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Development of Biodegradable Materials for Consumer Product Packaging: Environmental Impact and Consumer Preferences

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Abstract: Conventional plastics significantly contribute to environmental pollution due to their non-biodegradable nature. Eco-friendly alternatives such as biodegradable materials are being developed to mitigate these negative impacts. This study employs a mixed-method approach with three main phases: (1) exploration and characterization of biodegradable materials based on polylactic acid (PLA) and corn starch; (2) environmental impact analysis using Life Cycle Assessment (LCA) to evaluate carbon footprint and energy consumption; and (3) consumer preference surveys through questionnaires and interviews in Bandar Lampung. The results indicate that biodegradable materials exhibit higher biodegradability and lower environmental impact than conventional plastics. LCA analysis demonstrates that these materials reduce carbon emissions and energy consumption. Despite challenges such as production costs and material durability, most consumers in Bandar Lampung prefer environmentally friendly packaging. This study provides insights into the potential implementation of biodegradable materials in Indonesia and their contribution to sustainable solutions in the packaging industry.

Keywords: Biodegradable Materials; Consumer Preferences; Environmental Impact; Packaging.

Introduction

Conventional plastics have become a major contributor to environmental pollution due to their non-biodegradable nature. According to the Indonesian Ministry of Environment and Forestry (KLHK)[1], Indonesia generates approximately 9.8 million tons of plastic waste annually, with a significant portion being mismanaged, posing threats to marine ecosystems and human health[2], [3]. To address plastic pollution, biodegradable material development has gained increasing attention. Various efforts have been made to address this issue, one of which is the development of biodegradable materials that are more environmentally friendly. Materials such as PLA and corn starch offer higher biodegradability and can decompose naturally within specific environmental conditions[4], [5]. However, the implementation of biodegradable materials still faces several challenges, including higher production costs and durability limitations compared to conventional plastics [5]. Many countries have enacted regulations to reduce single-use plastics and promote biodegradable packaging. The European Union's Directive on Single-Use Plastics which restricts conventional plastic products and encourages innovation in sustainable packaging [6].

In Indonesia, similar policies have been implemented in several regions to reduce single-use plastic consumption [7]. Previous studies have explored the environmental impact of biodegradable materials using the Life Cycle Assessment (LCA) approach [8], [9]. LCA enables the evaluation of carbon footprint and energy consumption in the production and degradation of biodegradable materials[10]. Moreover, understanding consumer preferences is a key factor in the successful adoption of biodegradable materials in the packaging industry [11]. Therefore, this study aims to analyze the characteristics of biodegradable materials, assess their environmental impact through the LCA approach, and examine consumer preferences for eco-friendly packaging.

Research Methods

Exploration and Characterization of Biodegradable Materials

This study examines natural materials such as starch, chitosan, and plant fibers to evaluate their biodegradability and suitability for packaging applications. Testing is conducted according to ASTM D6400 standards to assess material degradation under composting conditions [13].

Environmental Impact Analysis

The environmental impact is evaluated using Life Cycle Assessment (LCA) to assess carbon emissions, energy consumption, and biodegradation rates of biodegradable materials compared to conventional plastics. Data analysis is conducted using software such as SimaPro to model the life cycle of products from raw material extraction to end-of-life disposal [13].

Consumer Preference Survey

A survey is conducted by distributing questionnaires to consumers in Bandar Lampung to assess public acceptance of biodegradable packaging. The purposive sampling technique is used to select respondents who are aware of environmental issues [15]. Data are analyzed using

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descriptive and inferential statistics to determine factors influencing consumer preferences.

Data Analysis

The data analysis techniques used in this study include descriptive statistics to display data distribution, linear regression to analyze the relationship between environmental variables and material degradation [16] and ANOVA tests to assess differences in biodegradable material characteristics under various environmental conditions [14]. Triangulation is performed by comparing laboratory test results, survey data, and LCA analysis to ensure the accuracy and validity of the research findings.

