strict EU norms (e.g., EN 13432); tax incentives for R&D	Fragmented enforcement; BSTI lacks AI-specific guidelines
Tech Adoption	AI-powered LCA tools (e.g., Sphera) for material screening	Low-cost optical scanners by local startups (e.g., Packages)
Consumer Trust	High in certified bioplastics (e.g., TÜV Austria labels)	35% trust in AI solutions; rural-urban divides
Ethical Governance	GDPR-compliant data use in AI models	No local AI ethics framework; reliance on global norms

According to Singh and Kalra (2025), using artificial intelligence (AI), this study investigates how individuals in Bangladesh are attempting to design biodegradable packaging that satisfies their cultural and social requirements. By tackling regional concerns such as monsoonal adaptability, limits on small and medium-sized enterprises (SMEs), and consumer behaviour, this study hopes to bolster the National Action Plan for Sustainable Plastic Management (2021–2030) and coordinate with the Sustainable Development Goal (Responsible Consumption) (Sala & Castellani, 2024). It aspires to bridge the gap between real-world situations and global AI developments.

This study uses social practice theory and the technology-organisation-environment paradigm to understand how AI is used in packaging production. It emphasises viable strategies, identifies AI adoption barriers, and offers sector leaders practical recommendations. This study highlights stakeholders' perspectives to link AI technologies with real customer needs and ecological standards. Preventing plastic pollution and showing AI can generate biodegradable equivalents boosts global environmental endeavours. The research provides a complete picture that influences individual and business decisions and raises public awareness of AI's environmental impact. Results open up AI for sustainability research by offering promising paths for future research.

LITERATURE REVIEW

The Role of AI in Biodegradable Packaging Design

AI is optimising distribution systems, speeding up resource research, and improving forecasts AI is revolutionising the eco-friendly packaging industry (Janssen & Helbig, 2024). To find the most cost- and labour-efficient combinations of biodegradable polymers, machine learning algorithms sort large datasets (Chen & Zhang, 2023). To minimise environmental impacts and guarantee that recyclable packaging meets international regulations, AI improves predictive deterioration modelling by precisely estimating breakdown rates. Reusable packaging becomes more economically viable as a result of AI's enhancements to the supply chain, as well as manufacturing effectiveness. BASF reduced their plastic biodegradable waste by 15% while maintaining cost efficiency with the use of artificial intelligence manufacturing methods (Carrillo-Hermosilla et al., 2024).

Stakeholder Attitudes Toward AI Integration

Industry stakeholders have expressed a range of opinions regarding the use of artificial intelligence (AI) in the production of reusable packaging. Startups face challenges like huge initial expenditures and data security issues, whereas manufacturers and other industry stakeholders see AI as a useful tool for speeding up studies while reducing costs (Freeman et al., 2021). Proponents of AI's ability to reduce plastic pollution include environmental groups and campaigners, while governments and regulatory bodies stress the importance of transparent and standardised frameworks (Gifford & Nilsson, 2014). There is a generational divide when it

comes to how customers view artificial intelligence (AI) in recyclable packaging; younger customers are more open to algorithm-generated eco-friendly packaging, while elderly customers are more sceptical due to concerns about responsibility and complexity (Arvidsson & Tillman, 2019).

Regulatory Context

Problems arise with the "Bangladesh Standards and Testing Institution" regulations based on artificial intelligence and with their uneven enforcement across the country. There is an increasing demand for ecological packaging from international purchasers, although domestic consumers exhibit price sensitivity (Marchant, 2019). The regulatory structure is hampered by overlapping jurisdictions among the Ministry of Environment, the Ministry of Commerce, and local municipal authorities, resulting in inconsistent recommendations for businesses. Recent approaches, such as the Extended Producer Responsibility frame, exhibit potential but need specifics around implementation (Van Calster & Reins, 2021). The lack of explicit tax incentives deters investment in AI solutions. In 2023, packaging innovations received only about 12% of the budgeted money from the Bangladesh Bank's Green Transformation Fund (Gupta et al., 2020). Table 2 illustrates a clearer path for Bangladesh to harmonise practices and avoid regulatory blind spots (Reza et al., 2024).

