Bioplastic Materials to Reduce Marine Plastic Litter in the Asia-Pacific Region

APEC OCEAN AND FISHERIES WORKING GROUP

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Asia-Pacific
Economic Cooperation

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I. BACKGROUND

Marine plastic pollution has gained significant global attention due to its growing environmental impact. The sight of litter on beaches and waterways has become increasingly common worldwide, and this marine debris is causing substantial harm to the environment, public health, and the economy. Currently, over eighteen trillion pounds of plastic have been manufactured whereas eighteen billion pounds of their waste find their way into the oceans annually (Gibbens, 2018). Moreover, it is projected that by 2040, 1.3 billion tons of plastic waste will have polluted both the world's land and oceans (Gill, 2020). This is alarming news, considering that plastic waste is difficult to degrade and can contaminate both terrestrial and marine environments, impacting life and ecosystems.

Approximately eighty percent of marine debris comes from terrestrial origins, including poorly managed landfills, industrial sites, wastewater discharge, stormwater runoff, and coastal tourism activities. In the East Asia and the Pacific economies alone, it accounts for 23% of the world's solid waste production, averaging 0.56 kilograms per person per day. This sets a global record for the highest levels of waste generation. Specifically, in 2016, six ASEAN member states, namely Indonesia; Thailand; Viet Nam; the Philippines; Malaysia; and Singapore, collectively generated 243 million tons of waste (ASEAN, 2021). While the economy rapidly consumes and disposes of plastic products, the overall waste collection coverage remains low at an average of 71%, leaving significant opportunities for plastic litter to enter waterways (Kaza et al., 2018).

The main issue with conventional plastic is its resistance to biodegradation, making it difficult to eliminate plastic waste from the environment. Plastic waste is also less efficient to recycle due to its low melting point, which makes it difficult to remove contaminants. As a result, the quality of recycled plastic tends to be lower than its original quality (Moore & Curley, 2009). Furthermore, incinerating plastic for energy production tends to be inefficient, requiring emissions control and producing hazardous combustion residues (UNEP, 2014). According to a survey conducted by the United Nations Environmental Programme (UNEP, 2014), approximately 22-43% of global plastic waste is disposed of through landfilling. However, this method could damage environmental aesthetics, release harmful chemicals into the environment, as well as result in wasted plastic without recycling efforts (Wijayanti et al., 2016).

However, despite being persistent in nature and contributing to environmental pollution, plastic remains one of the vital materials in modern life for people. For instance, it facilitates the development of technological products such as smartphones, computers, medical devices, and various other items. Furthermore, plastic is made from inexpensive and readily available raw materials, making plastic-based products accessible to a wide range of people. Therefore, there is a need for environmentally friendly plastic alternatives. One such alternative is bioplastic. Bioplastics are being recognized to promote the sustainable expansion of the plastics industry that offers a robust substitution for synthetic plastics in the near future. They have the potential to shift a considerable portion of large-scale plastics toward alternative waste management methods, particularly single-use plastics that pose recycling challenges. This reorientation is quite promising to support the plastic industry's sustainable development.

Bioplastic is generally defined as a material derived from renewable sources that can naturally degrade and can be used as a solution to address single-use plastic waste issues. Biodegradation is the process in which organic materials are broken down by the enzymes of living organisms, such as bacteria and fungi, making biodegradable materials more environmentally friendly as they are easily decomposable (Vert et al., 2012). Examples of biodegradable materials commonly used to create eco-friendly plastics include vegetable oil, potatoes, cornstarch, corn husks, pea starch, or microbiota. Additionally. according to the European Bioplastics Organization (EBO), the term 'bioplastics' encompasses two fundamental aspects: the plastic's origin, which can be bio-based, and its potential for biodegradation (refer to Figure 1). Bio-based plastics, as defined by the European Standard EN 16575 from 2014, are those derived from plant-based materials, often referred to as biomass. However, it's crucial to note that not all bio-based plastics exhibit biodegradable properties, and biodegradability is not exclusive to bio-based plastics (Cruz et al., 2022).

At present, bioplastics might be more appropriately applied to single-use consumer goods, such as food packaging, eating utensils, straws, or medical waste bags. It was currently reported that bioplastics constitute only 1% of the total global plastic production, which stands at 370 million metric tonnes in 2019. Substituting conventional plastics with bioplastics can be very challenging due to the superior durability, versatility, and lower cost of the synthetic plastics. Nevertheless, ongoing massive research and development efforts are underway to enhance the appropriateness of bioplastics across various industries. Researchers are exploring these environmentally friendly plastics for durable goods, such as phone cases, carpet fibers, car interiors, plastic pipe applications, and electricity (Suszkiw, 2005). Additionally, they are also frequently used as materials for making bags, trays, containers for fruits, veggies, eggs, and meat, as well as bottles for soft drinks, dairy products, and protective wrappings for fruits and veggies. It is projected that by 2025, annual growth rates will soar to approximately 30% (Moshood et al., 2022).

The Asia-Pacific economies takes the lead in producing more than 45% of bioplastics and biopolymers, valued at USD 2,548.3 million in 2021. China has been the largest market for bioplastics in this economy. Various companies in Europe, the US, and Asia are bioplastics producers, including prominent players like Corbion N.V. (Netherlands), Novamont (Italy), BASF (Germany), NatureWorks LLC (the US), Tianjin Guoyun (China), and CJCheilJedang (Korea). (www.straitresearch.com)

An increasing number of governments, both on the international and economy levels, have taken strategies to combat single-use plastics. These commodities, often used in short period and then disposed, contribute to a significant source of waste particularly in terms of marine litter. Furthermore, within various industries, the packaging sector emerges as the predominant consumer of plastics, accounting for roughly 40% of their utilization. Notably, in the European Union (EU), plastic packaging constitutes nearly 60% of post-consumer plastic waste. Most of this packaging serves a single-use purpose, and the lack of recycling and reuse, coupled with system failures, results in the generation of substantial quantities of solid waste. This, in turn, contributes significantly to adverse impacts on both terrestrial and marine ecosystems. On average, per capita generation of plastic packaging waste witnessed an increase from 27 kg to 35 kg between 2009 and 2019 (Cruz et al., 2022).

There are several factors that drive the adoption of bioplastics, encompassing the bioplastic performance, consumer perception, regulations, technological advancements, and resource availability. While the adoption and long-term viability of bioplastics rely on two technological areas: materials production and waste management (Moshood et al., 2022). From those factors, the increasing trend of restrictions on conventional plastics is considered as the major catalyst for the growth of bioplastic market. Due to environmental concerns in many Asian economies like China; India; Indonesia; Viet Nam; Thailand, and others, businesses are increasingly adopting bioplastics to capture a larger share of the consumer market. Consequently, the Asia-Pacific bioplastics market is on the rise. The enforcement of plastic bans in various economies, coupled with technological advancements, supportive regulations, and the business environment, are among the factors boosting the market forward.

Some economies, like the United Kingdom, have achieved success through the implementation of fees on single-use plastic bags, while others have chosen to enact an outright ban. For instance, Korea has instituted a ban on plastic bags in major supermarkets and bakeries, accompanied by a substantial fine of three million won (equivalent to roughly USD 2,600). These policies are typically adopted and enforced at the state, provincial, or municipal level within the US and Mexico. Chinese Taipei stands out with one of the most comprehensive strategies aimed at addressing the issue of single-use plastics. The initiative began with a prohibition on certain dining establishments, including chain restaurants and schools, distributing straws to customers in 2019. This restriction was later expanded to include all dining establishments starting in 2020. Concurrently, the government introduced fees for retailers providing complimentary plastic bags, disposable food and beverage containers, and utensils. The long-term goal is to implement a complete ban on single-use bags, utensils, straws, and containers by the year 2030.

Various policies and policy instruments are expected to shape the expansion of the bioplastics sector. These encompass policies on bioresources management, policies promoting research and development, trade and manufacturing policies, as well as mechanisms like subsidies, tax incentives, diversity quotas, standardization initiatives, and regulatory measures. Common characteristics and trends can be observed across economies: Few economies have established dedicated policies specifically aimed at bioplastics. Instead, many economies have primarily focused on policies promoting biofuels and bioenergy, which can put bioplastics at a disadvantage when it comes to competing for biomass resources. In fact, the adoption of comprehensive bioplastic strategies is mainly limited to the use and recycling of plastic bags. Several economies have implemented research and development initiatives and innovative policies to bolster the bioplastics sector. Many economies are actively striving to improve their capacity for manufacturing bioplastics, albeit constrained by the cost of expanding major facilities. The significant role of public procurement in stimulating industry growth has been acknowledged, particularly in large economies such as the US and the European Union. Moreover, there is a growing interest in formulating comprehensive bio-economic policies, with the potential for specific bio-plastics programs in numerous economies worldwide (Moshood et al., 2021).

To develop effective strategies for mitigating environmental pollution caused by plastic waste, various economies, including the Asia-Pacific that notably contributes to ocean plastic pollution, are engaging in collaborative efforts through organizing a discussion forum, namely

Workshop on Promoting Bioplastic Materials to Reduce Marine Plastic Litter in the Asia Pacific Economies. These forums will be attended by relevant representatives from each member of economies. The objective is to gain a comprehensive understanding of effective approaches to managing plastic waste and identifying practical steps to replace conventional plastics as the source of pollution, with bioplastics.

Prior to the workshop, preliminary research was conducted to gather a comprehensive understanding of the current state of bioplastic adoption in APEC member of economies. We aimed to identify the initiatives taken by the governments within the economies that aim to mitigate the marine ecosystems damage caused by plastic waste pollution. To achieve this, we sought to uncover a range of key information, including: (1) Existing regulations across the APEC economies related to initiatives for reducing plastic waste and their implementation; (2) Public perceptions in some representative APEC member economies regarding policies and their implementation in the context of plastic waste reduction; (3) Innovative practices and solutions already in place within APEC economies; (4) Collaborative efforts among various stakeholders within each economy to address the issue, and; (5) Initiatives undertaken by each economy to endorse the use of eco-friendly plastics and promote public awareness surrounding their adoption.

Information was collected by engaging key stakeholders, including experts, academics, policymakers, representatives from bioplastic companies, the general consumers, retail companies, and other relevant parties. Data gathering methods included conducting focus group discussions, distributing questionnaires, and conducting direct interviews.

The findings from this pre-workshop research will serve as a groundwork to formulate steps or policy recommendations. These recommendations will subsequently be presented and discussed during the workshop. Through these discussions among workshop participants, the aim is to generate practical strategy recommendations that align with the workshop's objective of mitigating marine environmental harm by promoting the use of eco-friendly plastics.

CHAPTER II. LITERATURE STUDY

2.1. Definition of Bioplastic

Bioplastics are a category of plastics derived from natural and renewable biomass sources such as sugarcane, corn starch, wood, waste paper, vegetable oils, fats, bacteria, algae, and more. In contrast, most commercially available plastics are produced from non-renewable petroleum-based sources, which can be detrimental to natural ecosystems. Bioplastics, however, pose no harm to the environment as they can naturally decompose into carbon dioxide. Consequently, there is a rapid increase in demand for bioplastics in various applications. Products crafted from bioplastics should be promoted for commercialization due to their renewability, biodegradability, compostability, and eco-friendliness (Sidek et al., 2019). Another definition of bioplastics are a type of plastic that are either biobased, biodegradable, or both. Due to their biodegradability and renewability, bioplastics are established as earth-friendly materials that can replace non-renewable plastics. However, early bioplastic development has been hindered by higher production costs and inferior mechanical and barrier properties compared to conventional plastics (Abang et al., 2023).

Polymers can be sourced directly from biomass, such as starch and cellulose, or produced through fermentative processes involving microorganisms, like polyhydroxyalkanoates (PHA), with an appropriate carbon source. Additionally, plant biomass can be chemically or biocatalytically transformed into precursor materials for various polymers, including polylactide (PLA) and polyolefins. It's worth noting that biobased products need not rely entirely on renewable sources; they can also incorporate raw materials derived from fossil fuels. Carbohydrate-rich food crops like corn or sugar cane are commonly employed in the production of biobased polymers, while non-food crops, like lignocellulosic materials, can be converted into chemical building blocks suitable for crafting a wide array of bioplastics. Although currently not economically feasible, this approach holds promise as a viable solution in the future. Furthermore, bioplastics can be derived from animal biomass (e.g., whey and chitosan) as well as protein- or oil-rich plant biomass (e.g., soy protein isolate and castor oil) (Geueke, 2020).

As per the European Bioplastics Association's definition (2021), a polymer qualifies as a bioplastic if it possesses either bio-based characteristics, biodegradability, or a combination of both (refer to Figure 1).

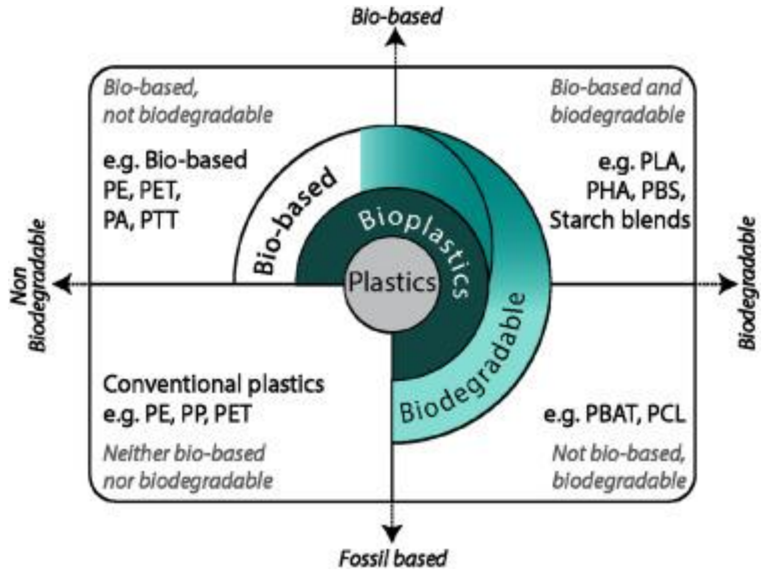


Figure 1. Illustrates distinct categories of bioplastics categorized according to the source of their raw materials and their environmental impact (Lavagnolo et al., 2023)

Bioplastics are often categorized based on their underlying chemical structure. Another useful way to classify bioplastics is to distinguish between two main categories: biodegradable and non-biodegradable varieties. Bioplastics are composed of materials derived from natural sources, including plants, animals, and microorganisms. These materials are typically, if not entirely, renewable resources.

Adding to the confusion is the common misconception that "biodegradable" and "compostable" are synonymous. "Compostable" actually refers to the ability of an organic material to biodegrade and transform into compost. The ISO 17,088:2021 standard defines compost as an "organic soil conditioner obtained by the biodegradation of a mixture primarily composed of plant residues, occasionally with other organic material, and having limited mineral content." Unlike the definition of "biodegradable," the definition of "compostable" outlines specific requirements that must be met for a plastic to be classified as "compostable." These requirements are established by European standards EN 13,432 and EN ISO 14,995 and include biodegradability (within six months, 90% of the material must be consumed by microorganisms and converted into CO_2), disintegrability (within three months, 90% of the material must consist of fragments smaller than two millimeters), absence of negative effects on the composting process, and low levels of heavy metals and no toxicity in the final compost (Lavagnolo et al., 2023)

2.2. Source material of Bioplastic

There are several source materials of bioplastic, which consists of plant-based bioplastics (cellulose, starch, protein based bioplastic), bacteria based bioplastics (Polyhydroxyalkanoates, and polylactic acid), micro algae, macroalgae, Polycaprolactone, and Oxo-biodegradable plastics (Jayakumar et al., 2023)

Bioplastics, derived from plant-based sources such as corn starch, vegetable oils, fats, wood chips, and other bio-waste materials, have gained commercial importance. Among these, starch-based bioplastics are extensively utilized in the production of biodegradable food packaging, bags, injection molding, and foam products. These starch-based plastics are manufactured using processes like blowing, injection molding, extrusion, and vacuum forming (Sirohi et al., 2021).