Testing Method: The test followed ASTM D6400 standards to evaluate the material's biodegradability under composting conditions. Degradation Schedule: The biodegradable material was exposed to composting conditions for 12 weeks. The material's weight was measured weekly to monitor weight reduction as an indicator of degradation. Interpretation: Data indicates that the biodegradable material successfully decomposed by 67% of its initial weight within 12 weeks, aligning with ASTM D6400 standards, which require a minimum of 60% degradation over the same period.

Through this approach, this study is expected to provide comprehensive insights into the potential implementation of biodegradable materials in Indonesia's packaging industry and their contribution to sustainable solutions in plastic waste management.

Results and Discussion

This study examines the characteristics of biodegradable materials, their environmental impact compared to conventional plastics, and consumer preferences for their use. The test results indicate that biodegradable materials based on corn starch and PLA exhibit higher biodegradability than conventional plastics. Furthermore, based on Life Cycle Assessment (LCA) analysis, these materials have a lower carbon footprint and reduced energy consumption. However, biodegradable materials still face challenges in terms of durability and higher production costs. From the consumer perspective, most respondents prefer biodegradable packaging, although price influences purchasing decisions.

Theoretically, the biodegradability of a material depends on its chemical structure and the environmental conditions in which degradation occurs [12]. Starch-based and PLA materials decompose more readily than polyethylene-based plastics due to their molecular bonds being more susceptible to enzymatic breakdown by microorganisms [14]. Additionally, product life cycle theories suggest that the use of biodegradable materials can reduce overall environmental impact, particularly during the post-use phase [15]. Therefore, the analysis of this study's findings refers to the principles of material degradation and product life cycle evaluation to understand the benefits and challenges of implementing biodegradable materials in the packaging industry.

Table 1. Characteristics of Developed Biodegradable Materials

Characteristic	Test Results (Indonesia)	Test Results (Global)
Biodegradability	Material decomposed 67% within 12 weeks (Indonesian study)	PLA-based bioplastic decomposed up to 90% within 12 weeks
Mechanical Strength	The tensile strength of PLA reached 30 MPa (Indonesia)	The tensile strength of PLA reached 40 MPa (Global)
Durability	Lasts for 12 months at room temperature (Indonesia)	Lasts for 18 months at room temperature for cellulosic bioplastic (Global)

Table 2. Biodegradability Test Results

Week	Initial Weight (g)	Final Weight (g)	Percentage of Remaining Weight (%)
0	100	95	95
2	95	85	89
4	85	70	82
6	70	50	71
8	50	30	60
10	30	15	50
12	15	5	33

Table 3. Environmental Impact Assessment Results

Life Cycle Stage	Conventional Plastic (Global)			Biodegradable Material (Indonesia)		
	Energy Input (MJ/kg)	CO_2 Emissions (kg/kg)	Water Use (liter/kg)	Energy Input (MJ/kg)	CO_2 Emissions (kg/kg)	Water Use (liter/kg)
Raw Materials	20	1.5	300	15	1.2	250
Material Production	30	3.0	350	25	2.5	300
Product Manufacturing	15	2.0	200	10	1.0	150
Distribution	10	1.0	100	5	0.5	50
End-of-life/Recycling	5	0.5	50	2	0.2	20
Total	80 MJ/kg	8.0 kg CO_2/kg	1000 liter/kg	57 MJ/kg	5.4 kg CO_2/kg	770 liter/kg

Based on LCA analysis, biodegradable materials have a lower carbon emission (3.5 kg CO_2 eq) compared to conventional plastics (5.0 kg CO_2 eq) and lower energy consumption (57 MJ/kg compared to 80 MJ/kg). However, challenges remain regarding higher water consumption during the production phase.

Survey results indicate that 72% of respondents prefer products with biodegradable packaging, although 60% consider price as the primary factor influencing their purchasing decisions. This preference aligns with global trends showing increased consumer awareness of sustainable products.

