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Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution?

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ABSTRACT

Plastic usage is increasing the number of pollutants in the environment. Plastic particles and other plastic-based pollutants are found in our environment and food chain, posing a threat to human health. From this perspective, the biodegradable plastics material focuses on creating a more sustainable and greener world with a smaller environmental imprint. This assessment should consider the entire life cycle assessment of the objectives and priorities for producing a wide range of biodegradable plastics. Biodegradable plastics can also have properties similar to traditional plastics while also delivering additional benefits due to their minimised impact on the environment in terms of carbon dioxide, as long as appropriate waste management includes such as composting, are contained. The demand for cost-effective, eco-friendly materials increases to reduce waste management and pollution issues. This study seeks to comprehensively understand biodegradable plastics production and applications research, product prospects, sustainability, sourcing and ecological imprint. Academic and industry interest in biodegradable plastics for sustainability has exploded in recent years. Researchers used the triple bottom line to analyse the sustainability of biodegradable plastics (economic profit, social responsibility, and environmental protection). The research also discusses the variables that influence the adoption of biodegradable plastics and a sustainable framework for improving biodegradable plastics' long-term viability. This study provides a thorough yet simple theoretical design of biodegradable plastics. The research findings and future research endeavours provide a new avenue for further research and contribution to the area.

1. Introduction

Although plastic materials, with their numerous make-ups and manufacturing costs, are of high quality, it is of great concern if this plastic material can be appropriately managed in our society [1]. While plastics have become highly valued for their long-lasting functional use, many perspectives on plastics-related environmental hazards and energy crises have recently been raised. Plastics are popular because they provide human beings with less financial charge of things they want [2]. Consumers are, however, now more aware of the harmful environmental effects of plastics. Therefore, because it can be sustained and handled in the global environment, bio-based and biodegradable polymeric materials are one of the most appropriate means to realise [3].

Also, different policymakers have established programs to promote research and improvement of bio-based plastics [4]. In this regard, efforts have been advanced by both the political and regulatory bodies in North America and Europe. The governments of Malaysia and Germany have shown considerable interest in biodegradable plastics research [5]. Therefore, this situation indicates the possibility of advancements in biodegradable plastics [6]. Governments, companies, and universities are making great efforts to find a feasible solution to plastics in the increasing social, economic, and environmental crisis. Bioplastics are becoming a viable alternative to traditional plastics and their uses. Bioplastics account for around 1% of the 370 million tonnes of total world plastic generated. However, through 2025, yearly growth rates are expected to be about 30%. The International Union of Pure and Applied Chemistry (IUPAC) describes bioplastic as a derivative of "biomass or monomers of plant origin that can be engineered at some stage during processing". Although the keywords bio-based and biodegradable plastics are frequently used interchangeably, they are not synonymous. Non-petroleum biological resources are used to make bio-based plastics [7]. Biodegradable plastics, which can be bio-based or petroleum-based, disintegrate when exposed to naturally occurring bacteria. Some bio-based plastics are biodegradable. However, not all biobased plastics are

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biodegradable plastics [8]. The term "biobased" exclusively refers to the material's manufacturing process. It does not refer to what happens to it at the end of its existence.

Biobased and Biodegradable plastic can be seen as one of the alternatives to accomplish this sustainable growth of the plastic industry and offer a solid alternative to petrochemical plastics in the near future [9] by redirecting part of large volume plastics to other waste management methods and littering single-use plastics that are otherwise difficult to recycle. *S*imultaneously, contributing to recycling non-renewable materials and environmental protection of biodegradable plastics from renewable resources, biodegradable plastics could serve as a possible solution for overwhelmed landfills [10,11]. Biodegradable plastic may decompose into carbon dioxide (CO_2) and water (H_2O) in 20–45 days if there is enough humidity, oxygen, and an appropriate number of microorganisms, which can be found in natural landfills or manure [12] compared to conventional plastics that their life expectancy is about hundred to thousand years [13,14].

The factors that drive biodegradable plastics' accomplishment rates and position are their sustainability credentials and customers, regulations, technology, and resources [15]. The adoption and sustainability of biodegradable plastics focused on two technology areas – materials production and waste management. The improved composting infrastructure, including compost sorting, would treat biodegradable plastics in the composting plant [16,17]. Improved, financially feasible sorting technology would also mitigate recycling issues. Fluorescent markers are a viable technology in this field [18]. Fluorescent markers include an entail labelling of the resin that generates a light that can be sensed and used to sort products when irradiated. In terms of material properties, one crucial point is that biodegradable plastics with the same characteristics as traditional plastics can be developed to ensure competition in the market. Policy and intervention will dramatically alter the rate at which biodegradable and biobased plastics are used [15,19].