In-depth, starch-based polymers are typically biodegradable polysaccharide compounds serving as an alternative to polystyrene (PS) materials. They find application in various sectors, including food processing, disposable tableware and cutlery, coffee machine capsules, and bottles. Starch, known for its affordability, renewability, and wide availability, serves as the foundation for these biopolymers. However, due to intermolecular tensions and hydrogen bonding, starch alone cannot be classified as a thermoplastic material. Consequently, the addition of a plasticizer (such as urea, glycerol, sorbitol, or glycerin) along with water is necessary to create thermoplastic starch (TPS), a flexible thermoplastic polymer (Khan et al., 2017).

Cellulose-based polymers represent another category of biodegradable polysaccharides. Nonetheless, they come with certain drawbacks, including limited water vapor barrier properties, subpar mechanical characteristics, challenging processing, and inherent weakness, particularly in the case of pure cellulose polymers. Cellulose, composed of glucose monomers linked by beta (one to four) linkages, is found predominantly in wood and shares similarities with starch. Cellulose is known for its exceptional mechanical strength, flexibility, biodegradability, and biocompatibility. Its hydroxyl groups allow it to form hydrogen bonds with neighboring molecules, facilitating crystallization (Holtzapple, 2003). Some research on bioplastics from cellulose is cellulose-xylan hemicellulose hydrolyzed lignin (Tedesschi et al., 2020).

Protein-based biomaterials are also emerging as promising sources for bioplastic production. Proteins sourced from both plants (such as soy, corn, pea, and whey gluten) and animals (collagen, gelatine, milk, and albumin) have been extensively studied for their potential in bioplastic production. Soy protein-based bioplastics, in particular, are gaining prominence due to their affordability, biodegradability, and functional thermoplastic properties (Perez et al., 2016).

Bioplastics produced from microbial sources hold great promise as sustainable alternatives to non-biodegradable petroleum-based plastics. These include polyesters, polyhydroxyalkanoates (PHAs), and polylactic acid (PLA) (Naser et al., 2021). Polylactide (PLA) is also known as one of the thermoplastic forms of biodegradable polyester. It consists of alternatives to polyethylene (LDPE and HDPE), polystyrene (PS) and polythylated poly (PET) of low and high density and is extensively used in the manufacturing of translucent, rigid containers, bags, jars and films (Wagner, 2014). PHAs, in particular, exhibit resistance to hydrolysis and offer excellent UV barrier properties, although they are soluble in chloroform and similar solvents but insoluble in water. PLA, derived mainly from corn starch, is a biodegradable thermoplastic polyester with high biocompatibility. Its monomer, lactic acid, is typically obtained through bacterial fermentation of corn, potatoes, and sugarcane (Balla et al., 2021). The high molecular weight, water solubility, excellent processing characteristics, and biodegradability of PLA render it a highly suitable material for use in food packaging (Webb et al., 2013)

Microalgae represent an intriguing alternative to traditional plastics, boasting higher levels of protein and carbohydrate polymers (Onen Cinar et al., 2020). These unicellular or multicellular photosynthetic organisms have the potential to produce various valuable metabolites applicable in food, bioplastics, bioenergy, and pigments (Liu et al., 2016; Ummalyma et al., 2020). Spirulina and chlorella, in particular, are microalgae known for their elevated protein content relative to their dry weight (Bhalamurugan et al., 2018). The development of bioplastics from microalgae using next-generation methods holds significant promise.

Bioplastics derived from seaweeds can be obtained through mechanical, biological, or chemical extraction methods. Unlike conventional plastics, seaweed-based bioplastics do not degrade into microplastics, making them environmentally superior. However, these bioplastics are often limited by their weaker mechanical and water barrier properties.

PCL is a biodegradable polyester made by ring-opening ε-caprolactone polymerization. This is a non-renewable resource. Because of its low melting temperature and biodegradability, for the most part, pure PCL is employed in medical applications. The low melting point (62 °C) makes it ideal for blending with other biopolymers (e.g., starch). PCL blends are also used as food contact materials (FCMs) (Tyler and Gregg, 2019)

Oxo-biodegradable plastics, which are petroleum-based polymers containing additives to enhance degradation, are notable. These additives typically consist of metal salts of carboxylic acids and dithiocarbamates, with transition metals like iron (Fe), nickel (Ni), cobalt (Co), and manganese (Mn) employed to aid degradation (Thomas et al., 2012). Oxo-biodegradable plastics can undergo degradation through both abiotic and biotic processes. Initially, oxidative degradation occurs with the action of prooxidants, followed by the conversion of oxidation products into carbon dioxide and biomass by microorganisms in a process known as oxo-degradation (Melchor-Martínez et al., 2022).

2.3. Standar and Certification

The three internationally acceptable standardization bodies are i) the international Organization for Standardization (ISO), the American Society for Testing and Material (ASTM) and the European Committee for Standardization (CEN). Standard-based labels will easily and clearly communicate and claim superiority in the usability of that particular product. All accepted standards are further certified, and a label or logo will be given for easy identification.

There are standards for bioplastic, biodegradable plastics, industrial composting, and standards for biodegradable in soil and marine environments. The European committee for standardization has forwarded some criteria for the bio-based conduct determination: the European norm EN 16640: analysis of carbon content by the radiocarbon method and based on biocarbon content, certificates can be obtained, EN 16785-1 (analysis of carbon content by radiocarbon method and elemental analysis), and EN 167855-2: a renewable content analysis by material balance method. (Jayakumar et al., 2023)

Standard for biodegradable plastics consist of: EN 13432 (biodegradable packaging) and EN14995 (This standard also defines the identical criteria set forth in TN 13432.) The industrial composting standard comprises the following elements: Australian Norm AS 5810, which allows for the home composting of biodegradable plastics; TUV AUSTRIA Belgium, stipulating that materials should achieve a biodegradability rate of 90% within 12 months at ambient temperature; and NF T 51-800, the French standard.

TÜV Austria Belgium has established a scheme focused on the degradation of bioproducts in both soil and marine environments, aligning with the EN 13432/EN 14995 standards. This scheme mandates that materials must undergo a 90% degradation within two years at ambient temperature. The EN standard 17,033 additionally outlines the criteria for biodegradable films, as previously mentioned. It's worth noting that certain standards, such as ASTM D7081, which pertained to the biodegradability of plastics in marine settings, have been discontinued.

- ASTM D6691 standard: determine the aerobic biodegradation of plastics in marine environments.
- ASTM D6692: method to determine the biodegradability of radiolabelled polymeric plastics materials in sea water
- ASTM D7473: method to determine the weight abrasion of materials in marine environment
- ISO 18830: standard method that determines aerobic biodegradation of non-floating plastic materials in sea water.

2.4. Drivers and barriers for consumers purchasing bioplastics

Most of the research in the field of bioplastic packaging applications has primarily centered on quantitative consumer surveys, particularly in areas such as food and beverage packaging. Findrik & Meixner stated that the research has highlighted several barriers to consumer adoption of bioplastics. These obstacles include consumers' limited knowledge about the environmental impact of bioplastics, uncertainties surrounding factors like material sourcing and end-of-life characteristics compared to conventional plastics, and the challenge of distinguishing bioplastics from traditional plastic materials. On the flip side, the research has also identified various drivers that encourage consumers to purchase bioplastics.

These include a positive consumer attitude toward environmentally friendly products, the availability of clear product information, and consumers' alignment with green values. Furthermore, bioplastic products that align with consumer preferences, such as affordability, a biogenic resource base, and local sourcing, have been found to act as strong motivators for purchase. There is a call for more in-depth analysis of labelling systems associated with bioplastic products, which can play a crucial role in shaping consumer perceptions and choices (Findrik & Meixner, 2023).

2.5. Bioplastics Productions

Global bioplastics production capacity is poised for a significant surge, projected to escalate from approximately 2.4 million tonnes in 2021 to 7.5 million tonnes by 2026. This remarkable growth is primarily driven by the substantial increase in the production of biodegradable materials like PBAT (polybutylene adipate terephthalate), which is expected to nearly quadruple. Additionally, PBS (polybutylene succinate) and bio-based PAs (polyamides) are contributing significantly to this expansion. The production of polylactic acid (PLA) will also continue to rise due to ongoing investments in PLA production facilities across Asia, the US, and Europe. Furthermore, production capacities for bio-based polyolefins, such as PE (polyethylene) and PP (polypropylene), have seen an increase as well. Currently, biodegradable plastics, including PBAT, PLA, and polybutylene succinate (PBS), constitute slightly over 64 percent (1.5 million tonnes) of the global bioplastics production capacity (Figure 2).

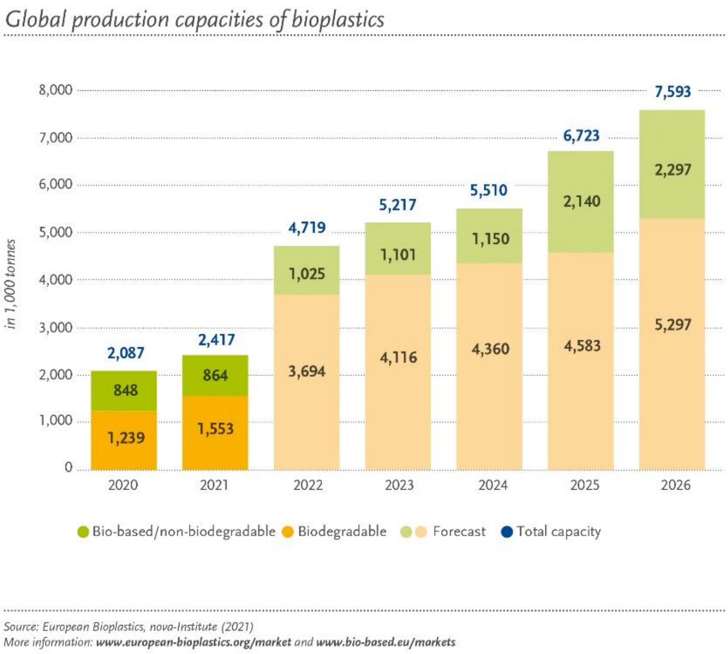


Figure 1. Global production capacities of bioplastics

Packaging remains the largest field of application for bioplastics with almost 48 percent (1.2 million tonnes) of the total bioplastics market in 2021. The data also confirms that bioplastics materials are already being used in many other sectors, and the portfolio of application continues to diversify.

Based on its raw materials, global bioplastics production in 2022 originated from PLA (20.7%); PE (14.8%); starch blends (17.9%); PTT (13.3%), and others (Figure 3).

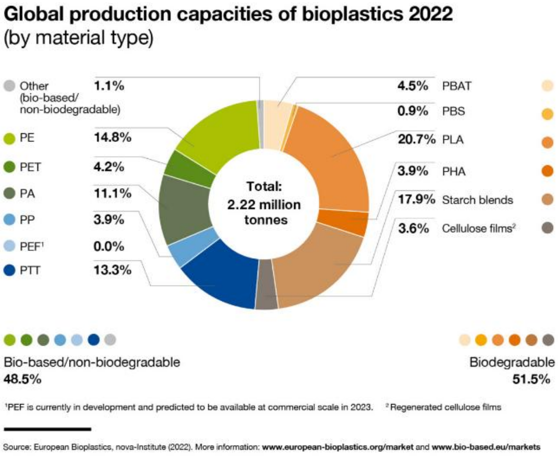


Figure 2. Global production capacities of Bioplastics 2022 by Material Type).
Source: https://www.european-bioplastics.org/bioplastics/materials/

Asia further strengthened its position as major production hub with almost 50 percent of bioplastics currently being produced in the economy. Presently, almost a fourth of the production capacity is still located in Europe. However, Europe's share and the share of other world economies will significantly decrease within the next five years. In contrast, Asia is predicted to have passed the 70 percent by 2026.

2.6. Bioplastic markets

The global bioplastics market size was valued at USD 7.56 billion in 2022 and is projected to grow from USD 8.72 billion in 2023 to USD 31.66 billion by 2030, exhibiting a CAGR of 20.2% during the forecast period (Figure 4).

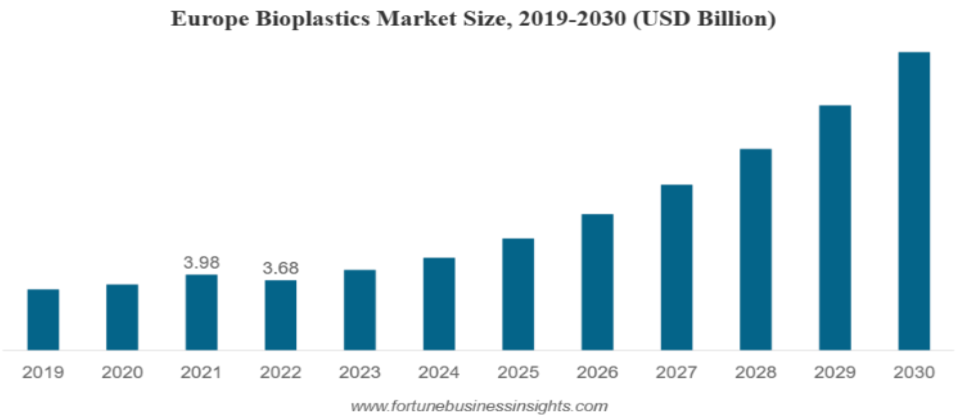
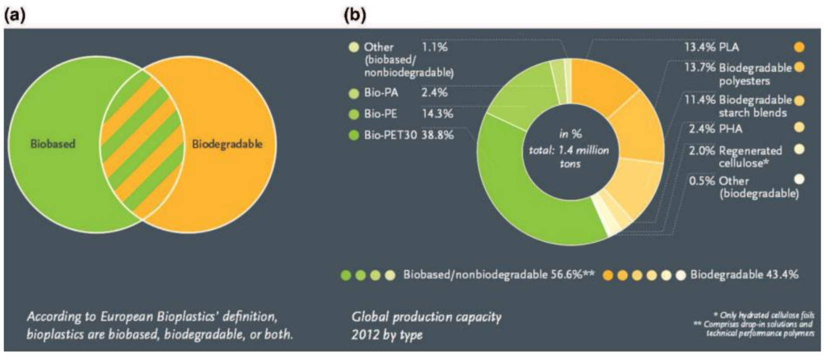


Figure 3. Europe bioplastics market size 2019-2030 (USD Billion)

(Source: www.Bioplastics Market Share, Growth & In -depth Analysis [2030])

The global bioplastics market is projected to grow from $7,616.0 million in 2021 to $15,552.3 million in 2028 at a CAGR of 10.7% in forecast period 2021-2028.