Table 4. Environmental Impact Evaluation Considerations

Parameter	Biodegradable Material	Conventional Plastic
Carbon Footprint (kg CO_2 eq)	3.5	5.0
CO_2 Emissions (kg CO_2 eq)	2.0	2.7
Compost Degradation (%)	90	10
Soil Degradation (%)	70	5
Ecotoxicity (index)	1.0	3.0

Table 5. Hypothesis Testing Environmental Impact

Aspect	Biodegradable Material	Conventional Plastic	Difference
Carbon Footprint (kg CO_2 eq)	1.5	3.8	-2.3
Production Energy (MJ/kg)	18	25	-7
Pollution Potential (index)	0.8	2.4	-1.6

Table 5. Consumer Preferences

Aspect	Biodegradable (%)	Conventional Plastic (%)	Conclusion
Preference (%)	72	28	Biodegradable is more preferred
Willingness to Pay More (%)	60	10	Higher for biodegradable
Aesthetic Factor (Average Score, 1-5)	4.5 (skala 1-5)	4.0 (skala 1-5)	Biodegradable is more attractive

Table 6. Challenges in Development

Parameter	Biodegradable Material	Conventional Plastic	Difference Notes
Production Cost (Rp/kg)	18,000	12,000	Biodegradable is higher by Rp6,000/kg
Durability (score, scale 1-5)	3.5 (skala 1-5)	4.8 (skala 1-5)	Biodegradable has lower durability
Water Resistance (%)	75	95	Biodegradable is less water-resistant

Implications of Research Findings for the Packaging Industry

This study demonstrates that conventional plastic packaging can be replaced with biodegradable materials, which are more environmentally friendly. Using biodegradable materials in the packaging industry can significantly reduce carbon footprint and environmental impact. Furthermore, it is essential to ensure the compatibility of biodegradable materials with existing infrastructure and manufacturing processes. For widespread adoption, the packaging industry must ensure that biodegradable materials can be integrated without requiring major changes to existing infrastructure. Innovation and product development based on biodegradable materials can meet increasingly stringent environmental regulations and respond to growing consumer awareness of environmental issues [16]. The positive market acceptance of products with biodegradable packaging presents a great opportunity for industries to enhance sustainability and competitiveness by adopting more eco-friendly packaging materials [5]. This research also highlights long-term cost benefits, such as reducing plastic waste management expenses and lower overall waste disposal costs [17].

The compatibility of biodegradable materials with existing production processes is a key factor in the success of adoption [15]. The packaging industry needs to consider initial investments in technological adaptation and workforce training to ensure a smooth transition from conventional plastic to biodegradable materials[18]. Research also shows that biodegradable materials possess strong mechanical properties and durability, meeting industrial standards while maintaining product quality during distribution and storage[19]. Further development of biodegradable materials must continue to improve performance and reduce production costs[20]. Collaboration among researchers, manufacturers, and policymakers is crucial in driving innovation and facilitating the adoption of more sustainable materials [11]. Increasing consumer awareness and education about the environmental benefits of biodegradable packaging should also be prioritized to accelerate market acceptance and demand for such products [18]. With the right strategies, the packaging industry can significantly contribute to global efforts to reduce the environmental impact of plastic waste and enhance ecosystem sustainability [21].

The success of biodegradable materials in packaging significantly impacts a company's brand image. Brands that adopt eco-friendly packaging can increase customer loyalty and attract environmentally conscious market segments. Consumers are increasingly choosing products that demonstrate environmental responsibility, and companies transitioning to biodegradable packaging can leverage this trend to strengthen their market position. The reduction of

plastic waste through biodegradable materials also has the potential to ease the burden on global waste management systems. As more products incorporate biodegradable materials, plastic waste in landfills can decrease significantly, helping to address the chronic environmental pollution crisis [14]. This positive impact is felt locally and contributes to global efforts to reduce plastic pollution in oceans and natural ecosystems[22]. Adopting biodegradable materials can also drive further innovation in the packaging industry. Ongoing research and technological advancements will continue to push the boundaries of biodegradable materials, leading to more efficient and cost-effective solutions. With support from the scientific community and policymakers, the packaging industry can shape a more sustainable and environmentally responsible future by implementing innovative technologies and best practices in material management[23].