As a result, biodegradable plastics may be used instead of traditional plastics. It already has a significant impact in various sectors [7]. Despite this, their limited mechanical strength restricts their use. Synthetic fibres such as glass and carbon fibres are often employed to strengthen bioplastics. However, they are not biodegradable. As a result, more ecologically friendly, plentiful, and low-cost materials, such as lignocellulosic fibres and lignin, can be used to replace them [20]. Mould temperature rise, dehydrothermal treatment, and ultrasound application are some alternative physical strengthening techniques. When applied to soy protein-based bioplastics, heat treatment enhanced mechanical properties, dehydrothermal treatment increased superabsorbent capacity, and ultrasounds resulted in a structure with fewer holes. As a result, the bioplastics that have been processed might be utilised in various applications [21].

In contrast with biofuel development supporters, biodegradable plastics lack government policies [19]. Deposit bans (zero waste to deposit or waste mitigation to deposit) have an excellent connection to lower plastic deposit rates. However, it is cautious to ensure that all measures are related to particular recycling priorities and then tracked so that the amount of plastic waste incinerated does not only rise [18]. To promote the switch to biodegradable materials, fiscal policy initiatives would be required. This includes funding for low greenhouse gases practices and strong landfill prices (which will boost pathologic waste management's competitive position); and market control of farm feedstock's (to ensure they cope with natural gas, thereby pushing migration towards biological materials) [18]. Therefore, to navigate the global sustainability of biodegradable plastics uncertainty, a firm must gain a strategic advantage. Although risk management is critical for businesses, sustainability has introduced a new layer to the uncertainties surrounding biodegradable plastics' long-term viability [22].

2. Bioplastic polymers

The word bioplastic is frequently used interchangeably with the term biodegradable. Some bioplastics are biodegradable, but not all of them are [23]. Bioplastics can be defined as polymers that fulfil one or both of the following criteria: they are bio-based and biodegradable [24]. The term "bio-based" refers to a polymer that is made fully or partially from biomass, which includes any type of renewable organic material of biological origin, as well as organic waste [8]. The term "biodegradable" refers to a material's ability to degrade into natural components such as carbon dioxide, water, and biomass due to microorganism action [25]. In a more particular sense, biodegradable plastic is a plastic substance that meets certain official biodegradability requirements, where a specified quantity of degradation must be scientifically observed within a specific length of time and under particular conditions [7]. Meanwhile, biodegradable plastic undergoes biodegradation in industrial composting facilities and must adhere to strict guidelines. As a result, bioplastics are divided into three categories: those that are both biobased and biodegradable, those that are solely biobased, and those that are only biodegradable (see Fig. 1). *Poly (lactic acid) (PLA)* [26,27], *poly (hydroxy alkanoates) (PHAs)* [28], and bio-based *poly (butylene succinate) (bio-PBS)* [29], as well as plastics based on starch, cellulose, lignin, and chitosan, are some examples of bioplastics that are both bio-based and biodegradable. Bio-based *poly (amides) (bio-PP), poly (ethylene) (bio-PE)*, and *poly (ethylene terephthalate) (bio-PET)* are examples of bioplastics that are bio-based but not biodegradable [30]. Finally, *poly (caprolactone) (PCL)* [31], *poly (vinyl alcohol) (PVA)* [32], and *poly (butylene adipate terephthalate) (PBAT)* are examples of biodegradable bioplastics derived from fossil resources [33]. Furthermore, bio-based and chemically similar to their fossil-based equivalents, such as bio-PE, are sometimes referred to as drop-in polymers [7,34,35].

3. Overview of the bio-based and biodegradable plastics

Food packaging, (food service) ware, (retail) bags, fibres/nonwovens, and agricultural applications are all seeing an increase in the use of bio-based and biodegradable plastics [37]. Bio-based drop-in plastics, such as bio-PE and bio-PET, are compatible with fossil-based plastics and may be used in the same applications [38]. To guarantee that a packaged product has the appropriate shelf life, carefully selecting a bio-based and biodegradable packaging material is essential, just as it is with fossil-based plastics. Some plastic properties, such as bio-based plastics low water vapour barrier, might hinder one use while providing a benefit in another [4]. PLA is a disadvantage in a water bottle, but it benefits (breathable) vegetable and fruit packaging. The exact food safety requirements apply to bio-based and biodegradable plastics as they do to fossil-based plastics. Many bio-based plastics have certifications indicating that they are good for food contact [39].