Source: (https://www.fortunebusinessinsights.com)

Figure 4. Market size for bioplastics a) biobased vs biodegradable materials b) split by material

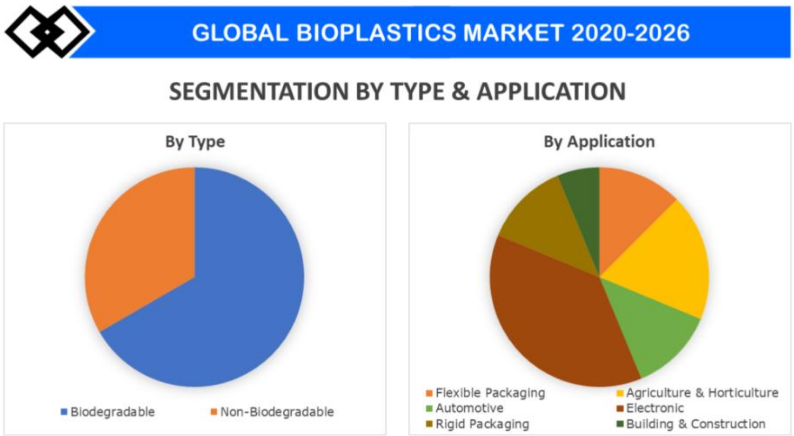


Figure 5. Global bioplastics market 2020-2026, segmentation by type and application

CHAPTER III. METHODOLOGY

3.1. Method

3.1.1. General approach

This study was grounded in a comprehensive dataset obtained through the application of three distinct data collection methodologies: (i) scopus database search, (ii) surveys, (iii) field observations, and (iv) in-depth interviews. The data was then carefully analyzed using bibliometric analysis (Donthu et al., 2021) and descriptive statistical approaches (Montgomery D. C. et al., 2003). In brief, this study was conducted following schematic steps as illustrated in Figure 7.

Search was done using the Scopus database with a time range created entirely (without time limits). The search is carried out through the following process: Data Collection Method Data collection was conducted on September 26, 2023, using the Scopus database. VOSviewer is software developed for analysing and creating bibliometric maps.

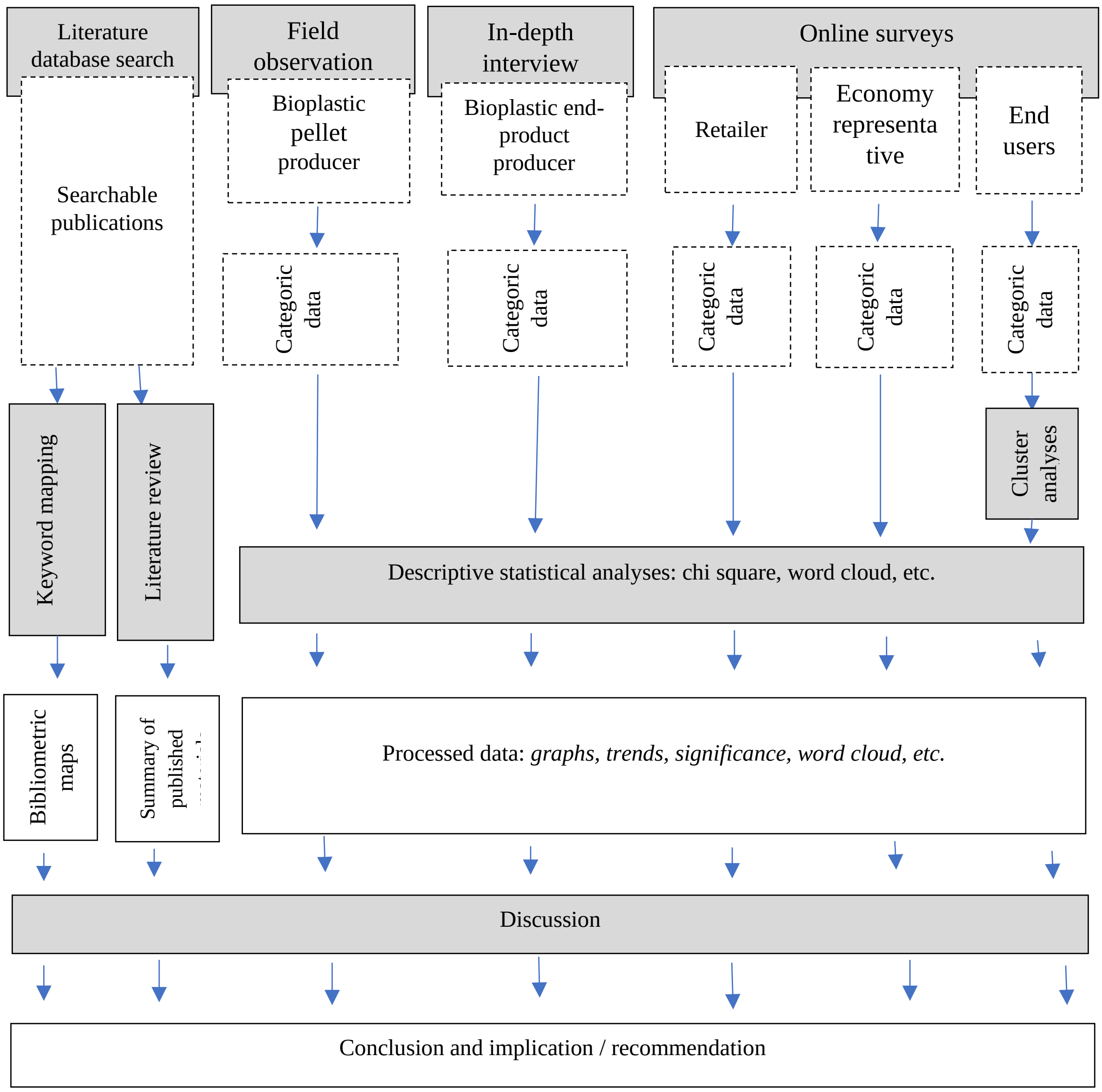


Figure 6. The research schematic step

3.1.2. Data collection

a. Scopus database search

Search using the Scopus database with a time range created entirely (without time limits). The search is carried out through the following process. Data Collection Method Data collection was conducted on September 26, 2023, using the Scopus database. Keyword searches were performed in the title, abstract, or keyword field (TITLE-ABS-KEY) with the following steps:

Table 1. Keywords searches

Initial search	TITLE-ABS-KEY ("bioplastic") AND (LIMIT-TO ("Australia") OR LIMIT-TO ("Canada") OR LIMIT-TO ("Chile") OR LIMIT-TO ("China") OR LIMIT-TO ("Hong Kong") OR LIMIT-TO ("Indonesia") OR LIMIT-TO ("Japan") OR LIMIT-TO ("Malaysia") OR LIMIT-TO ("Mexico") OR LIMIT-TO ("New Zealand") OR LIMIT-TO ("the Philippines") OR LIMIT-TO ("Peru") OR LIMIT-TO ("The Russian Federation") OR LIMIT-TO ("Singapore") OR LIMIT-TO ("Korea") OR LIMIT-TO ("Chinese Taipei") OR LIMIT-TO ("Thailand") OR LIMIT-TO ("the US") OR LIMIT-TO ("Viet Nam") OR LIMIT-TO (“Papua New Guinea”) OR LIMIT-TO (“Brunei Darussalam”)	Number of documents 1573

b. Literature review

Literature review was meant to uncover information regarding definitions of bioplastic, source material of bioplastic, standard and certification, drivers and barriers for consumers purchasing bioplastics, bioplastic market, bioplastic production, and export import data. The literature sources that we review to get this information are: journal, website, and database trademap (trademap.org).

c. Survey

We adopted an online survey approach (Evans and Zarb, 2005) to explore information about a number of relevant matters related to the development and use of bioplastics in community groups with various different characteristics. The variety of characteristics includes residence, age, sex, income, education and work. Samples from these community groups were drawn following the *random* sampling technique (Noor et al, 2022). *This random sampling* is intended so that the representation of the selected sample is free from bias in representing the total population. For this reason, we try to approach or represent the population so that it can be used as a bias-free representation. If there is a sample with dubious responses, then we discard the answers from the problematic sample. Sampling is declared to be error if the sample taken is suspected of not being representative of an existing population. In this survey, we obtained responses from samples from all parts of Indonesia. Considering the differences in human population inhabiting the economy, the samples from Java Island and Sumatra Island are more than samples from other parts of Indonesia.

d. In-depth interview

In this section, a qualitative descriptive methodological approach (Nassaji, 2015; Hennink et al, 2010) adopted to examine problems based on factual evidence obtained through interview techniques reinforced by observation and review of relevant documents. Snowball sampling technique (Naderifar et al., 2017), is used to identify and recruit individuals who are willing to be interviewed and have relevant knowledge. In our research, they were officials from bioplastic pellet manufacturers and pellet practitioner users who used it to make end products including various forms of plastic bags and cutlery. The interviews focused on gathering insights and explanations related to various aspects of bioplastics development. This includes aspects that we consider relevant such as production/fabrication, marketing, policies/regulations that must be observed. In operation, the interview was situational and contextual, with full involvement from the researchers.

e. Field observation

As mentioned above, field observation is needed to complete the explanation of the resource person in in-depth interviews. In this stage, referring to Kumar (2022), we made various direct observations. The objects we saw were bioplastic pellet plants and bioplastic end product plants. Relevant photographs were taken during our observations. In addition, we also seek additional information from the officers who guard these objects.

3.1.3. Analyses

a. Keyword Mapping

Keyword mapping was done using the VOSviewer program. VOSviewer is software developed for analyzing and creating bibliometric maps. The results of this mapping can be used to identify research gaps or novel research areas. This activity produces three data maps, namely network visualization, overlay visualization, and density visualization.

- The minimum occurrence counts for a keyword analyzed is set at 5. However, for the topic of bioplastics in the Asia-Pacific economies, the number of keywords is substantial, so an occurrence counts of 10 is chosen.
- With a minimum occurrence count of 10 (full counting), a total of 508 keywords meeting the criteria are obtained out of a total of 11,142 keywords.
- For ease of map readability, only the 508 keywords with the strongest co-occurrence relationships are displayed in the visualization.

b. K-Modes *Cluster analysis*

Cluster analysis was used in this research to categorize objects based on their similarity measures. In this analysis, we adopted the K-Modes Method, a widely recognized technique for grouping large sets of categorical data into specific clusters, each characterized by its mode or the most frequently occurring values (Khan and Ahmad, 2013). Through this clustering, it is expected that the proposed policy recommendations will be more focused, designed specifically according to these clusters. This is aimed at minimizing policy biases by implementing policies that are not overly general. The K-Modes method is capable of generating clusters through a more detailed process, requiring less computation time for cluster formation, and is highly effective in clustering high-dimensional data (Kartikasari et al., 2021).

The procedures involved in performing cluster analysis using the K-Modes method are as follows:

1. Decide on the number of clusters (k) to be created from a dataset comprising r data points. The number of data points should exceed the number of clusters.
2. Select the initial k modes from the data, which will serve as the cluster centers (centroids). The number of centroids chosen should correspond to the intended number of clusters.
3. Compute the distance between each object and every centroid. The distance is determined using the simple matching dissimilarity measure. For example, suppose B1 and B2 are respectively the first and second objects, each with n categorical variables. The level of dissimilarity between B1 and B2 can be defined as the total mismatch among corresponding categorical variables in both datasets. The greater the similarity between the two datasets, the smaller the mismatch value. The equation for this simple dissimilarity measure is presented as follows:

$$d(B1, B2) = \sum_{j=1}^{n} \delta\left(x_{1j}, x_{2j}\right)$$

$$\delta(x_{1j}, x_{2j}) = \begin{cases} 0, x_{1j} = x_{2j} \\ 1, x_{1j} \neq x_{2j} \end{cases}$$

Whereas

x_{1j} : the value of the jth variable for the first object.

x_{2j} : the value of the jth variable for the second object.

4. Objects are arranged based on their proximity to the centroid using the nearest neighbour formula. The specific cluster that is closest to an object can be identified by evaluating the value of the simple matching dissimilarity measure.
5. Once all the data has been placed into their closest clusters, the adjustment of centroids for each cluster based on the mode of each variable among the cluster members that have been formed.
6. Recalculating the distance of each data point to the new centroids is performed using the simple matching dissimilarity, similar to step (3). If, during the recalculated distance assessment, a data point is found to be closer to a different cluster than the current one, it is then repositioned into the closer cluster.
7. The steps (5) and (6) are repeated until no further data points change clusters. For respondents from the user community group, we collected data from 331 individuals residing across various provinces in Indonesia. These individuals represented a wide spectrum of educational backgrounds, income levels, occupations, and other relevant differentiating variables. Within this respondent pool, we examined the differences in responses to the questions listed in the survey questionnaire. We treated the questionnaire questions as variables, and for this study, we have 18 variables as outlined in Table 2:

Table 2. The variables of bioplastic user respondent groups

Label	Variables	Description
X1	Sex	0: Female 1: Male
X2	Residence	1: Sumatera 2: Jawa

		3: Lainnya
X3	Occupation	1:Civil Servant/Civil Servant under Contract/Government Contract Worker/Armed Forces/Police 2: Fisherman/Fish Farmer 3:Other Self-Employed (Merchant/Shop Owner/Tailor, etc.) 4: Laborer/Employee 5: Student 6: Retiree 7: Housewife 8: Others
X4	Age	1: Teenagers (< 20 years old) 2: Pre-productive (21-30 years old) 3: Productive (31- 60 years old) 4: Post-productive (> 60 years old)
X5	Average monthly income	1: Very low (< IDR 4 million) 2: Low (IDR 4-10 million) 3: Lower-middle (IDR 11-20 million) 4: Upper-middle (IDR 21-45 million) 5: High (> IDR 45 million)
X6	Respondents' knowledge of bioplastics.	1: 1: Completely unaware 2: Yes, a little knowledge 3: Yes, know a lot but not in detail 4: Yes, know a lot and know the details
X7	Respondents' knowledge regarding the adverse effects of conventional plastic usage.	1: Completely unaware 2: Yes, a little knowledge 3: Yes, know a lot but not in detail 4: Yes, know a lot and know the details
X8	Respondents' active role in addressing environmental issues caused by conventional plastic.	1: Completely unaware 2: Aware, but not actively engaged and still using conventional plastic as usual 3: Aware and actively engaged in efforts to reduce the use of conventional plastic 4: Aware and actively engaged, providing input on single-use plastic restriction regulations
X9	Respondents' knowledge of government regulations regarding the use of bioplastics	1: Completely unaware 2: Aware, through friends or social media 3: Aware, through mainstream media (radio, TV, newspapers, etc.) 4: Aware, through active face-to-face interactions conducted by government agencies
X10	Respondents' stance on regulations limiting the use of conventional plastic.	1: Disagree 2: Agree, but not currently 3: Agree if the situation becomes extremely critical 4: Agree under any circumstances
X11	Frequency of bioplastic usage by respondents	1: Never 2: Rarely 3: Often

		4: Always
X12	Services provided by the stores or groceries where respondents shop concerning the utilization of bioplastic containers/bags.	1: Sellers directly provide conventional plastic bags/containers. 2: Sellers offer buyers the choice of using conventional plastic or bioplastic. 3: Sellers encourage buyers to use bags/containers made from bioplastic. 4: Sellers require buyers to use bioplastic bags/containers
X13	Respondents' opinions on how law enforcement authorities approach imposing sanctions on stores or consumers regarding the use of bioplastics.	1: Never at all 2: Yes, for a while but not anymore 3: Yes, but not frequently 4: Yes, very strictly
X14	Respondents' attitudes towards government regulations concerning the reduction or prohibition of conventional plastics.	1: Disagree 2: Agree, but not currently 3: Agree if the situation becomes extremely critical 4: Agree under any circumstances
X15	Respondents' opinions on the current prices of bioplastic products/packaging	1: Very expensive 2: Somewhat expensive 3: Not expensive 4: Very cheap
X16	Respondents' opinions on the practicality of using bioplastics.	1: Far less user-friendly compared to using conventional plastic 2: Slightly less user-friendly compared to using conventional plastic 3: Nearly as user-friendly as using conventional plastic 4: More user-friendly than conventional plastic
X17	Respondents' opinions on the quality (strength) of bioplastic products.	1: Their strength is significantly below what I expected. 2: Their strength is approaching my expectations. 3: Their strength is already sufficient 4: Their strength exceeds what I need.
X18	Respondents' willingness to pay a higher price for bioplastic products.	1: Not willing 2: Willing, but not at the moment 3: Willing if necessary 4: Willing under any circumstances

Referring to the general guidelines mentioned above, we subsequently carried out the clustering steps as follows:

1. Determining values for k = 2, 3, 4, 5, 6, 7, 8.
2. Randomly selecting centroids (cluster centers) for each cluster.

3. Calculating the distance between each object and the centroid using a simple dissimilarity measure.
4. Assigning objects to the nearest centroid based on their distance.
5. Finding the mode of each variable as the cluster centroids.
6. Re-calculating the distance of each object to the new centroids using a simple dissimilarity measure.
7. Reassigning objects to the nearest centroid based on distance.
8. If any objects change clusters, repeat steps five through seven until no objects change clusters.
9. Determining the best cluster using the Dunn Index. The Dunn Index is formulated as follows:

$$D = \frac{min_{1 \le i < j \le n} d(C_i, C_j)}{max_{1 \le k \le n} d(C_k)}$$

Whereas

$d(C_i, C_j)$: The distance between cluster i and cluster j

$d(C_k)$: The distance among members within cluster k

10. Determining the profiling of each cluster
11. Testing the difference in the distribution proportions of data in each cluster using the Chi-Square test. The hypothesis used is as follows:

$H_0: p_1 = p_2 = \cdots = p$

H_1: There is at least one p-value that differs.