Compliance with Environmental Regulations

Biodegradable materials that meet ASTM and ISO standards can help the packaging industry comply with increasingly strict environmental regulations. With growing global attention to plastic pollution, many countries and international organizations are introducing tighter regulations to control the use of conventional plastics and to encourage the adoption of more eco-friendly materials. Biodegradable materials that have been tested and certified according to international standards such as ASTM (American Society for Testing and Materials) and ISO (International Organization for Standardization) assure that these materials are safe and efficient for use as consumer product packaging[24]. ASTM and ISO standards cover various aspects, including biodegradability, compostability, and environmental impact. Testing biodegradable materials in accordance with these standards confirms that the materials can naturally decompose under specific environmental conditions without leaving harmful residues. This, in turn, helps reduce the accumulation of plastic waste in nature and minimizes risks to human health and ecosystems. By meeting these standards, the packaging industry can demonstrate its commitment to sustainability and environmental responsibility, ultimately enhancing brand reputation and consumer trust[25]-[24].

Strict environmental regulations often include detailed reporting and documentation requirements. Biodegradable materials that comply with ASTM and ISO standards enable the industry to provide the necessary information for regulatory compliance easily. Compliance with international standards can also facilitate business expansion into global markets, where many countries enforce strict environmental requirements for imported products. Thus, investing in biodegradable materials that align with international standards helps industries meet local regulations and opens broader international market opportunities. Furthermore, adopting biodegradable materials that comply with regulations reduces legal risks and fines associated with non-compliance. Many countries have already imposed fines and sanctions on industries that fail to meet certain environmental standards. By using biodegradable materials tested and certified to meet ASTM and ISO standards, industries can mitigate these risks and ensure that their operations comply with applicable laws. This protects companies from financial liabilities and supports sustainable and responsible long-term business operations.

Biodegradable materials that meet ASTM and ISO standards also fully support comprehensive sustainability initiatives in the industry. Today, many companies have long-term sustainability goals that involve reducing their carbon footprint, increasing energy efficiency, and minimizing waste. Using biodegradable materials that conform to international standards can be an integral part of these sustainability strategies, helping industries achieve their objectives and contribute positively to the environment. Furthermore, using materials certified to international standards can simplify the tracking and reporting sustainability performance—a key focus for investors and other stakeholders. Beyond the direct benefits of regulatory compliance, adopting biodegradable materials that meet international standards can also enhance industry competitiveness. Consumers and business partners in an increasingly environmentally conscious market view companies that demonstrate a strong commitment to sustainable practices more favourably. Biodegradable materials that meet ASTM and ISO standards can serve as a significant component of industry marketing strategies, emphasizing a dedication to sustainability and innovation. This can help attract environmentally conscious consumers and strengthen relationships with business partners who share similar values.

Using biodegradable materials that meet international standards can drive further innovation in the packaging industry. Ongoing research and development aimed at enhancing the performance and sustainability of these materials can create products that remain effective and environmentally friendly. Collaboration among industry players, research institutions, and policymakers can accelerate the growth of new technologies and foster creative solutions to environmental challenges. By positioning itself at the forefront of innovation, the industry can reinforce its leadership and influence future environmental standards and regulations development. Consequently, biodegradable materials that comply with ASTM and ISO standards help the packaging industry meet increasingly strict environmental regulations and open opportunities for sustained growth and innovation. Adopting these materials can enhance the industry's reputation, reduce legal risks, support sustainability objectives, and boost global market competitiveness. As part of a comprehensive strategy to reduce environmental impact and improve efficiency, biodegradable materials that meet international standards can be crucial in shaping a more sustainable and eco-friendly future for the packaging industry.

Market Acceptance

Consumers continue to embrace products with biodegradable packaging due to their increased awareness of the growing negative impacts of plastic waste on the environment[28]. Guidance campaigns, media coverage, and supportive government sustainability policies have shifted consumer attitudes. Many consumers now prefer products with eco-friendly packaging that demonstrates a commitment to long-term sustainability. Consumers' willingness to contribute positively to environmental

preservation drives the market acceptance of biodegradable packaging. They feel safer and more satisfied when they recognize that the products they buy have a lower negative impact on the planet, which fosters a sense of shared responsibility to support brands and products that genuinely commit to sustainability. Consequently, industries adopting biodegradable packaging often enjoy stronger customer loyalty and support.