Table 2: AI regulatory Global Context

Country	AI in Packaging	Biodegradable Regulations	Relevance
India	AI-enabled mycelium packaging pilots in Mumbai	Extended Producer Responsibility (EPR) regime	Shared challenges in SMEs
Brazil	Computer vision for sugarcane-based plastics	Green Seal & Forest Code	Agro-waste integration
Indonesia	AI to monitor PLA packaging life cycles	National Plastic Waste Reduction Plan	Similar monsoon impacts
EU (benchmark)	Digital Product Passport + EcoMod tools	Stringent LCA, carbon labelling, tax incentives	Reference for policy transfer

AI Technologies In Biodegradable Plastic Packaging

To solve regional problems with packaging innovation, Bangladesh is employing AI technology. To foretell how materials will degrade in tropical environments, machine learning models are taught using regional datasets (Dolnicar & Grün, 2023). To detect material faults at a far lower cost than imported equipment, startups such as Packages are developing low-cost optical scanners. Bangladesh relies on foreign-trained specialists due to talent shortages, as only 23% of colleges offer specific AI programs. For example, neural networks trained on the qualities of jute fibre integrate global AI structures with local knowledge, leading to the most promising applications (. Park & Zhong, 2025). Areas with spotty internet service are also seeing an uptick in the use of edge computing technologies. To ensure that these technologies are accessible to technicians who do not speak English, organisations like Brain Station 23 are developing AI interfaces in Bengali (Qureshi et al., 2023).

Biodegradable Materials

Biodegradable materials are a growing field in Bangladesh, where scientists are creating natural substitutes such as composites made of starch and jute. The country's jute industry has great sustainability and performance potential, but there are still problems with the supply chain, and local output can only cover 15% of the demand (Li et al., 2025). There might be price swings of up to 40% between harvest and lean seasons due to seasonal changes in the supply of local starch. Combining locally sourced jute with minimally imported PLA, hybrid materials like the jute-PLA composites utilised by Pran-RFL Group for snack packaging are cost-effective. Micronation Bangladesh and other firms are growing mycelium-based materials on agricultural waste; nevertheless, scaling is difficult because there are no sterile manufacturing facilities (Wensing et al., 2023). Figure 1 shows the AI implementation flowchart (Swart et al., 2024).