The chi-square test statistic is defined as follows (Triola, 2010):

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \left[\frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}} \right]$$

$$E_{ij} = \frac{n_{i.} . n_{.j}}{n}$$

Whereas

O_{ij} : The frequency of observations in row i and column j

E_{ij} : The expected frequency in row i and column j.

$n_{i.}$: The total number of observations in row i.

$n_{.j}$: The total number of observations in row j.
n : The total number of observations
r : The total number of rows
c : The total number of columns

The criterion for rejecting H_0 is met when the $\chi^2 > \chi_{tabel}$ at the significance level α with degrees of freedom $(r-1)(c-1)$, or when the p-value < 0.05.

c. *Chi-Square* Test

The chi-square test was used to assess the similarity of proportions for categorical variables within each group, including clusters. The data for this non-parametric analysis were presented in the form of a contingency table. We applied this analysis following the method described by Negara and Prabowo (2018). The steps involved in the chi-square test are as follows:

i. Formulating hypotheses. The hypotheses utilized are as follows:
$H_0: p_1 = p_2 = \cdots = p$
H_1: At least one p-value is different.

ii. Determining the expected frequency values (E_{ij})
$$E_{ij} = \frac{n_{i.}.n_{.j}}{n}$$
whereas:
$n_{i.}$: The number of observations in the ith row.
$n_{.j}$: The number of observations in the jth column.
n: The number of observations

iii. Calculating the *chi square* test statistics, as follows: (Triola 2010):
$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\left[\frac{\left(O_{ij}-E_{ij}\right)^2}{E_{ij}}\right]$$
whereas:
O_{ij} : The number of observations in row i and column j.
E_{ij} : The expected value in row i and column j.
r : Number of rows
c : Number of columns

iv. Determining the χ^2_{tabel} value at the significance level α with degrees of freedom $(r-1)(c-1)$ to assess statistical significance.

v. Compare the χ^2 value and χ^2_{tabel} value; reject the null hypothesis (H_0) if $\chi^2 > \chi^2_{tabel}$ atau if the $p-value < 0.05$.

d. Wordcloud

Wordcloud is a text mining technique used to visually represent specific verbal responses obtained from our survey. In this visualization, words are displayed with varying font sizes, reflecting how often they appear. As explained by Inayah and Purba (2020), Wordcloud analysis helps readers identify frequently mentioned words related to a specific topic. The size of each word in the Wordcloud corresponds to its frequency of occurrence. The steps involved in Wordcloud analysis are as follows:

i. Gathering data in the form of text-based information.
ii. Data sortation includes steps like word normalization, removal of irrelevant terms, and case folding to standardize the data structure.
iii. Sum the frequencies of word types that occur.
iv. Creating *Wordcloud*

e. Descriptive analysis

Descriptive analysis, also referred to as descriptive statistics (Bush, 2020), was used in this study to provide informative and comprehensible descriptions or summaries of the dataset for readers. This approach helps to elucidate insights from uninterpreted data. Descriptive analysis is widely utilized and is expected to remain a valuable tool for researchers due to its efficiency (Kemp et al., 2017). It is flexible and can be customized to address specific information needs. In general, the stages of this analytical process include the following:

1. Data Collection: This step involves gathering data, which can be accomplished through various methods, such as conducting surveys.
2. Data Sortation: In this phase, data is refined by tasks such as reformatting, categorization, or removal of outliers.
3. Application of Descriptive Statistics: To obtain the desired information, specific descriptive statistical techniques, such as creating charts or tables, are employed.

CHAPTER IV. RESULT AND DISCUSSION

4.1. Bibliometric of Bioplastic Research in APEC Economies

We conducted this bibliometric analysis to get an idea of the bioplastic-related matters being discussed by global scientists. The benefits that can be obtained by using bibliometric analysis methods, namely analyzing trends in individual research or fields of study, providing evidence for the impact of individual research or fields of study, and discovering new and emerging research fields.

The search results by year show that research on "Bioplastic Development in the Asia Pacific Economy" has been started since 1894. In 1895 to 1965 there was no publication, then from 1967 to 1977, 1979, from 1981 to 1989, and in 1992 there was no publication. The most publications are in 2022 with 285 documents as shown in Figure 8. The APEC economies that do not have publications on bioplastics are Brunei Darussalam and Papua New Guinea.

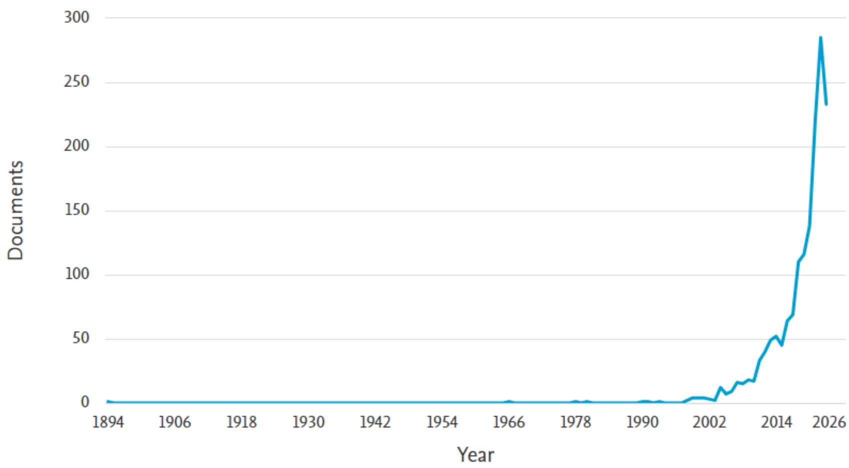


Figure 7. Number of publications by year**,** Growth trend in the number of publications in the period 1894-2023 (per year).

The publication with details each year can be seen in Table 3.

Table 3. The publication with details each year

Year	Total Publications	Year	Total Publications
1894	1	2005	7
1895 - 1965	0	2006	9
1966	1	2007	16
1967 - 1977	0	2008	15
1978	1	2009	18
1979	0	2010	17
1980	1	2011	33
1981 - 1989	0	2012	40
1990	1	2013	49
1991	1	2014	52
1992	0	2015	45
1993	1	2016	64
1994 - 1997	0	2017	69
1998	2	2018	110
1999	4	2019	116
2000	4	2020	138
2001	4	2021	219
2002	3	2022	285
2003	2	2023	233
2004	12	**Number of document**	**1573**

The distribution of authors studying bioplastic from 1894 to 2023 was analyzed in terms of economy. The graph is displayed in Figure 9 The US emerged as the most active collaborator. This highlights the US's significant involvement in bioplastic and its recognition of bioplastic application within the economy.

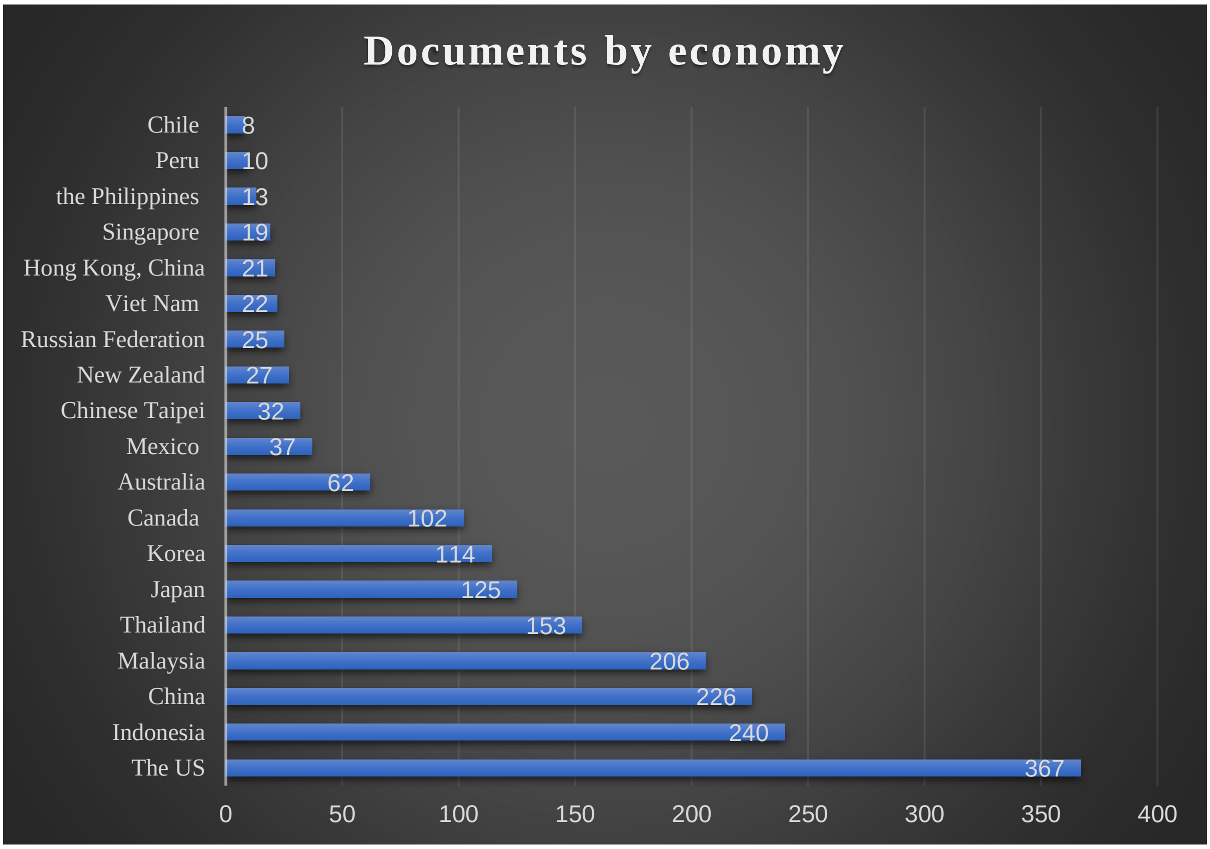


Figure 8. Number of publications of bioplastic publications in APEC Economy

Collectively, the US had the highest number of publications (367), and Indonesia produces 240 publications and followed by China with 226 publications in the Scopus database.

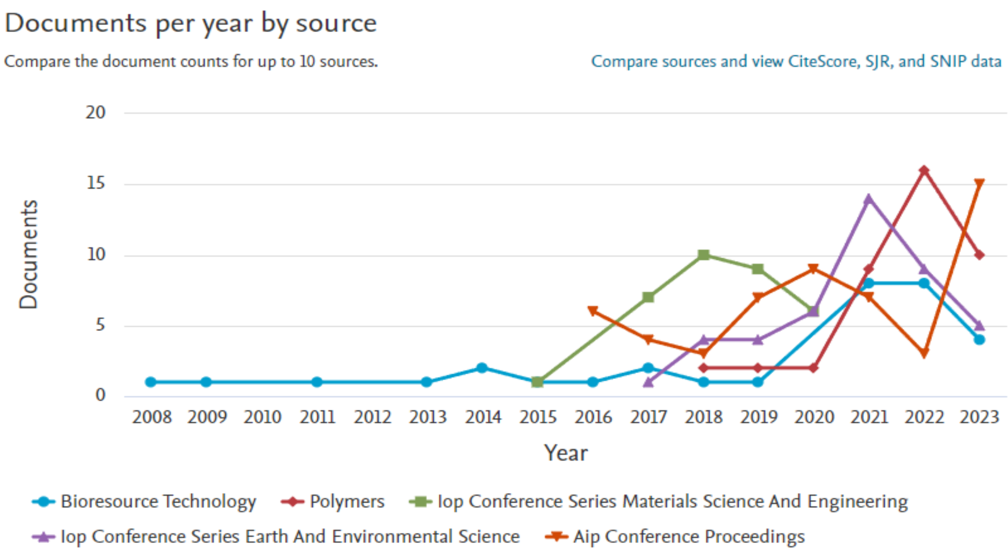
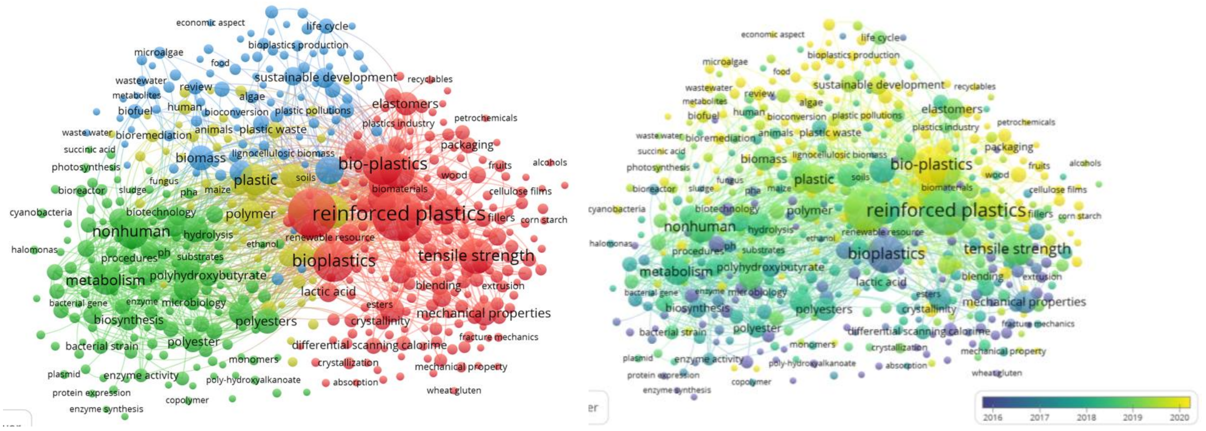


Figure 9. Number of publications by source

The results of network visualization show that the mapping of research words Bioplastic development in the Asia Pacific economies is divided into four clusters with a total of 508 keywords. The relationship between clusters as visualized with a display based on *network* between keywords as shown in Figure 11. The larger the circle or *node* that reads *keywords* or keywords taken from the title, abstract and keywords, means that the field has been done a lot. The closer the distance between *nodes* or keywords, it means that the relationship between these keywords is often used together in one journal article.