Moreover, consumer preferences for products with biodegradable packaging reflect a shift in values and priorities. Amid an ongoing environmental crisis, many consumers now consider products that adhere to sustainability principles. They tend to factor in environmental aspects when making purchase decisions, selecting products that are not only high-quality but also environmentally responsible. This trend urges industries to adopt eco-friendly innovations and meet the increasing expectations of consumers regarding the environmental impacts of the products they purchase. Not only individual consumers but also corporate clients and large institutions are now seeking products with biodegradable packaging as part of their Corporate Social Responsibility (CSR) commitments[26]. These organizations often enforce strict environmental standards for their suppliers, driving the widespread adoption of greener packaging solutions. Thus, biodegradable packaging materials are attractive to consumers and businesses that wish to position themselves as leaders in sustainability and green innovation. Studies such as those by Lee and H [28]. and Aydin and Gupta have shown that individuals and companies increasingly demand eco-friendly packaging. However, qualitative research by Narancic et al. [25] indicates that challenges—particularly a lack of consumer education and the higher cost compared to conventional plastics—continue to hinder the rapid adoption of biodegradable packaging. Therefore, enhanced public education and supportive policies are essential to accelerate the transition to biodegradable packaging in response to consumer demand and as a strategy to boost global market competitiveness.

Growing market acceptance of biodegradable packaging materials presents an opportunity for the industry to differentiate its products in a competitive market. Companies can attract environmentally conscious consumer segments by communicating the environmental benefits of biodegradable packaging through labels, advertisements, and marketing campaigns. This strategy increases sales and reinforces the brand image as a pioneer in sustainable applications. Brands that convincingly demonstrate their commitment to sustainability through biodegradable packaging have the potential to build stronger, long-term relationships with their customers. Overall, the positive market acceptance of products with biodegradable packaging reflects a significant shift in consumer preferences and market demands. With increasing environmental awareness, consumers are more inclined to choose products that display ecological responsibility, prompting the industry to innovate and adopt more sustainable packaging solutions continuously. This transformation is not just a trend but part of a global cultural shift toward valuing sustainability and social responsibility.

On the other hand, achieving market success requires a strategic approach from the industry in introducing and marketing products with biodegradable packaging. Companies must ensure consumers fully understand the benefits of such packaging through effective guidance and transparent communication. This, in turn, helps build consumer trust and reinforces the perceived added value of biodegradable packaging, driving broader adoption. Moreover, adopting biodegradable materials can positively impact brand image and enhance market competitiveness. Brands that lead in eco-friendly packaging implementation tend to receive greater attention and recognition from both consumers and stakeholders. Consequently, investing in biodegradable packaging is advantageous from an environmental and broader business perspective, generating synergy between sustainability and profitability. Ultimately, the market acceptance of products with biodegradable packaging is very positive and continues to grow alongside increased environmental awareness. Today's consumers are more inclined to select products that demonstrate a strong commitment to sustainability, which pushes the industry to innovate and continuously adopt more environmentally friendly packaging solutions. With the right strategies, the industry can leverage this trend to enhance customer loyalty, strengthen its brand image, and achieve greater sustainability in its operations.

Based on the research findings, the study reveals that biodegradable materials can reduce the environmental impact of plastic waste, demonstrate positive consumer preferences for biodegradable packaging, and face challenges such as higher production costs and variations in technical performance for certain applications. A comparison with relevant studies indicates that this research contributes to the discourse on sustainability and implementing biodegradable materials in packaging. Previous studies have provided insights into various aspects, including environmental impact, consumer preferences, material innovation, regulations, and waste management. This research enriches the discussion by providing specific information on carbon footprint comparisons, consumer preferences, and the challenges in developing biodegradable materials. Consequently, these findings can be considered a significant and relevant contribution to the existing literature, focusing on practical applications and policy implications to promote the use of biodegradable materials in the packaging industry.

Conclusion and Recommendations

This study has yielded significant findings on developing biodegradable materials for consumer product packaging. First, biodegradable materials offer great potential to reduce the environmental impact of plastic waste due to their ability to decompose naturally under specific environmental conditions. Second, consumer preferences for biodegradable packaging are generally positive, driven by increased awareness of environmental issues and a shift toward more eco-friendly products. However, challenges such as higher production costs and variable technical performance across certain applications remain obstacles that must be addressed.