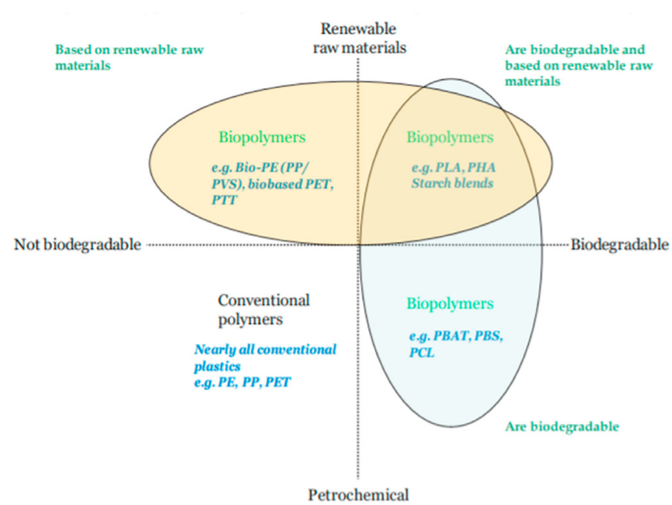

Fig. 1. Types of bioplastics, both biodegradable and non-biodegradable
Source: Adapted from European bioplastics [36].

Presently, the level of awareness in society regarding the effect of plastic waste in the environment has made it necessary to reduce its impact on natural resources and decrease the emission of CO_2 [13]. Plastics, which take a long time to decompose and are immune to natural processes, account for a large portion of household and industrial waste (10–30%) [40]. They contain chemicals that can threaten the atmosphere, and they need more resources to manufacture [41]. The accumulation of plastic waste obstructs water and oxygen flow, causing harm to the atmosphere and all living things. The traditional way of disposing of plastic waste was to dump it in landfills. Because of environmental issues and insufficient garbage capacity, the emphasis is now on recycling waste materials [42]. Even if it is possible to reuse plastic materials environmentally friendly, further tests should be done to ensure that the content achieves the appropriate consistency. Recycling also has several issues, including difficulties in recycling due to a complicated polymer composition, lack of specific beneficial properties, and the need for advanced technologies or more resources [43,44]. Dust and toxic gases (CO_2, NOx, and SOx) are released into the atmosphere as traditional plastic composites are recycled [13,45]. Companies involved in packaging need to search for other environment-friendly resources to reduce how plastic waste fills the environment drastically to overcome these problems. Adopting biodegradable plastics is a novel way out of the increasing demand for plastic packaging [42].

Biodegradable plastics are easily disintegrated by living organisms' activities, commonly known as microbes in the water [46]. This type of plastics can be substituted for plastics that are non-degradable to minimise the stress from the dwindling availability of landfill sites and plastic pollution. Also, the application of biodegradable plastics can decrease greenhouse gas emissions in the course of usage [42].

After being disposed of, biodegradable plastics are naturally reduced into nontoxic constituents in a manufacturing composting location [47]. The rate at which plastic materials are being adopted in packaging has led to biodegradable plastics. The use of polymers materials in packaging products meant to be used within a short time is deemed unnecessary [30]. Thus, biodegradable packaging was adopted because it disintegrates very fast in a manufacturing composting location. It can be created through synthetic or natural resin [48]. Petroleum-based products are used to produce synthetic biodegradable plastics, a non-renewable resource.

In contrast, natural biodegradable plastics can be primarily produced from renewable resources or synthesised from renewable substances [49]. Because renewable-based biodegradable plastics are created from plants, they have attracted increased attention due to the significant benefits to the industry. Besides, bio-based plastics can reduce the total dependence on petroleum supply, which will curtail carbon emissions into the atmosphere [42]. The most considered bio-based and eco-friendly plastic resources examined currently are PLA and polyhydroxyalkanoates (PHAs) [50]. The starting material for PLA and PHA production is extracted from annually renewable plant materials. This ensures that all aliphatic polyesters will, in theory, be processed sustainably. These bio-based plastics may be restored to CO_2 and then be photosynthesized by plants because they are biodegradable [51]. The development of PLA and PHA can thus be considered carbon-neutral and null pollution processes. In the long run and internationally, the net amount of carbon is constant in the atmosphere [52]. Bio-based and biodegradable plastics, including PLA and PHA, are commonly called eco-friendly and renewable to decrease fossil fuels. There is also a prediction for the expanded use of these products and the production for regulatory purposes of new levels of international biodegradability [53]. The modification of the molecule features (which are the weight of the molecule, sequence of the monomer distribution, and crystallinity) can regulate the rate at which PLA and PHA disintegrate. The biomedical and pharmaceutical fields have succeeded in using the PLA and its copolymers to produce recyclable sutures and matrices intended to coordinate the drug's delivery [54].