(a) (b)

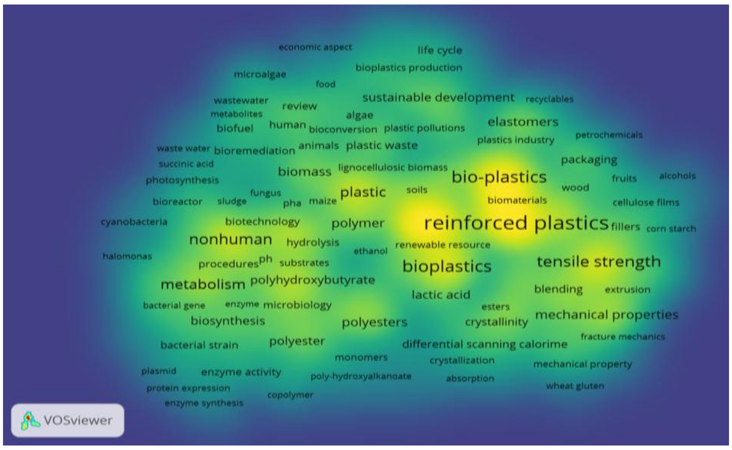


Figure 10. Mapping based on network keywords that often appear (a), Overlay visualization (b), and density visualization (c)

This visualization maps the historical footprint of the research. The dark color of the circle indicates research that has been done in a more distant time than the predetermined period of time. The results of this visualization show that the latest research topic (yellow circle). The 10 most recent keywords are economic aspect, life cycle, bioplastics production, microalgae, food, sustainable production, wastewater, sustainable development, and recyclables.

Based on density visualization, it shows that density is indicated by blue, green, and yellow nodes. The yellow nodes indicate the number of keywords that appear the most and are the most researched topics: bioplastic, reinforced plastic, tensile strength, metabolism, and non-human.

4.2. Review on Current Issues of Bioplastic Development in the World and APEC Economies

4.2.1. Export - Import

The global trade in bioplastics products has been growing rapidly. The world's export value has increased nearly sixfold, from USD 100,379,000 in 2013 to USD 592,119,000 in 2022 (Trademap.org, 2023). The US is the leading exporter of bioplastic products, accounting for nearly 50% of the market share. Thailand is one of the fast-growing exporters in this industry. In 2015, their exports were worth only USD 13,000, but they increased to USD 87,069 in 2022.

The export values from APEC economies during the period from 2013 to 2022 have mostly fluctuated and did not experience significant growth. Chinese Taipei and Thailand are the two major producers of tapioca starch, mainly exporting to several economies in Asia and Europe/USA.

During the period 2013-2022 there was an increase in exports and imports of world bioplastic products. The number of exports and imports has increased sharply since 2015, there has been an increase in the value of exports and imports almost 6 times (Figure 12).

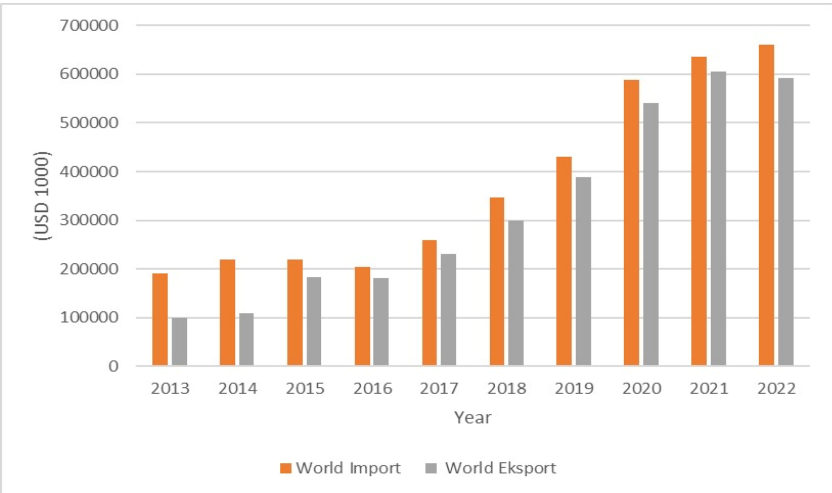


Figure 11. Export and Import Value of World Bioplastics in 2013-2022, in USD thousand) (Source: Trademap.org, processed)

Some of the major exporting economies include the US; Thailand; China; Japan; Korea; and Chinese Taipei. The export values of other economies fluctuate. Indonesia has not played a significant role in bioplastic export trade, with its value remaining very small and fluctuating. Considering the abundant availability of raw material resources for bioplastics, there is a need for policies to encourage the growth of the bioplastic industry in Indonesia. In addition to the availability of raw materials, there is an increasing demand for bioplastic products. The world's top exporters are the US, and Thailand, while the main importers are Chinese Taipei; China; Korea; and the US. (Table 4).

Table 4. Development of Bioplastics Export Value in 2013-2022

Exporters	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
World	100,379	109,634	184,159	180,937	231,699	298,710	388,986	541,038	605,068	592,119
Australia	-	3	3	1	-	48	214	43	37	36
Brunei Darussalam	-	-	-	-	-	-	-	-	-	-
Canada	97	116	88	272	283	94	342	314	280	354
Chile	-	-	10	12	1	-	75	44	-	7
China	2,283	2,675	2,447	9,003	9,196	11,664	9,202	10,319	23,483	29,144
Hong Kong, China	1,340	937	1,378	2,570	1,150	1,062	695	818	559	198
Indonesia	13	27	-	1	-	3	12	-	25	-
Japan	1,472	1,440	1,632	1,631	2,022	1,929	1,847	1,654	1,968	1,462
Republic of Korea	155	74	65	80	245	44	354	3,052	1,136	1,044
Malaysia	141	56	140	1,363	1,812	1,189	186	163	243	237
Mexico	12	-	56	285	-	159	-	-	-	-
New Zealand	547	146	22	58	3	14	8	8	36	63
Papua New Guinea	-	-	-	-	-	-	-	-	-	-
Peru	-	-	-	-	-	-	-	1	-	-
the Philippines	-	-	-	-	-	-	-	-	2	-
The Russian Federation	-	908	252	-	3	162	35	82	36	1
Singapore	1,141	319	47	21	45	196	134	27	62	93
Chinese Taipei	369	725	753	2,521	937	3,528	1,424	2,327	1,920	1,023
Thailand	69	7	13	288	1,035	4,175	46,563	74,477	111,056	87,069
the US	77,720	64,308	104,184	116,465	145,314	173,877	203,807	242,966	243,763	257,502
Viet Nam	-	-	-	6	2	-	43	2,221	609	61

Sumber: Trademap.org

Several economies are the world's bioplastic exporters, the US is a major bioplastic exporter. Thailand is an APEC economy whose export value is growing rapidly from 2015-

2022 (Figure 13). While some APEC economies develop relatively slowly (Indonesia; Viet Nam; the Philippines; Singapore; and Malaysia).

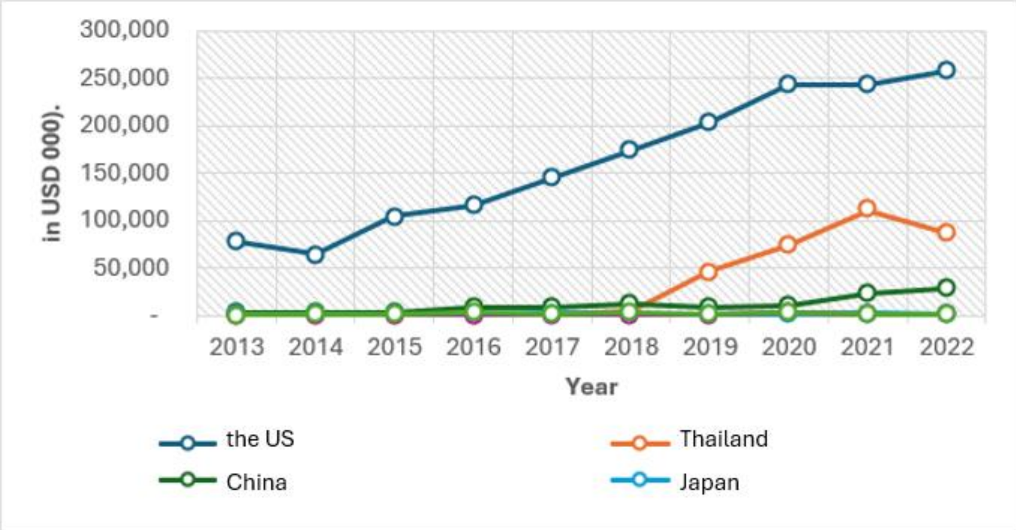


Figure 12. World's Top Bioplastics Exporters (in USD thousand).

(Source: trademap.org processed)

4.2.2. Bioplastic Product and Production

Based on statistical data reported by European Bioplastics in 2022, the highest utilization of bioplastic materials is in the production of packaging products, constituting a production capacity of 48%. This includes flexible packaging items such as shopping bags, multi-purpose plastic films, and others, as well as rigid packaging types like tray containers. Other significant product categories encompass textiles and consumer goods, constituting respectively 15% and 14% of the total usage. Additionally, products in various other sectors, including automotive, agriculture, electronics, construction, and others, individually account for less than 7% each of the overall production capacity.

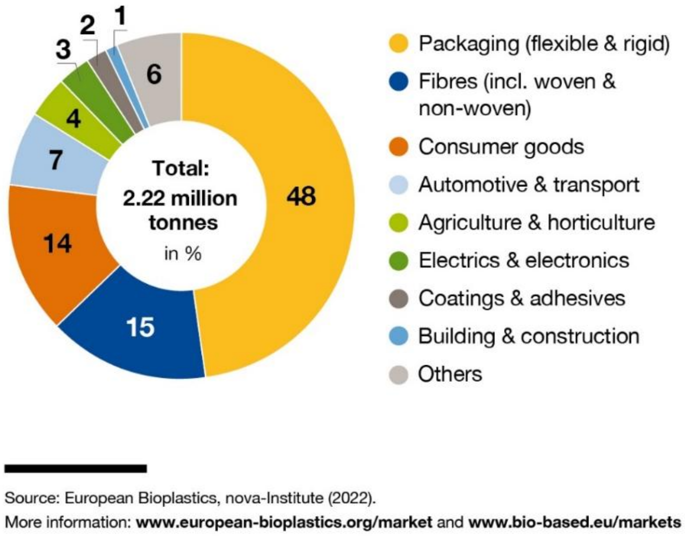


Figure 13. Global market segmentation of bioplastic-based products in 2022 (Source: European Bioplastics, 2023)

Various kinds of bioplastic products such as straws, glasses, carry bags, shopping bags, garbage bags, spoons, forks, knives, cups, food trays etc. Examples of bioplastic products used in various application areas are presented in this section.

1. Packaging/bags

   Products: Carry Bags, Shopping Bags, Garbage Bags, Clear Film and Sheet, etc.

   Samples:

Cassava shopping Bags

PLA food Strays

PLA/PBAT/starch bag

Biodegradable trash bags

Compostable laundry Bags

Biodegradable plastic film

2. Foodservice

Products: Tableware (spoons, forks, knives, cups, food trays, etc.)

Samples:

PLA food containers

Corn starch cutleries

Bagasse food containers

PLA Straws

3. Agriculture

Products: Mulch, fruit protection cover, seedling pots, etc.

Samples:

Starch polyester mulch

PLA mulch film

Biodegradable seedling pots

4. Consumer electronics

Products: Power plug, electronic enclosure, etc.

Samples:

Bio-PE power plug

PHA lithium battery cover

PLA electronic enclosure

5. Cosmetics

Products: Cosmetic jars, cosmetic packaging, etc.

Samples:

Bio-PE cosmetic containers

PHA cosmetics packaging

6. Medical

Products: Hospital trash bags, masks, etc.

Samples:

Medical trash bags

Medical-grade masks

7. Automotive & transport

Products: Car interior, car accessories, spare parts, etc.

Samples:

Bio-based polyamide car engine cover

Bioplastic car interior

Bio-based polyester car fuel line

8. Fabrics

   Products: Bioplastic leather, fabrics, woven, etc.

   Samples:

Cocoa bioplastic leather

Coffee-seaweed bioplastic leather

9. Others

   Products: Phone case, adhesive, 3-D printing filament.

   Samples:

PLA 3D printing filament

PLA barrier tape

Biodegradable phone case

4.3. Survey of bioplastic development

4.3.1. APEC Economies

No	Economy	Canada	Malaysia	Viet Nam
1	Regulation in place	Specifically designed for bioplastics usage: • Single-Use Plastics Prohibition • Recycled content and labeling rules for plastics	Non-binding policy: Roadmap Towards Zero Single-use Plastics 2018-2030	Not specifically designed for bioplastics usage: • Economic instruments in environmental protection targeting (i) industry equipment and products, (ii) Ecolabel

2	Objectives of regulations	• Prohibit the manufacture, import, and sale of single-use plastic containing synthetic plastics. • → bioplastics are in the scope of recycled content requirements and recyclability labelling rules.	• To stop using synthetic plastic bags	• Establish a specific list of environmental industry technologies, equipment, and products. • Provide incentives and assistance to those who comply with or support the regulations. • Implement HS codes for environmental goods. • Offer incentives to Ecolabel-certified services.
3	First time introduced and enforced	• Reg I: 2023-2024. • Reg II: 2023 -2024.	• 2018 - 2030 Roadmap	• 2020 - 2022
4	Implementation and development.	Many stakeholders with passive participation	Many stakeholders with active participation	Limited stakeholder involvement
5	Regulation awareness campaign.	• Systematically disseminated to a wide community. • The Government of Canada provides updates through email subscriptions and on social media platforms such as LinkedIn and the government website.	Systematically disseminated to limited segments •	• Systematically disseminated to a wide community. • published and promoted through media channels, so it has been widely spread.
6	Manufacturers' acceptance:	a. Only a few targets can accept the bioplastics. b. They are accepted by almost 50% of the target. *Explanation*: The SUP Prohibition Regulation is not well accepted by bioplastic manufacturers considering that bioplastic alternatives are treated in the same manner as conventional plastics except for an exemption of compostable plastic alternatives for one of the six item categories in the scope of the prohibition.	Only a few targets can accept bioplastics.	Only a few targets can accept the bioplastics.. *Explanation*: The bioplastics industry is in its early stages in Viet Nam. While there are bioplastics producers in the economy, they have limited alignment with government targets, primarily because no specific targets have been set, or at least none that the respondent could find.
7	distributors' (retailers. stores, etc) acceptance	*Explanation*: Comprehensive information on distributor compliance with the regulations is not available.	Only a few targets can accept bioplastics.	Only a few targets can accept bioplastics. Explanation: same as above
8	end users' acceptance	Only a few targets can accept bioplastics. *Explanation*: At present, there is a lack of comprehensive understanding and recognition regarding the recycling or end-of-life management of bioplastics. Additionally, when it comes to compostable products, only a limited number of organic waste facilities accept and process them. Financial support may be required to address these challenges.	Only a few targets can accept bioplastics.	Only a few targets can accept them. *Explanation*: same as above
9	Monitoring effectiveness	*Explanation*: The regulations are relatively new and evaluation of the effective implementation of these regulations has yet to be assessed at this time.	Ineffective	Ineffective; some might even say that they are non-existent.
10	Enforcement effectiveness	The regulations are relatively new, and a comprehensive assessment of their enforcement is yet to be conducted.	Ineffective	Ineffective; some might even say that they are non-existent.