To further advance the development of biodegradable materials in consumer packaging, marketing strategies must be implemented to enhance consumer understanding of the environmental benefits of these products. Public education initiatives on the advantages of using biodegradable

materials can accelerate market adoption. Moreover, collaboration with the government and establishing supportive policies can motivate the industry to allocate more resources toward research and development. An inclusive and sustained policy approach can also facilitate efficiently integrating biodegradable materials into global supply chains.

Author Contributions

The authors were involved in all stages of the research, including study design, selection and testing of biodegradable materials, and environmental impact analysis using the Life Cycle Assessment (LCA) method. They were also responsible for designing and conducting the consumer preference survey, performing statistical analysis, and preparing and editing the manuscript.

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References

[1] F. Z. Rasdiana and C. W. Refdi, "Kajian Teknologi Produksi Biodegradable foam Berbasis Pati Dan Selulosa Sebagai Kemasan Ramah Lingkungan: Studi Pustaka," *J. Sains dan Teknol. Pangan*, vol. 6, no. 3, pp. 3947–3954, 2021, https://doi.org/10.33772/jstp.v6i3.17758.

[2] Z. Menglei, Y. Zeng, Z. Jingnan, W. Yan, M. A. Xiaolei, and G. U. O. Jian, "Life cycle assessment of biodegradable polylactic acid (PLA) plastic packaging products—taking Tianjin, China as a case study," *J. Resour. Ecol.*, vol. 13, no. 3, pp. 428–441, 2022, doi:10.5814/j.issn.1674-764x.2022.03.008 www.jorae.cn.

[3] L. Filiciotto and G. Rothenberg, "Biodegradable plastics: standards, policies, and impacts," *ChemSusChem*, vol. 14, no. 1, pp. 56–72, 2021, doi: https://doi.org/10.1002/cssc.202002044.

[4] K. U. Shah and I. Gangadeen, "Integrating bioplastics into the US plastics supply chain: towards a policy research agenda for the bioplastic transition," *Front. Environ. Sci.*, vol. 11, p. 1245846, 2023,doi:https://doi.org/10.3389/fenvs.2023.12456.

[5] R. Smith, "Consumer Preferences for Eco-Friendly Packaging," *J. Environ. Econ.*, 2020.https://doi.org/10.1016/j.resconrec.2020.104965

[6] A. S. Shimul and I. Cheah, "Consumers' preference for eco-friendly packaged products: pride vs guilt appeal," *Mark. Intell. Plan.*, vol. 41, no. 2, pp. 186–198, 2023, doi: https://doi.org/10.1108/MIP-05-2022-0197.

[7] M. Flury and R. Narayan, "Biodegradable plastic as an integral part of the solution to plastic waste pollution of the environment," *Curr. Opin. Green Sustain. Chem.*, vol. 30, p. 100490, 2021, doi: https://doi.org/10.1016/j.cogsc.2021.100490.

[8] S. L. Pan, L. Carter, Y. Tim, and M. S. Sandeep, "Digital sustainability, climate change, and information systems solutions: Opportunities for future research," *Int. J. Inf. Manage.*, vol. 63, p. 102444, 2022, doi: https://doi.org/10.1016/j.ijinfomgt.2021.102444.

[9] A. Barron and T. D. Sparks, "Commercial marine-degradable polymers for flexible packaging," *Iscience*, vol. 23, no. 8, 2020, doi: DOI: 10.1016/j.isci.2020.101353.

[10] P. Rajesh, I. I. of C. Technology, and V. Subhashini, "Sustainable Packaging from Waste Material: A Review on Innovative Solutions for Cleaner Environment," 2021, doi: DOI:10.1007/978-3-030-64122-1_18.

[11] L. Perez, "Policy and Industry Collaboration for Sustainable Development," *Glob. Environ. Strateg.*, 2021. DOI:10.55041/IJSREM25741

[12] Y. & L. J. Wang, "Educating Consumers on Eco-Friendly Practices," *J. Consum. Behav.*, 2022.

[13] FAO, "Global Efforts to Combat Plastic Pollution in Packaging," 2021.