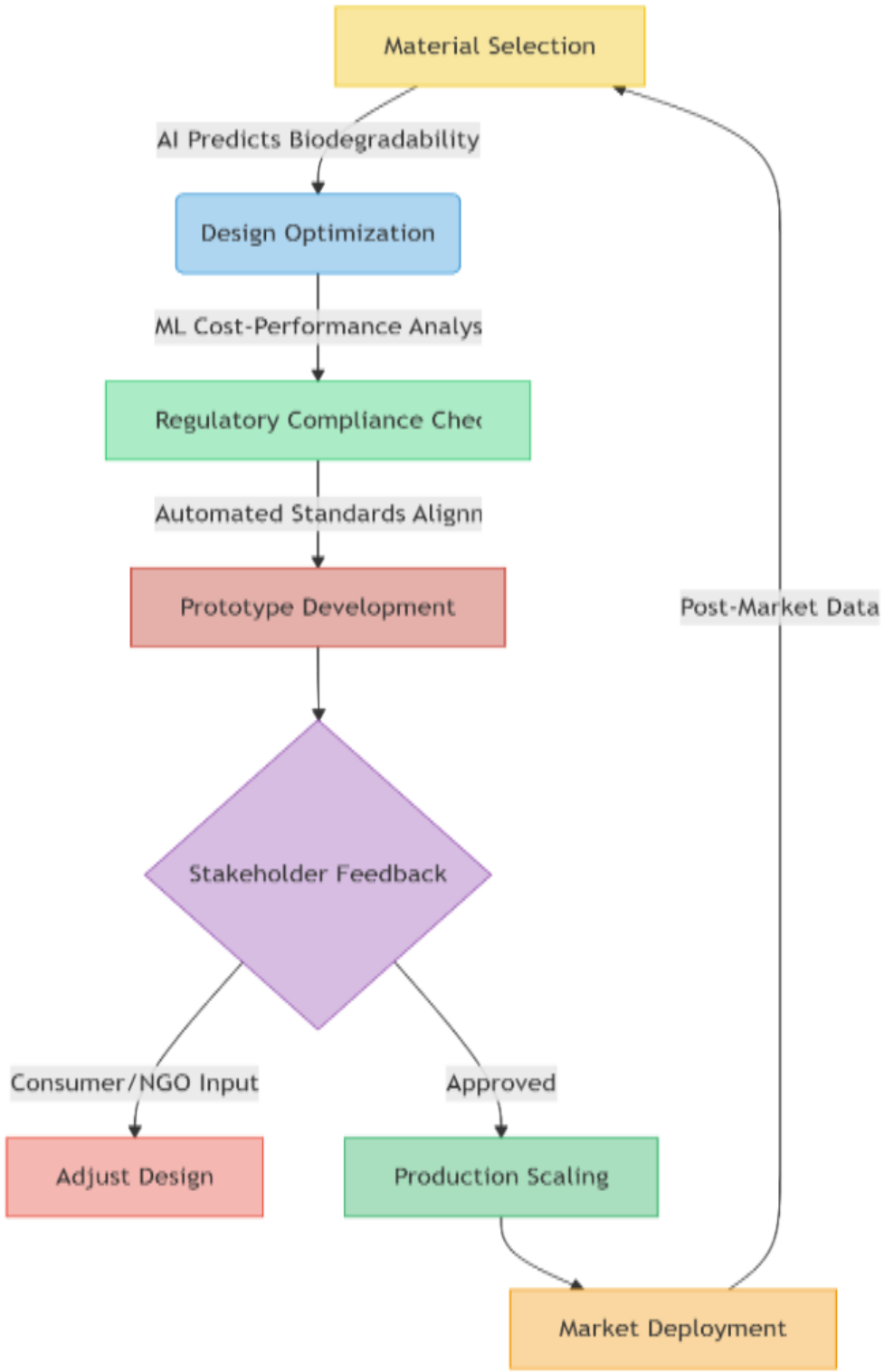

Figure 1: AI-Implementation Flowchart

Stakeholders

AI solutions are being employed by both export-oriented enterprises in Bangladesh to comply with EU laws and domestic-focused SMEs, creating a complex ecosystem of stakeholders in sustainable packaging. The apparel sector, with 4,500 plants and an annual packaging requirement of $6 billion, shapes market power (Fernández-Vázquez et al., 2023). Not only that, but waste pickers and religious leaders play an important role; for example, anti-plastic preaching is included in the sermons of fifteen per cent of metropolitan mosques (Gupta & Zhao, 2024). While the dispersed structure of these groups presents coordination challenges, it also provides opportunities for targeted interventions such as the "Green Packaging Initiative" introduced by the Bangladesh Garment Manufacturers and Exporters Association.

Design Process

Biodegradable packaging driven by artificial intelligence in Bangladesh is a complicated process that necessitates careful localisation. Because of the extreme temperatures and moisture in Bangladesh, the biodegradation rates of the materials used must be carefully considered. The BUET research team has created a decision-making matrix that gives preference to materials that are readily available in the area, such as jute and rice husk (Bocken, et al., 2021). Several special difficulties arise during performance testing, including the need to conduct accelerated ageing experiments. When optimising costs, it is important to take into account the economic realities of Bangladesh, where packaging costs more than 5% of product value (. White et al., 2023). With the help of AI, businesses like Brain Station 23 were able to cut their costs by 22%. Cultural considerations are also a part of the design process. For example, the visual appeal of the package may need to be adjusted to appeal to both conventional customers and international standards (Zicari et al., 2023).

Sustainable Outcomes

In Bangladesh, early adopters of AI-driven packaging saw a 42% reduction in plastic waste, which bodes well for the garment sector and the country as a whole. But there are still problems with economic viability and infrastructure deficiencies (Haddaway et al., 2020). Local SMEs encounter 35–40% more initial costs, compared to export-oriented factories that report 18% long-term cost reductions. While 68% of young people in cities are on board, 72% of people in rural areas are more concerned with cost (Chen et al., 2023). Cases that successfully integrate all three aims are rare, but examples include the artificial intelligence (AI)-designed mango packaging by Pran-RFL Group, which received 82% customer approval while reducing environmental effects by 55% (De Meyer et al., 2024). Waste pickers who use sorting apps that use artificial intelligence claim a 25% increase in their earnings, revealing an unexpected social benefit in the informal sector. With 39% of biodegradable packaging breaking down too quickly in floods, climate vulnerability is still an issue. Hybrid solutions incorporating local knowledge with AI designs promise to meet ecological objectives and boost revenue (Packaging Digest, 2024).