11	Evaluation on regulation	No evaluation has been conducted at this time.	No	No
12	Result of evaluation	No evaluation has been conducted at this time.	No	No
13	Importance of economic factors	Very important. *For the Industry*: Economic factors play an integral role, including infrastructure costs and waste facility operations. *For Consumers*: Canadian consumers are strongly motivated to reduce single-use plastic food packaging, but they may be less willing to pay for alternative options.	Very Important	Very Important *Explanation*: No Data. It is only based on the respondent's assessment and experience.
14	practical / practicality importance	Very important *Suggestion*: Alternative materials intended to replace conventional synthetic plastics are expected to meet similar standards. For instance, when phasing out single-use plastic straws and switching to paper straws, concerns arose because the practicality and functionality of the alternatives did not align with those of conventional plastic straws.	important	Rather important *Explanation*: During the COVID-19 pandemic, there was an increased demand for a specific brand of bio-bags designed to preserve the freshness of produce due to their unique chemical composition. However, after the pandemic was over, the company's sales declined.
15	Physical strength characteristic	Very important *Suggestion*: Functional and mechanical performance are crucial factors when considering bioplastics as an alternative to synthetic plastics. Achieving performance comparable with conventional plastics ensures that the quality of products does not suffer due to the transition to bioplastics.	Important	Important *Explanation*: Based on individual respondent assessments, the Vietnamese do judge the quality of products. Therefore, it is believed that consumers will assess the physical feel and strength of the bioplastic as indicators of its quality.
16	How willing are the people in your economy to pay more to change their use of conventional plastics to bioplastics?	Willing to do so but not at the moment. For consumers, studies have shown that Canadian consumers are highly motivated to reduce single-use plastic food packaging but are less willing to pay for alternatives.	Not willing	Willing to do so but not at the moment. The bio-bag company mentioned above offers a more expensive product. However, during the Covid pandemic and lockdown situations, their sales increased as consumers recognized the value of storing food and keeping it fresh for longer.
17	Other aspects of improvement	Although there has been a shift in consumer behavior, bioplastic alternatives are still being treated similarly to conventional plastics, and compostable alternatives are not considered a top innovative priority.	Education and Awareness	Viet Nam's primary focus is reducing the use of single-use plastics and moving towards a full ban. The law also highlights Extended Producer Responsibility and plastic recycling. Interestingly, the term 'bioplastic' is not mentioned anywhere in Viet Nam's extensive Environment Law, which comprises 500+ pages.

4.4. Indonesian case

4.4.1. In-depth interviews with bioplastic pellet and end product producers

We had in-depth discussions with senior officials at the three bioplastics plants we chose to represent their Indonesian counterpart. One factory in Banten Province produces pellets and one each in Central Java and West Java Provinces produces the final product (bioplastic sheet). The following is summing up our discussion on these three plants.

In Indonesia, there is pellet bioplastic company that has been producing plastic masterbatch and polymer compounds since 1990. In 2011, the company also started producing biodegradable pellets. These two major business units were established to address the growing challenges in the plastic conversion industry, which require full attention to sustain a sustainable business future. The ISO 9001 certification was achieved in 2000, the 5S concept was implemented in 2007, OHSAS 18001 was also achieved in 2010, and finally, ISO 14001 was awarded in 2014, solidifying the company as a reliable industry partner. The pellet product has been certified as biobased 50-85% (Testing basis: ASTM D6866).

The pellet bioplastic product is a bio-based polymer compound made from renewable natural materials such as cassava or corn starch, as well as vegetable oil derivatives. The raw materials of starch are not significantly different in price, whether it's corn starch or tapioca starch.

End product producers of bioplastic was established in 2001 and operates in the field of conventional plastic product manufacturing, including shopping bags, medical supplies, and plastics for agricultural purposes. However, bioplastic production only commenced in 2018. In expanding its bioplastic production, the company has a primary focus on manufacturing finished bioplastic products to meet market demand. The raw bioplastic materials are sourced through a partnership with PT. Intera Lestari Polimer, more commonly known as Enviplast.

The company manufactures a range of bioplastic products, including shopping bags primarily designed for the garment industry, laundry bags used in the hospitality sector, trash bags, plastic bags for hospital purposes, and plastics for general consumer use. These bioplastic raw materials are sourced from both domestic and international suppliers. These include cassava starch obtained from Lampung, specifically the Sungai Budi area, as well as imported bioplastic materials such as Polybutylene adipate co-terephthalate (PBAT) and Polyvinyl alcohol (PVOH). The company also engages in material formulation (compounding) activities for the production of finished bioplastic products through its R&D team.

According to information provided by the company, a prominent bioplastic manufacturer in Asia, China and Viet Nam currently lead in bioplastic production in the economies. Thailand is also in the developmental phase. However, when it comes to sourcing raw materials, especially local ones like cassava starch, the company has faced particular challenges. These challenges involve competing with industries such as animal feed and textiles, as well as other companies offering higher prices or profit margins compared to bioplastics. Consequently, bioplastic manufacturers often find themselves obtaining lower-quality raw materials, such as cassava with lower starch content, because higher-quality cassava has already been purchased by other companies at a higher price.

The company presently uses the same machinery for bioplastic production as they do for their main products, conventional plastics. Their bioplastic production volume is currently limited and depends on irregular customer orders, which amounts to approximately two up upthree tons per month. Likewise, the amount of raw materials required for production aligns with this demand. Additionally, the demand for bioplastics is presently restricted to domestic customer orders.

The current production capacity is significantly lower than it was before the Covid-19 pandemic. Previously, the company primarily served international markets, including Australia, where they regularly sold 50 tons of bioplastic products each month. However, the global economic downturn resulting from the pandemic has led to a complete absence of foreign demand for bioplastics up to this point. Currently, the company has a sizable workforce, consisting of 160 employees in the production department and 10 in management.

The production activities and market demand for the company's bioplastic products are actually influenced by government regulations, such as the ban on conventional plastics for shopping bags and the requirement for certain businesses like retail and hospitality to use environmentally friendly plastics. When these regulations were initially enforced by the government, there was a surge in demand for bioplastics. However, as these regulations were short-lived, lasting only two up to three months, and lacked proper oversight from authorities. As a result, companies have stopped purchasing bioplastics from the company. Therefore, it can be assumed that current government regulations do not significantly impact production strategies, market penetration, or competition with other companies.

In the context of developing bioplastic production in Indonesia, the company has made a significant contribution. This is evident through the leadership of the company, who has actively participated in designing regulations related to standardization and the utilization of bioplastics by domestic companies, along with relevant government agencies such as the Ministry of Environment and Forestry, the Ministry of Marine Affairs and Fisheries, bioplastic associations, and other stakeholders. Additionally, the company has taken an active role in a consortium alongside several bioplastic enterprises. The company contributions and inputs to government regulation development include:

1. The company is active participation in the development of the unified standards (SNI) for eco-labelling bioplastic products.
2. The company suggestion for a tax policy on bioplastics aimed at fostering the growth of the bioplastic industry. This involves implementing lower taxes compared to conventional plastic products.
3. The company has also provided insights into government incentives, such as customs and tax exemptions for bioplastic production activities. This approach aligns with the strategy employed in Indonesia's textile industry, where the government supports or grants tax exemptions for the importation of textile machinery to enhance domestic textile production technology.

According to bioplastic producers, the current development of bioplastics in Indonesia is in an unfavorable phase where companies operating in this field are facing difficult decisions, whether to continue bioplastic production or cease it. This is due to several factors, including:

1. Higher production costs and product prices compared to conventional plastics.
2. Highly specific bioplastic production technologies, including specific raw materials and production processes. For instance, producing certain types of products requires specialized production machinery.
3. Global standardization of bioplastic products varies by economy, making it challenging for bioplastic production for export commodities, as it must align with the importing economy's requirements.
4. Promoting bioplastic use domestically faces many challenges, with some associations and companies negatively impacted by the growing use of bioplastics pressing the government to develop regulations promoting bioplastic production and usage.
5. Disagreement about the term "bioplastic" among government agencies, companies, and consumers within the economy. Some perceive bioplastic products as reusable plastics, while others interpret them as compostable plastics.

4.4.2. Field observation

The pellet bioplastic products in the company are of 2 types: pellet bioplastic WS (water soluble) and WR (water resistance). Pellet bioplastic WS compound is designed to produce an eco-friendly film that can be converted into finished products like shopping bags, garbage bags, laundry bags, pet waste bags, polybags and wrapping materials, finished products are sensitive to humidity and should be kept in their original packaging to maintain constant material properties, bags can be recycled together with paper waste and needs no industrial composting facility, since it can be degraded with the help of macro and micro-organisms in compost condition.

Characteristics of bioplastics produced by the producer does not contain PE/PP/PET/PS, reusable, recyclable with paper, biodegradable in nature within 180 days, Safe for the environment (non-toxic) passes Acute Oral Toxicity test by WIL Research NL, does not contain thermo-plastic at all, has good anti-static features (suitable for wrapping electronic objects), has a good oxygen barrier feature of 0.365 ml/m2/day; RH 0%, 230C; ASTM D3985, oil resistant, and soluble in hot water (80° Celsius). Bioplastic sheet production machine made from bioplastic pellets described in Figure 15.

Figure 14. Bioplastic sheet production machine made from bioplastic pellets

Pellet bioplastic WR is a biopolymer compound which designed to produce an eco-friendly film that can easily be converted into finished products like carrier bags, offers a solution for today's most pressing environmental demand: sustainability. It is offered in the form of compound and does not contain any conventional plastics such as PE, PP, PET, PS, strong and flexible, and resistant to tearing and water.

Figure 15. Bioplastic pellet

They remain stable in all types of weather and humidity conditions. Microorganisms will assist in the biodegradation process as the main ingredients of bioplastic pellet WR are starch, derivative vegetable oil and biodegradable polyester. It biodegrades in nature without leaving any hazardous residues, can be composted using home composting methods which is more energy efficient instead of industrial composting, and designed to provide an answer to market needs for broad eco-friendly film applications.

4.4.3. First user perception survey

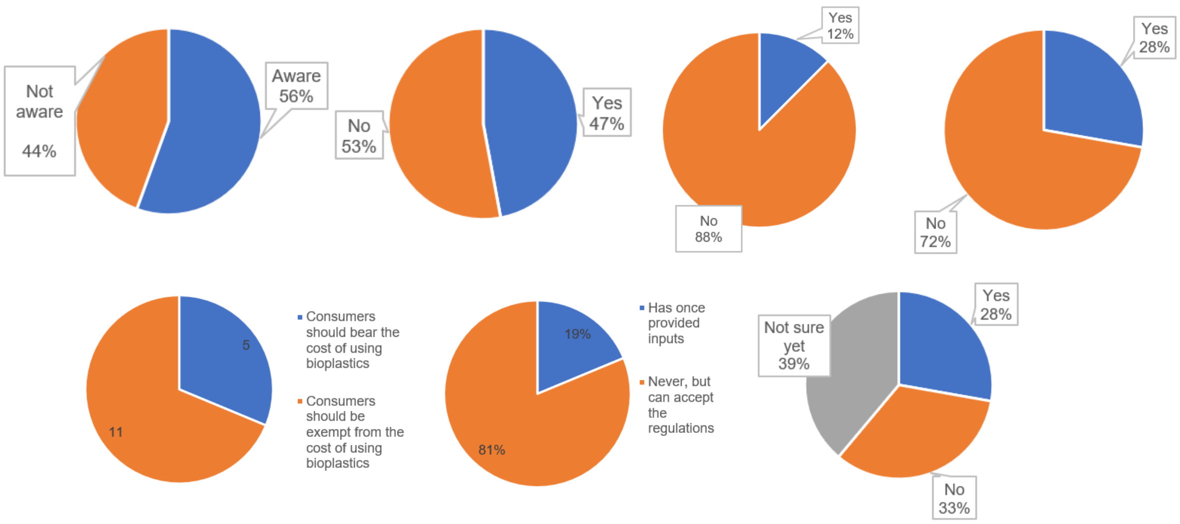


Figure 16. a. Whether respondent is aware of the existence of bioplastic products; b. Whether respondent's company has used bioplastics; c. Whether respondent's company objects to existing bioplastics regulations; d. Respondent's opinion of whether the use of bioplastics affect his or her company's competitiveness; e. whether consumers should bear the cost of using bioplastics; f. Whether respondent's company provides input to government re. the use of bioplastics; g. Whether the use of bioplastics has an effect on the company's cost structure

4.4.4. End user perception survey

4.4.4.1. Cluster Analysis

Here are the results of the analysis cluster, which is intended to group respondents based on their similar responses. The analysis resulted in four clusters as presented below.

Table 5. The clustering results for k=2, 3, 4, 5, 6, 7, 8

k	Cluster	Numbers of cluster	*centroid*
2	1	164	0, 2, 1, 3, 2, 3, 4, 3, 3, 4, 2, 1, 1, 4, 2, 3, 2, 4
	2	167	1, 2, 1, 3, 1, 2, 3, 2, 1, 3, 2, 1, 1, 3, 3, 3, 3, 3
3	1	129	0, 2, 1, 3, 2, 3, 3, 2, 1, 3, 2, 1, 1, 3, 2, 3, 3, 3
	2	123	0, 2, 1, 3, 2, 3, 4, 3, 3, 4, 2, 1, 1, 4, 2, 3, 3, 4
	3	79	1, 3, 5, 2, 1, 3, 3, 3, 2, 3, 2, 2, 1, 3, 3, 3, 2, 3
4	1	118	0, 2, 1, 3, 2, 3, 3, 2, 1, 3, 2, 1, 1, 3, 2, 3, 3, 3
	2	100	0, 2, 5, 3, 2, 3, 4, 3, 3, 4, 2, 2, 1, 4, 2, 3, 2, 4
	3	56	1, 1, 5, 2, 1, 2, 3, 3, 1, 3, 2, 1, 1, 3, 3, 3, 3, 3
	4	57	1, 3, 1, 3, 2, 3, 3, 2, 2, 4, 2, 1, 1, 4, 2, 3, 2, 3
5	1	66	0, 2, 1, 3, 2, 2, 3, 2, 2, 3, 2, 1, 1, 3, 2, 3, 3, 3
	2	102	0, 2, 1, 3, 2, 3, 4, 3, 1, 4, 2, 1, 1, 4, 2, 3, 2, 4
	3	57	1, 1, 5, 2, 1, 2, 3, 2, 1, 3, 2, 1, 1, 3, 3, 3, 3, 3
	4	32	1, 2, 1, 3, 1, 2, 3, 2, 1, 2, 2, 1, 1, 2, 2, 3, 2, 2
	5	74	0, 2, 1, 3, 2, 3, 3, 3, 3, 3, 2, 2, 1, 3, 2, 3, 3, 3
6	1	67	0, 2, 1, 3, 2, 2, 3, 2, 1, 3, 2, 1, 1, 3, 2, 3, 3, 3
	2	82	0, 2, 1, 3, 2, 3, 4, 3, 3, 4, 2, 1, 1, 4, 2, 3, 3, 4
	3	43	1, 3, 5, 2, 1, 2, 3, 3, 1, 3, 2, 1, 1, 3, 3, 3, 3, 3
	4	24	1, 1, 1, 3, 1, 1, 3, 2, 1, 2, 2, 1, 1, 2, 2, 3, 3, 2
	5	67	0, 2, 1, 3, 2, 3, 3, 3, 3, 3, 2, 2, 1, 3, 2, 3, 3, 3
	6	48	1, 2, 5, 1, 1, 3, 4, 2, 2, 4, 2, 1, 1, 4, 3, 4, 2, 4
7	1	55	1, 2, 1, 3, 2, 2, 3, 2, 1, 3, 2, 1, 1, 3, 2, 3, 1, 3
	2	74	0, 2, 5, 3, 2, 3, 4, 3, 1, 4, 2, 1, 1, 4, 2, 3, 3, 4
	3	38	1, 1, 5, 2, 1, 2, 3, 3, 1, 3, 2, 2, 1, 3, 3, 3, 3, 3
	4	27	1, 1, 1, 3, 1, 1, 3, 2, 1, 2, 2, 1, 1, 2, 2, 3, 3, 2
	5	42	0, 2, 1, 3, 2, 3, 4, 3, 3, 3, 3, 2, 1, 3, 2, 3, 2, 3
	6	39	1, 2, 5, 2, 1, 3, 4, 2, 2, 4, 2, 1, 1, 4, 3, 4, 2, 2
	7	56	0, 2, 1, 3, 2, 3, 3, 3, 3, 3, 2, 1, 1, 3, 2, 3, 3, 3