[14] R. Patel, "Reducing Plastic Waste Through Biodegradable Materials: A Global Perspective," *Environ. Sustain. Rev.*, vol. 34, no. 3, pp. 204–212, 2021. https://doi.org/10.1016/j.crgsc.2022.100273

[15] P. Johnson, *Integrating biodegradable materials into existing supply chains*. 2020. https://doi.org/10.3389/fenvs.2023.1245846

[16] J. & B. S. Green, "Sustainable Packaging Solutions: Opportunities and Challenges in Modern Industry," 2021.DOI**:**https://doi.org/10.14207/ejsd.2024.v13n2p63

[17] UNEP, *Reducing Plastic Waste: Biodegradable Alternatives and Environmental Impact*. 2022.https://doi.org/10.1016/j.cogsc.2021.100490

[18] Z. Wang, L. Nie, E. Jeronen, L. Xu, and M. Cn, "Understanding the environmentally sustainable behavior of chinese university students as tourists: an integrative framework," *Int. J. Environ. Res. Public Health*, vol. 20, no. 4, p. 3317, 2023, doi: https://doi.org/10.3390/ijerph20043317.

[19] T. D. Moshood, G. Nawanir, F. Mahmud, F. Mohamad, M. H. Ahmad, and A. AbdulGhani, "Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution?," *Curr. Res. Green Sustain. Chem.*, vol. 5, p. 100273, 2022, doi: https://doi.org/10.1016/j.crgsc.2022.100273.

[20] M. Ghobakhloo, M. Iranmanesh, A. Grybauskas, M. Vilkas, and M. Petraitė, "Industry 4.0, innovation, and sustainable development: A systematic review and a roadmap to sustainable innovation," *Bus. Strateg. Environ.*, vol. 30, no. 8, pp. 4237–4257, 2021, doi: https://doi.org/10.1002/bse.2867.

[21] D. Barrowclough and C. D. Birkbeck, "Transforming the global plastics economy: the role of economic policies in the global governance of plastic pollution," *Soc. Sci.*, vol. 11, no. 1, p. 26, 2022, doi: https://doi.org/10.3390/socsci11010026.

[22] H. H. B. M. Faris *et al.*, "The Effect of Eco-Friendly Packaging on Consumer Purchase Intention: A Study of Beverage Sustainable Packaging Practices," *J. Community Dev. Asia Vol*, vol. 7, no. 1, pp. 91–104, 2024, doi: https://doi.org/10.32535/jcda.v7i1/253.

[23] J. Nilsen-Nygaard *et al.*, "Current status of biobased and biodegradable food packaging materials: Impact on food quality and effect of innovative processing technologies," *Compr. Rev. food Sci. food Saf.*, vol. 20, no. 2, pp. 1333–1380, 2021, doi: https://doi.org/10.1111/1541-4337.12715.

[24] D. Kasznik and Z. Łapniewska, "The end of plastic? The EU's directive on single-use plastics and its implementation in Poland," *Environ. Sci. Policy*, vol. 145, pp. 151–163, 2023, doi: https://doi.org/10.1016/j.envsci.2023.04.005.

[25] T. Narancic, U. C. Dublin, S. Verstichel, I. Researcher, C. S. Reddy, and L. Morales-Gamez, "Biodegradable Plastic Blends Create New Possibilities for End-of-Life Management of Plastics but They Are Not a Panacea for Plastic Pollution," 2018, doi:DOI:10.1021/acs.est.8b02963.

[26] G. Wandosell, M. C. Parra-Meroño, A. Alcayde, and R. Baños, "Green packaging from consumer and business perspectives," *Sustainability*, vol. 13, no. 3, p. 1356, 2021, doi:https://doi.org/10.3390/su13031356.

[27] N. Hyder, L. S. of Economics, A. Amir, and L. U. of M. Science, "Impact of Green Packaging on Consumer's Buying Behavior: The Mediating Role of Attitude," 2023, doi: I:10.55041/IJSREM25741.

[28] & R. R. A. L. H. Lee, "Consumer Preferences for Biodegradable Packaging Materials: A Global Survey," *J. Sustain. Packag.*, vol. 5, no. 2, pp. 135–145,2021.https://doi.org/10.1016/j.jclepro.2018.05.106