Theoretical Framework

Two supplementary scientific frameworks provide the groundwork for this research, which enhances our comprehension of technology uptake in environmentally friendly packaging. which include the "Technology-Organisation-Environment (TOE) Framework (Tornatzky & Fleischer, 1990)" and the theory of social practice (SPT) (Shove et al., 2012). Regarding the design, production, and use of packaging, "Social Practice Theory (SPT)" is useful for analysing how AI integration becomes ingrained in daily routines. Biodegradable polymers and AI technologies are part of the substances; capabilities are the skills needed to execute AI, and meanings are the stakeholders' views of AI's value. These three interrelated components are the focus of this structure (Geels, 2011). The contextual variables influencing the implementation of artificial intelligence can be structured using the "Technology-Organisation-Environment" paradigm (Jobin, Ienca & Vayena, 2019). Furthermore, we analyse ethical implications for artificial intelligence packaging usage through the lens of the Responsible Innovation Approach, paying special attention to issues of transparency, accountability, and sustainability.

Conceptual Framework

The conceptual structure identifies several fundamental components. These elements include artificial intelligence technologies such as machine learning and predictive analytics, biodegradable materials such as PLA and starch-based polymers, and major stakeholder groups that involve manufacturers and consumers simultaneously. These factors interact with one another through various paths, wherein artificial intelligence (AI) affects technological development and research cycles, feedback from stakeholders determines acceptance pathways, and governing structures both facilitate and hinder invention (Zwier et al., 2025). In the end, these connections affect three crucial aspects of the results: the decrease of the harmful effects on the environment, the economic feasibility, and the social acceptance of the packaging solutions that are produced.

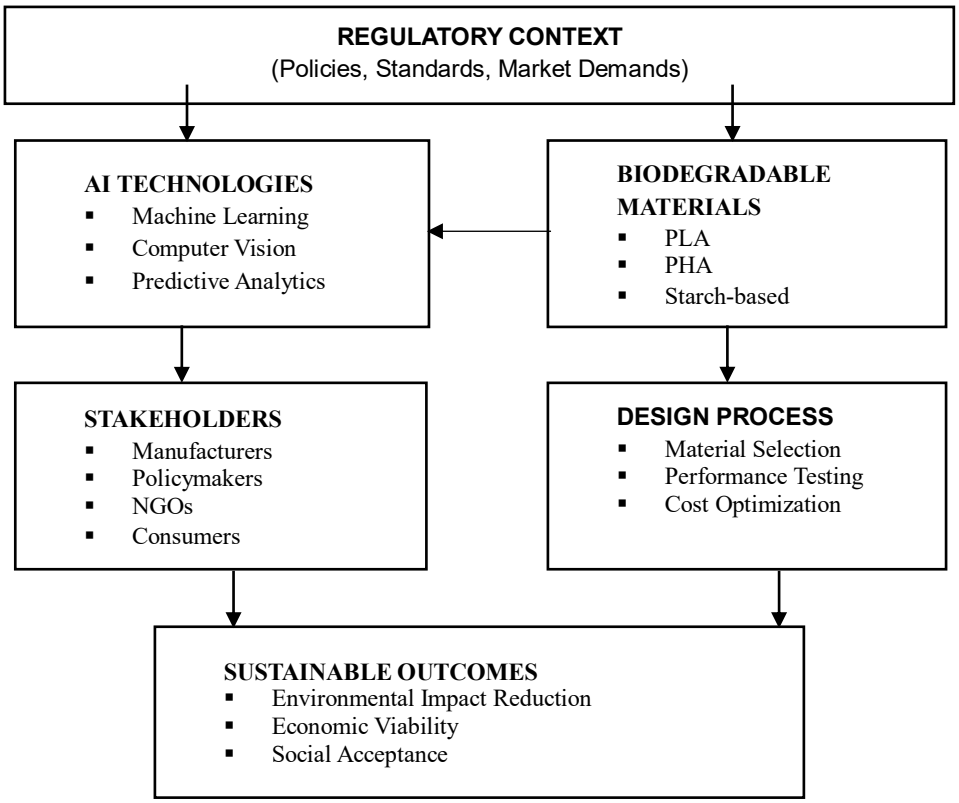

Figure 2: Conceptual Framework.