8	1	48	0, 2, 1, 3, 3, 2, 3, 2, 1, 3, 2, 2, 1, 3, 2, 3, 2, 3
	2	36	1, 2, 5, 2, 1, 3, 4, 2, 1, 4, 1, 1, 1, 4, 2, 3, 2, 2
	3	41	1, 3, 5, 2, 1, 2, 3, 3, 1, 3, 2, 1, 1, 3, 3, 3, 3, 3
	4	29	1, 1, 1, 3, 2, 1, 3, 2, 1, 2, 2, 1, 1, 2, 2, 3, 3, 2
	5	25	1, 2, 1, 3, 2, 3, 3, 3, 3, 3, 3, 2, 1, 3, 3, 3, 2, 3
	6	19	1, 1, 5, 1, 1, 2, 4, 2, 2, 4, 2, 1, 1, 3, 3, 4, 3, 1
	7	55	0, 2, 1, 3, 2, 3, 3, 3, 3, 3, 2, 1, 1, 3, 2, 3, 3, 3
	8	78	0, 2, 1, 3, 2, 3, 4, 3, 3, 4, 2, 1, 1, 4, 2, 3, 3, 4

After the clusters for k=2, 3, 4, 5, 6, 7, and 8 were formed, we determined the optimal number of clusters using the Dunn Index. The Dunn Index is a cluster validation method that assigns the highest score for clustering algorithms that create clusters with high internal similarity and low similarity between clusters. Its purpose is to identify well-separated clusters. A higher Dunn Index value indicates a more optimal number of clusters. Table 2 displays the Dunn Index values obtained for k=2, 3, 4, 5, 6, 7, and 8.

Table 6. The *Dunn index*

k	*Dunn index*
2	0.1706
3	0.1393
4	0.1767
5	0.1393
6	0.1436
7	0.1393
8	0.1706

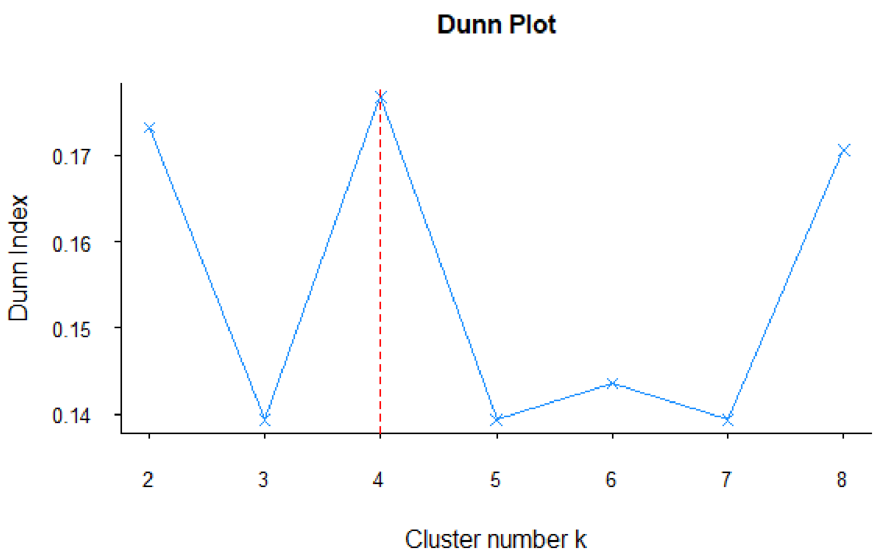


Figure 17. The *Dunn Index*

Based on the Dunn Index values obtained, it was found that k=4 had the highest Dunn Index score. Therefore, k=4 was selected as the optimal value for clustering respondents using the K-Modes cluster analysis.

Table 7. The Characteristics of each cluster for k=4.

Variables	Clusters			
	1	2	3	4
Sex	Female	Female	Male	Male
Residence	Jawa	Jawa	Sumatera	Others
Occupation	Civil Servant/Civil Servant under Contract/ Government Contract Worker/Armed Forces/Police	Students	Students	Civil Servant/ Civil Servant under Contract/ Government Contract Worker/Armed Forces/Police
Usia	Productive (31- 60 years old)	Productive (31- 60 years old)	Pre-productive (21-30 years old)	Productive (31- 60 years old)
Average monthly income	Low (IDR 4-10 million)	Low (IDR 4-10 million)	Very low (< IDR 4 million)	Low (IDR 4-10 million)
Respondents' knowledge of bioplastics.	Yes, know a lot but not in detail	Yes, know a lot but not in detail	Yes, a little knowledge	Yes, know a lot but not in detail
Respondents' knowledge regarding the adverse effects of conventional plastic usage.	Yes, know a lot but not in detail	Yes, know a lot and know the details	Yes, know a lot but not in detail	Yes, know a lot but not in detail
Respondents' active role in addressing environmental issues caused by conventional plastic.	Aware, but not actively engaged and still using conventional plastic as usual	Aware and actively engaged in efforts to reduce the use of conventional plastic	Aware and actively engaged in efforts to reduce the use of conventional plastic	Aware, but not actively engaged and still using conventional plastic as usual
Respondents' knowledge of government regulations regarding the use of bioplastics	Completely unaware	Aware, through mainstream media (radio, TV, newspapers, etc.)	Completely unaware	Aware, through friends or social media
Respondents' stance on regulations limiting the use of conventional plastic.	Agree if the situation becomes extremely critical	Agree under any circumstances	Agree if the situation becomes extremely critical	Agree under any circumstances
Frequency of bioplastic usage by respondents	Rarely	Rarely	Rarely	Rarely
Services provided by the stores or groceries where respondents shop concerning the utilization of bioplastic containers/bags.	Sellers directly provide conventional plastic bags/containers.	Sellers offer buyers the choice of using conventional plastic or bioplastic.	Sellers directly provide conventional plastic bags/containers.	Sellers directly provide conventional plastic bags/containers.
Respondents' opinions on how law enforcement authorities approach	Never at all	Never at all	Never at all	Never at all

imposing sanctions on stores or consumers regarding the use of bioplastics.				
Respondents' attitudes towards government regulations concerning the reduction or prohibition of conventional plastics.	Agree if the situation becomes extremely critical	Agree under any circumstances	Agree if the situation becomes extremely critical	Agree under any circumstances
Respondents' opinions on the current prices of bioplastic products/packaging	Somewhat expensive	Somewhat expensive	Not expensive	Somewhat expensive
Respondents' opinions on the practicality of using bioplastics.	Nearly as user-friendly as using conventional plastic	Nearly as user-friendly as using conventional plastic	Nearly as user-friendly as using conventional plastic	Nearly as user-friendly as using conventional plastic
Respondents' opinions on the quality (strength) of bioplastic products.	Their strength is already sufficient	Their strength is approaching respondent's expectations.	Their strength is already sufficient	Their strength is approaching respondent's expectations.
Respondents' willingness to pay a higher price for bioplastic products.	Willing if necessary	Willing under any circumstances	Willing if necessary	Willing if necessary

Furthermore, the findings presented in Table 8 can be simplified and expressed through the following cluster groupings. It is only intended to give focus to those policies to be developed. Other individuals can in fact belong to one of these clusters.

Cluster 1: Female government workers residing in Java

Cluster 2: Female students residing in Java

Cluster 3: Male students residing in Sumatera

Cluster 4: Male students residing outside Java and Sumatera

This clustering enables the government to better target these four distinct groups of citizens, providing more focused and precise intervention strategies.

Figure 18-23 displays the frequency of responses from participants, organized into four distinct clusters. These clusters correspond to questions related to variables relevant to regulatory design in accordance to bioplastic development.

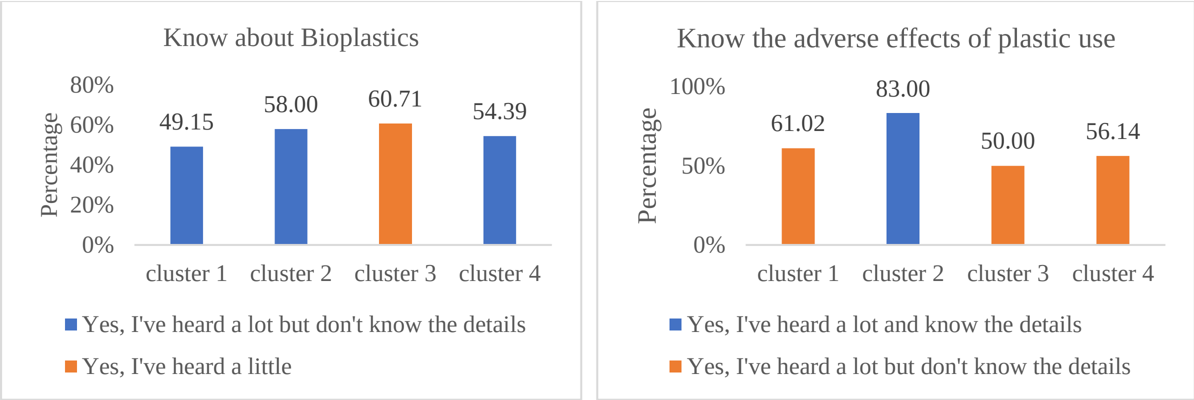


Figure 18. a. the number of responses from participants concerning their knowledge of bioplastic products (p-value chi-square test: 0.000); b. the number of responses from participants concerning their awareness of the negative impacts associated with the use of conventional plastic products (p-value chi-square test: 0.000).

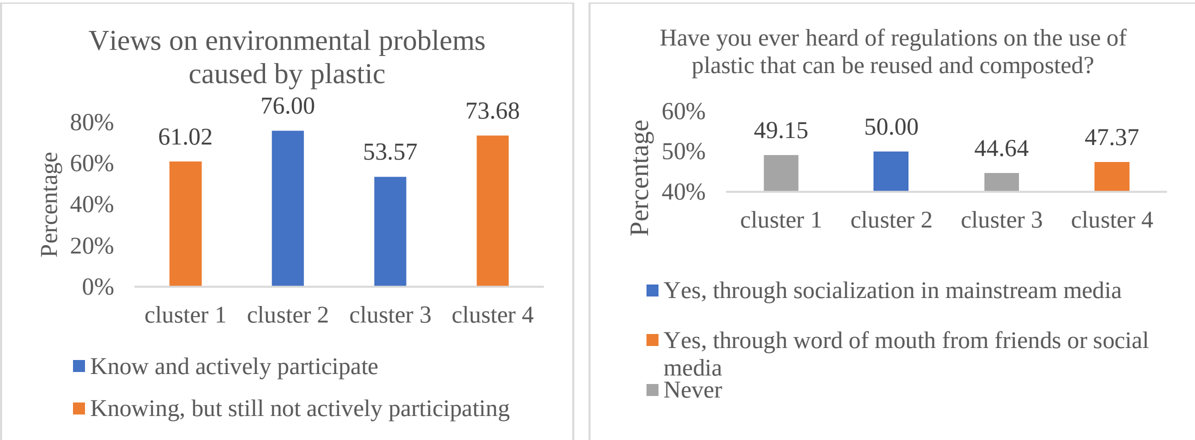


Figure 19. a. the number of responses from participants regarding their active involvement in addressing environmental damage caused by the use of conventional plastics (p-value chi-square test: 0.000); b. the number of responses from participants regarding their awareness of government regulations concerning bioplastics usage (p-value chi-square test: 0.000).

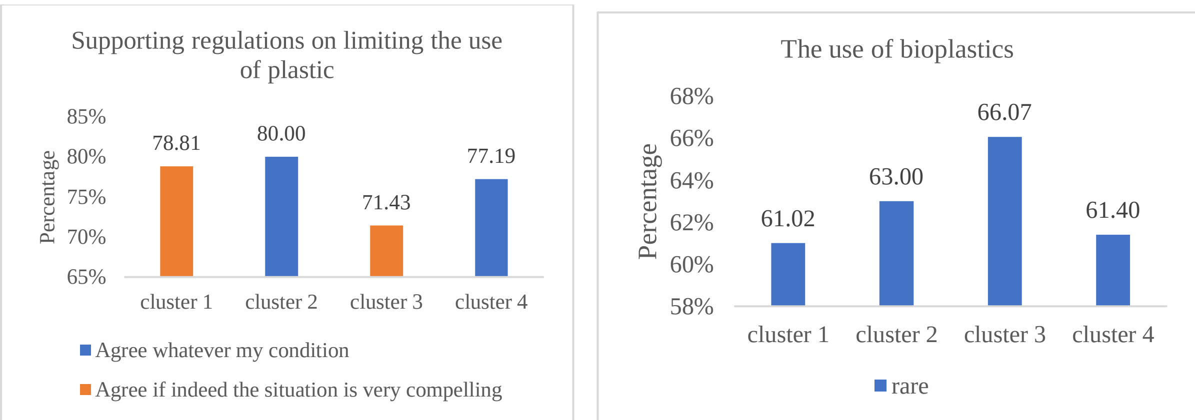


Figure 20. a. the number of responses from participants regarding their stance on regulations that restrict the use of conventional plastics (p-value chi-square test: 0.000); b. the number of responses from participants regarding bioplastic usage in their daily lives (p-value chi-square test: 0.0392).

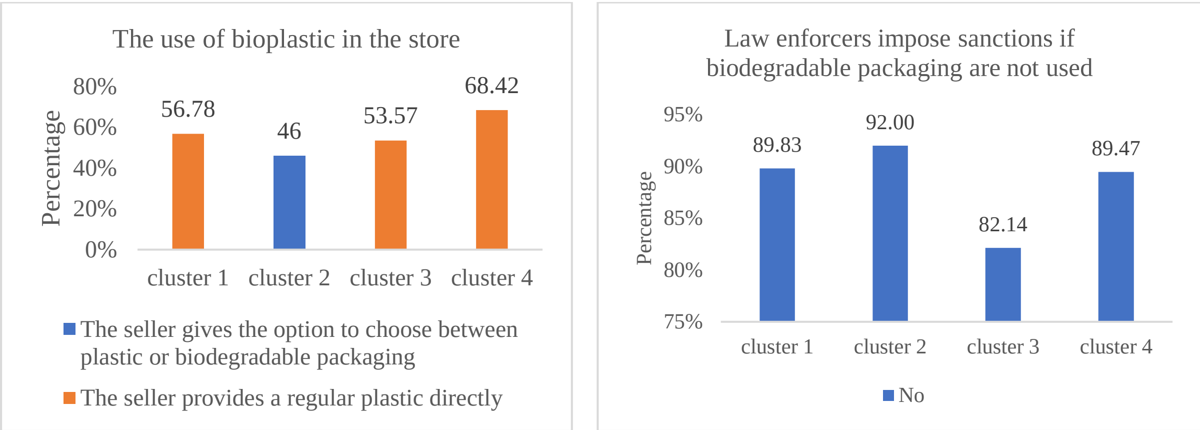


Figure 21. The number of responses from participants regarding services provided by stores or groceries concerning to the use of bioplastic containers and bags (p-value chi-square test: 0.000) , b. the number of responses from participants regarding their opinions on how law enforcement authorities approach imposing sanctions on stores or consumers who do not use bioplastics (p-value chi-square test: 0.0386).