4. Methodology

The data for this study was gathered in a systematic way from credible sources, starting with a collection of relevant keywords for searching and obtaining material from databases and presenting the literature analysis. According to Tranfield et al. [55], the purpose of a literature review is to discover gaps in the existing literature and knowledge constraints [56, 57]. In short, the study used a four-step technique (see Fig. 2) that included identifying the data, screening preliminary data, evaluating eligibility, and ultimately including the data. The purpose of gathering this information is to propose new ideas and suggestions for future study. The researchers used the Scopus and Web of Science (classifications and insights) databases to compile their findings [58]. Many researchers regard the Scopus database as trustworthy [59–61]. Furthermore, academicians have praised the Web of Science database for high-quality indexing information. Many previous research has relied on it as a credible and high-quality data source [58,62].

4.1. Metadata analysis

The data was compiled using the Scopus and Web of Science integrated databases. The search includes all papers published between 1990 and 2022. TITLE-ABS-KEY ("Biodegradable plastics" OR "green packaging" OR "bioplastics" OR "bio-based plastics") are the words used in the study. The initial search criteria were limited to the article's title, abstract, and keywords. Six hundred and seventy-five pages were first created using three keywords.

In addition to articles, the first search result contained conference papers, books, and book chapters. Except for the articles, all (conference papers, books, and book chapters) were finally withdrawn. Consequently, following the first refining, 3484 papers survived as articles. After deleting duplicates, a total of 3462 publications were selected for the metadata analysis.

The researchers used 3462 Scopus articles for metadata assessment and 174 Web of Science articles to give insights and future prospects. Papers that appear in the Web of Science web browser are also included in Scopus (3462). The metadata study included publication dates, journals, nations, topic areas, and institutions for 3462 articles. To improve reading, some of the statistics in this study are presented in a summary style rather than a full list.

The researchers used 174 articles to give insights and prospects. As a result, the study reveals that the information is taken from trustworthy sources. Furthermore, because it indexes journals from other important databases such as Science Direct, Wiley, Elsevier, Emerald, MDPI, Taylor & Francis, IGI Global, Springer, and others, these databases are appropriate for generalizability purposes. On the other hand, the data should originate from a much more reputable source to convey the insights and prospects for the future. Many previous research used subjective judgement to choose data to analyse the collected data [59,60]. As a result, data were rigorously acquired from the Scopus and Web of Science using keywords search to verify that the data originated from a rich data source and kept an impartial conception of the study. Papers that appear in the Web of Science web browser are also included in Scopus [58].

4.1.1. Publications by year

The appearance of papers on bio-based plastics and biodegradable plastics began in 1990 and continued to develop steadily until 2014. The Fig. 3 shows that there has been an exponential increase since 2014 and continues until now. Furthermore, the trend line shows an upward tendency, implying that the literature on bio-based and biodegradable polymers is continually expanding. In 2021, 549 articles had been published, which is a substantial increase over prior years. As of January 5th, 2022, the published articles on bio-based plastics and biodegradable plastics have up to 46 articles. As a result, there are growing concerns and attention in bio-based plastics and biodegradable plastics, which