RESEARCH METHODOLOGY

This research examined the factors influencing the integration of AI in biodegradable plastic packaging to explore the stakeholders' attitudes. As such, for this study, the sampling strategy utilises purposeful selection to ensure the representation of varied perspectives, employing maximum variation sampling, snowball sampling for specialised experts, and theoretical sampling as significant themes emerge (Creswell & Poth, 2018). The present study employs an investigative qualitative technique (Braun & Clarke, 2006). This approach combines phenomenology methodologies with a case study investigation of five firms that are at varying phases of using artificial intelligence. The purpose of this study is to investigate the actual life experiences of participants with AI packaging technology. In addition to two focus groups consisting of six to eight respondents each, the primary data-gathering process consists of thirty semi-structured interviews lasting between forty-five and sixty minutes with a wide range of participants. These participants include packaging designers, sustainability officers, regulatory experts, representatives of non-governmental organisations, and customers who are environmentally concerned. A few examples of secondary data resources are sustainability for businesses reports, white papers on artificial intelligence usage from the sector, and related regulation publications (Floridi et al., 2018).

This paper has looked at different ways to use AI to understand how people feel about biodegradable plastic packaging, along with the rules, AI technologies, biodegradable materials, the people involved, the design process, and sustainable results (Geels, 2011; Folino et al., 2020; Kumar & Singh, 2021). To qualify all the measurement points to demonstrate the degree of consent of participants, thematic analysis has been considered with the incorporation of familiarisation with transcripts, initial code generation, theme development and refinement. We will only construct each questionnaire object in English. The data collected has been analysed using the ATLAS.ti program, which involved administering questionnaires in person.

Data Analysis Process

The qualitative methodology efficiently elucidated intricate attitudes, including apprehensions of job displacement among package designers (Silver & Lewins, 2024). By comparing and contrasting several businesses, the case study approach revealed how company culture affects the adoption of artificial

intelligence. Business constraints, different artificial intelligence jargon, and lightning-fast technological advancements were all difficulties. Confidential assessments, meticulous language definition, and continual improvements addressed these concerns.

Analysis of Key Challenges and Barriers

The use of AI in recyclable packaging might completely alter the industry, but there are a lot of obstacles that need to be overcome first. The huge cost involved in execution is a big problem, particularly for small and medium-sized enterprises (Yin, 2024). To bridge this gap, public-private partnerships and government subsidies might be required. Artificial intelligence raises serious questions regarding ownership and security in materials research, which in turn raises serious concerns about data privacy and intellectual property. Cybersecurity risks reduce trust in AI systems and put private research data at risk. Regulatory and standardisation shortcomings leave manufacturers and regulators with ambiguity, potentially contradicting claims about biodegradability and even greenwashing. Trust and acceptability from the public are crucial for effective execution, which calls for targeted campaigns of education, transparent communication, and involvement from all parties involved.

Discussion on Stakeholder Collaboration and Ethical Considerations

There are ethical considerations and the need for third-party coordination surrounding the integration of AI into designs for biodegradable packaging. To coordinate technological progress with social, environmental, and economic objectives, a multi-stakeholder approach is necessary. To develop artificial intelligence (AI) approaches that are both technically achievable and ethically sound, business representatives should collaborate with professionals and authorities. Being open-source, artificial intelligence models and cross-industry collaborations can enhance information dissemination and reduce obstacles to entry for smaller enterprises. Ethical aspects, bias assessments, stakeholder engagement, and policymakers are essential in fostering ethical AI use and encouraging growth. Public relations initiatives can inform consumers about the advantages of AI-driven biodegradable packaging. Table 3 shows the principles from the Responsible Innovation Framework to balance technological innovation with public trust (Stilgoe et al., 2024).