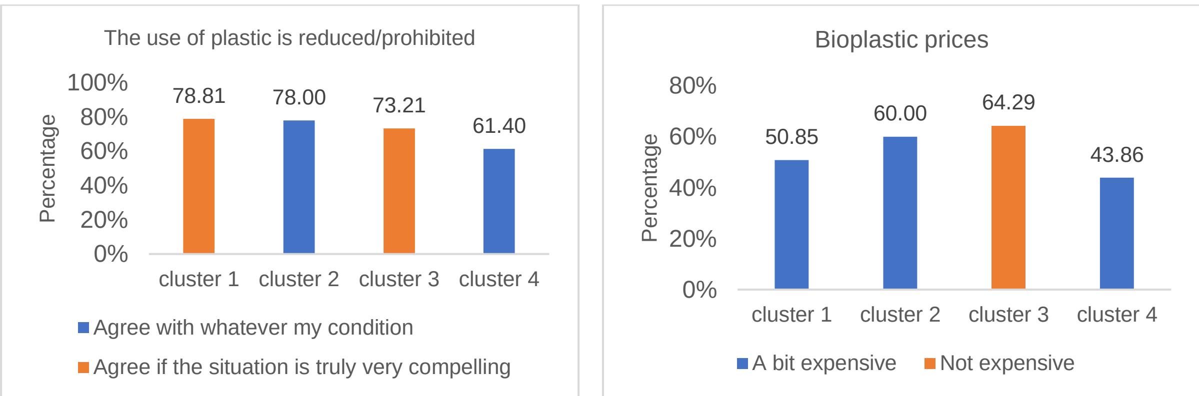


Figure 22. The number of responses from participants regarding their attitudes towards government regulations concerning the reduction or prohibition of conventional plastics (p-value chi-square test: 0.000); b. the number of responses from participants regarding their opinions on the current prices of bioplastic products/packaging (p-value chi-square test: 0.000).

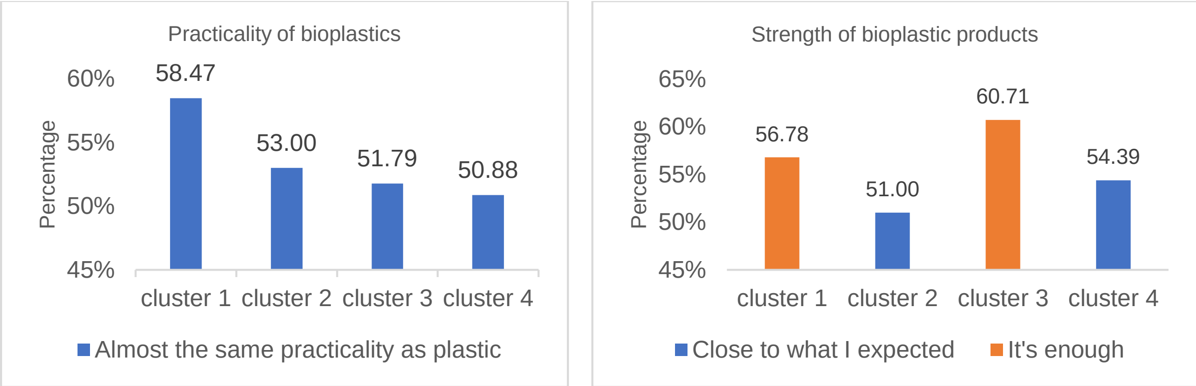


Figure 23. a. the number of responses from participants regarding their opinions on the practicality of using bioplastics (p-value chi-square test: 0.3872) ; b. the number of responses from participants regarding their opinions on the quality (strength) of existing bioplastic products (p-value chi-square test: 0.000)

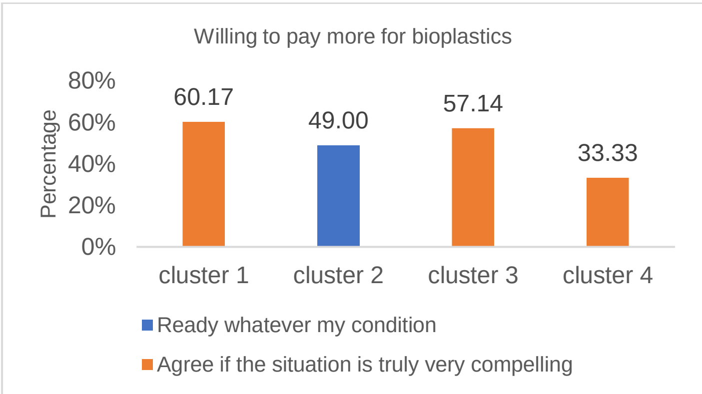


Figure 24. The number of responses from participants regarding their willingness to pay a higher price for bioplastic products (p-value chi-square test: 0.000)

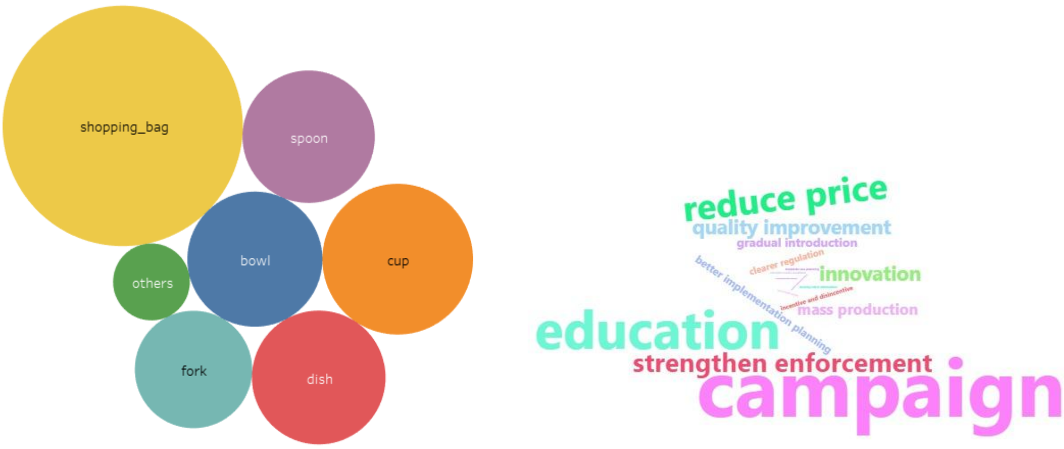


Figure 25. Word cloud of: a. bioplastic products known by respondents; b. regarding aspects that respondents consider important in bioplastic development

The subject of bioplastics has gained significant attention relatively recently, mainly within the last decade. Bibliometric analysis shows that, despite documented reports on plastic development and usage dating as far back as 1892, with occasional studies in between, there was a notable increase in the number of scientific publications specifically focused on "bioplastics" in 2022.

Notably, economies in the Asia Pacific economies have made significant contributions by producing numerous articles that cover various aspects of bioplastics development. The four leading economies contributing to the bioplastic literature are the US; Indonesia; China; and Malaysia. The breadth of public response to the issue of bioplastics in these economies are evident not only in the quantity of publications but also in the diversity of topics discussed. These encompass areas such as economics, life cycle analysis, production, food applications, sustainability, wastewater treatment, and recycling.

Currently, bioplastics make up about 1% of the world's total plastic usage, and this percentage is expected to increase to approximately 3-4% by 2027. Several factors contribute to this optimistic projection including (1) Changing consumer behavior, driven by increasing environmental awareness, (2) The availability of raw materials sourced from sustainable crops, such as starch-rich plants like cassava, corn, and sugarcane, and (3) Advances in first-generation carbohydrate extraction technology, which involve utilizing carbohydrates from non-food plants. These sources include cellulose, agro-industrial waste, straw, palm fruit bunches, agro-waste (second generation), and materials derived from aquatic sources like algae and microalgae (the third generation).

The positive trends observed in bibliometrics appear to be closely linked to the increased usage of bioplastics on a global scale, which is reflected in the international trade of this commodity. The value of bioplastics exports worldwide has seen a sixfold increase, growing from USD 100 million in 2013 to USD 600 million in 2022 (according to Trademap.org in 2023). Projections suggest that the global bioplastics production capacity will rise from around 2.2 million tons in 2022 to approximately 6.3 million tons by 2027.

In line with the bibliometric trends, the US is the leading exporter of bioplastic products, holding around half of the current market share. Interestingly, despite actively contributing to bioplastics literature, some economies like Indonesia and Malaysia do not have a significant role in global bioplastics trade. Thailand, however, stands out as the only developing economy with the potential to become a major player in the bioplastics industry.

Commercially available bioplastics are being used in a wide range of everyday applications, including packaging, automotive, agriculture, electronics, and construction, among others. Notably, shopping bags have become a major sector within the bioplastics market, representing nearly half of total bioplastic production. This trend is largely driven by growing environmental concerns related to single-use plastics, particularly in the context of shopping bags and food packaging. Furthermore, governments have responded by implementing regulations to ban environmentally harmful products, with a particular focus on shopping bags and various single-use plastic items. These, in turn, have significantly increased the demand for bioplastics as a more sustainable alternative.

The survey of users reported in this paper provides a plausible clue. In the survey that took cases on users in Indonesia as mentioned in the previous section of this paper, practicality is one of the respondents concerned. A number of respondents even mentioned that even for packaging bags, the physical characteristics of bioplastics are not yet meeting their expectations, certainly more challenging for other types of products (Figure 30b). A corroborating response was also recorded in a survey involving resource persons representing APEC economies. Respondents analogized the lack of success in switching the use of plastic straws to paper straws for reasons of practicality and functionality, which apparently is also the case with bioplastic products.

The practicality and functionality are clearly not the only challenges in the development of bioplastic products. The respondents, including Indonesian bioplastic producers, end users, and representatives from other APEC economies, have also identified other important issues. They have proposed solutions like public education, intensive campaigns, research and development, effective regulatory design, and regulatory enforcement to promote bioplastic use. However, among these challenges, one stands out as a critical obstacle that needs immediate attention to accelerate bioplastic adoption: the need to reduce the price of existing bioplastic products. Although bioplastics can be made from renewable resources like cassava, sugarcane, corn, potatoes, and other crops, the processing technology for these materials still needs advancement. This is essential to upgrade technology that can produce bioplastic products with competitive pricing compared to existing conventional plastics. Additionally, it's necessary to explore and develop alternative sources of raw materials for bioplastics, including marine-derived resources and non-food sources.

The observations and in-depth interviews conducted at a bioplastic processing plant revealed that cassava is the company's preferred choice for raw materials, primarily due to economic considerations. For example, the current price per kilogram is IDR 8,000 for tapioca, IDR 200,000 for carrageenan, IDR 10,000 for rice flour, etc. (unpublished report). It's essential to note that bioplastic processing plants typically do not frequently mix different types of raw materials, often due to considerations related to the specific functional properties of particular raw materials. Additionally, we conducted another field investigation at a bioplastic processing company located in Central Java, which, similar to the previous facility, primarily utilized cassava starch as its main raw material. Our findings suggest the need for exploring innovative combinations/blendings of various bioplastic raw materials in the future. This exploration is essential for producing bioplastic items that not only align with consumer preferences but are also cost-effective.

Considering the results of the bibliometric analysis, which indicated a predominant focus on reinforced bioplastics, we recommend a shift in research focus. This shift should allocate more research efforts toward exploring the optimal raw material mixtures. To address existing challenges effectively, these studies should focus on two key aspects: achieving economic feasibility and ensuring the desired physical characteristics of bioplastic products.

The survey results from various APEC economies' representatives, including end users, indicate that the high pricing seems to be a more flexible factor in wealthier societies. For example, in developed economies like Canada, participants noted that consumers are generally motivated to reduce their use of single-use plastic food packaging, even if they are somewhat hesitant to pay more for alternatives. This high level of motivation is certainly encouraging. However, the primary challenge is to enhance the financial viability of companies operating in this context. Reducing input costs, particularly those associated with infrastructure and waste facility operations, can significantly improve economic feasibility. It's essential to emphasize that this doesn't diminish the importance of ongoing efforts to find cost-effective raw materials and material blends that align better with consumer preferences.

During this investigation, we have also highlighted several critical challenges, including low consumer awareness, inadequate market regulations, and the absence of a proper waste management strategy. These issues need to be addressed effectively to ensure the optimal development and usage of bioplastics without unintentionally causing additional problems. Therefore, we strongly recommend that APEC economies take measures to conduct extensive research and innovation and establish a comprehensive policy framework for managing the processing of biodegradable plastics. This framework should encompass all aspects of the process, including material sourcing, labeling, standards, and certification systems. It is also essential to prioritize quantitative research to better understand the factors influencing people's willingness to use single-use plastics. We believe that addressing these issues is a prerequisite for the successful implementation of government policies aimed at safeguarding the environment.

CHAPTER V. CONCLUSION

The use of environmentally friendly bioplastic products is on the rise, driven by changing consumer behavior and greater awareness of the environmental impact of plastic waste. This trend has been reinforced by government regulations in many economies that ban single-use plastics, such as shopping bags, straws, and disposable tableware. The global bioplastics industry is also expanding, including within the APEC economies. This expansion is evident in the bibliometric analysis performed in this investigation, which shows that several APEC economies are making significant contributions to scientific research on bioplastics. However, the dominant players in the global bioplastics trade are still primarily the US and other developed economiess, with Thailand being the only developing economy in the APEC economy that has a notable presence. Based on our research findings, several factors seem to hinder the widespread adoption of bioplastics in society, especially within the APEC member of economies. These factors can be summarized as follows: **(1) Lack of Efficient Bioplastic Production Technology**: There is a need for more efficient/advanced technology that can produce bioplastics from natural resources, resulting in cost-effective production and competitive pricing to conventional plastics, **(2) Challenges in Achieving Equivalent Quality/Strength**: The current technology and innovation in creating bioplastic products need further development to match the strength of conventional plastics to enhance bioplastics' properties. Moreover, we must explore other alternative raw materials, such as marine-based resources and non-food natural sources, **(3) Inconsistent Implementation of Regulations**: The inconsistent commitment and weak enforcement of government regulations regarding the ban on single-use plastics present a challenge, and **(4) Lack of Government Intervention**: There is a need for stronger government intervention to support the growth of the bioplastics development ecosystem, primarily driven by the private sector. This support could include incentives and policies to stimulate the bioplastics industry. Considering the projected global growth in bioplastic usage in the future, it is advisable, based on the findings of this study, that APEC economies seriously focus on designing more effective policies related to bioplastic technology development and the implementation of bioplastic products. This strategic approach should be complemented by a strong commitment to the existing regulations and solid support for the development of practical technologies. Such support is expected to lead to innovations capable of addressing the challenges associated with the current use of bioplastics.

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