Table 3: Cross-Country Regulatory & Ethical Frameworks

Country	AI Ethics Approach	Biodegradability Oversight
Kenya	AI ethics tied to digital access and labour	Compostability linked to local climate zones
Vietnam	Focus on algorithmic fairness in agriculture	Transition policies for SMEs
Bangladesh	Nascent guidelines, fragmented institutions	Regulatory overlaps, weak enforcement
EU	GDPR-compliant AI ethics, human-centred design	Clear compostability testing (EN 13432)

ANALYSIS AND FINDINGS

The research investigates the incorporation of artificial intelligence (AI) in biodegradable plastic packaging within Bangladesh. The study used a combination of methods, incorporating interviews with 30 stakeholders and a quantitative examination of business performance data. The study looks at four main factors: the laws in place, the use of AI technology, how easy it is to get and use local biodegradable materials, and how stakeholders work together. The research identified substantial discrepancies between policy objectives and their execution, especially in enforcement across various geographic areas as well as business sectors. It underscored the necessity for technological change to render AI solutions operational in Bangladesh's infrastructure-deficient context, where power interruptions and inadequate understanding of technology pose substantial obstacles to adoption. The results indicate three prevailing factors that influence adaptive behaviour.

Industry experts recognise the ability of artificial intelligence to expedite materials innovation; yet 78% of small and medium enterprises (SMEs) reported problems related to costs associated with implementation and data connectivity. Authorities acknowledged AI's utility in gauging compliance but raised apprehensions over the validation of biodegradability assertions under varying environmental conditions. A contradiction arose:

merely 35% of consumers placed trust in AI-generated solutions, a phenomenon linked to "black box anxiety" and a lack of comprehension regarding AI decision-making processes. Consumers aged 18 to 35 show increased acceptability when presented with transparent certification methods. Divisions in organisational culture were evident, as "AI-first" industries retrained personnel while traditionalists resisted digital transformation. Five organisations disclosed reverse mentoring initiatives in which junior; data-literate staff enhanced the skills of high-ranking managers.

Implications

This study suggests that Bangladesh's sustainable growth and worldwide competition in the packaging sector are affected by ecological and economic factors. Disposable alternatives may fail to achieve their supposed advantages without improvements in waste management systems, as insufficient facilities for composting might lead to contamination of recyclable processes. An economic imbalance is emerging between big manufacturers and smaller enterprises, affecting the workforce and the development of industry. In society, awareness of consumer and cultural considerations affects the rate of acceptance, with metropolitan populations demonstrating more receptivity to environmentally friendly packaging.

Limitations

The research on AI integration in sustainable packaging has identified numerous limitations. The probable lack of regions with analogous economic, environmental, and regulatory conditions arises from its singular focus on the context of Bangladesh. The sample may inadequately reflect informal sector employees and smaller rural enterprises. The sample size and composition may play a significant role. Moreover, the cross-sectional design of the data imposes constraints by failing to account for the potential evolution of views and technological adoption over time. The study makes guesses about the technology needed for AI adoption that might not reflect the real situation, and it might miss how urban bias affects who is chosen as stakeholders. Ongoing research is essential to maintain the relevance of findings in the rapidly changing domains of artificial intelligence (AI) governance and biodegradable material legislation. Future research on AI integration in sustainable packaging should employ mixed methods approaches, incorporate longitudinal data, and engage a broader spectrum of stakeholders.

RECOMMENDATIONS

The research proposes a collaborative action plan including multiple stakeholders to tackle issues related to biodegradable packaging. Policymakers ought to prioritise the development of climate-responsive standards, the establishment of enforcement mechanisms, and the incentivization of small producers. Industry stakeholders ought to invest in AI technologies and partner with research institutes to create climate-resilient material formulations. Educational institutions and NGOs ought to enhance technical capacity via vocational training programs and public awareness initiatives. Pilot initiatives must incorporate informal waste labourers into the recycling framework. International development partners must concentrate on finance strategies to mitigate adoption risk. Ongoing investigation on the efficacy of biodegradable materials across various regions and seasons in Bangladesh is also advised.

CONCLUSION

The research examines the socio-technical framework of AI in biodegradable packaging, emphasising the necessity of balancing technological proficiency with ethical implications. It employs social practice theory to elucidate the "messy middle" of AI adoption, whereby material improvements must correspond with workplace competencies and cultural significances. The results offer a framework for responsible innovation, highlighting the necessity of balanced investment in algorithmic advancement and trust-enhancing infrastructure. The study offers diagnostic instruments for practitioners to evaluate organisational preparedness and provides policy suggestions for governance structures to foster innovation and avert unexpected outcomes. The research identifies AI as an essential component of a broader systemic shift towards circular material economies.

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