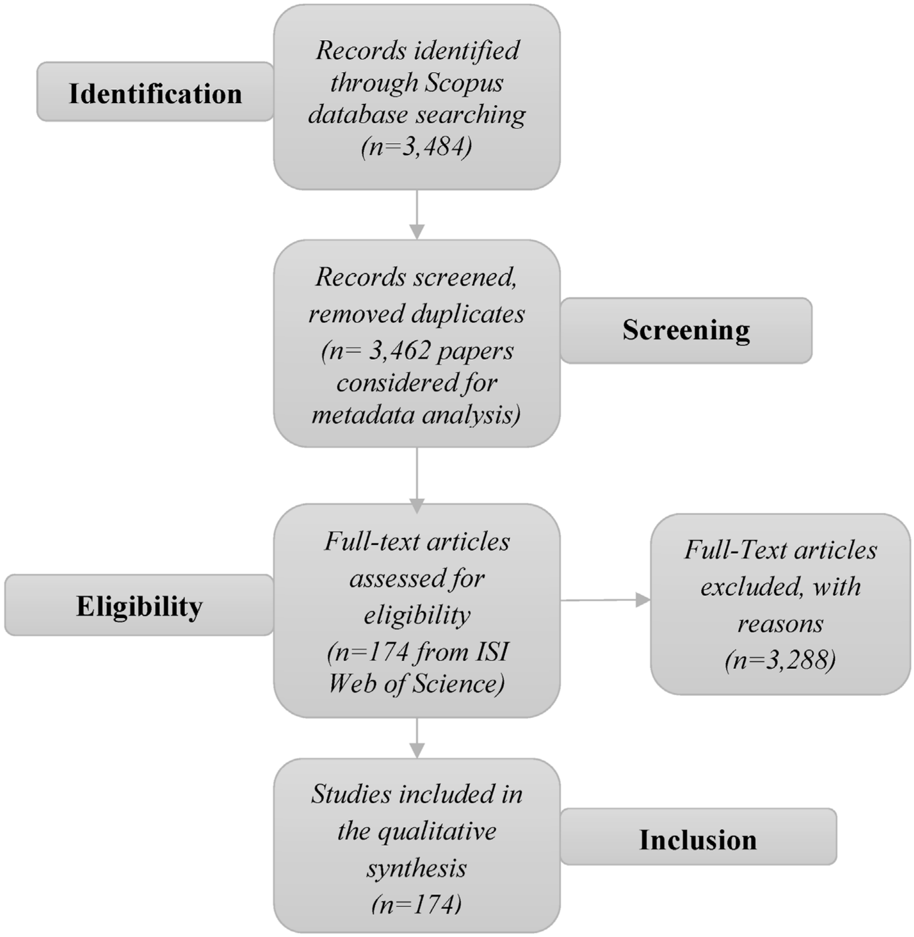

Fig. 2. Process of identifying, selecting, and including papers.

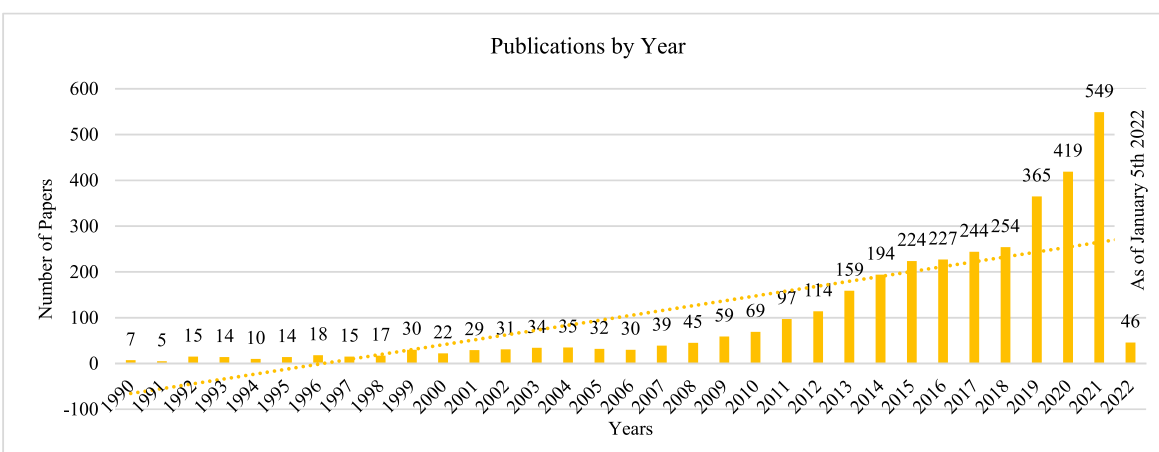

Fig. 3. Publications on bio-based and biodegradable plastics by year.

coincides with developing issues such as environmental stability, industrial and household pollution, and business and government concerns about social responsibility.

4.1.2. Publications by journals

Journal of Polymers and the Environment published the most publications (110), out of a total of 3462, as seen in Fig. 4. This is also the same journal with a high impact factor (3.667). As a result of its effect and popularity in the field of bio-based and biodegradable plastics, the Journal of Polymers and the Environment might be recognised as the number one journal. The International Journal of Biological Macromolecules is the second most popular journal, with 89 papers on bio-based and biodegradable plastics published out of 3462 with an impact factor of 6.953. Carbohydrate Polymers published 84 articles and has a high impact factor of (9.381). Despite the fact that the Science of the Total Environment published just 44 of the total publications, it has a significant impact factor of 7.963 (Table 1), putting it among the best for this field.

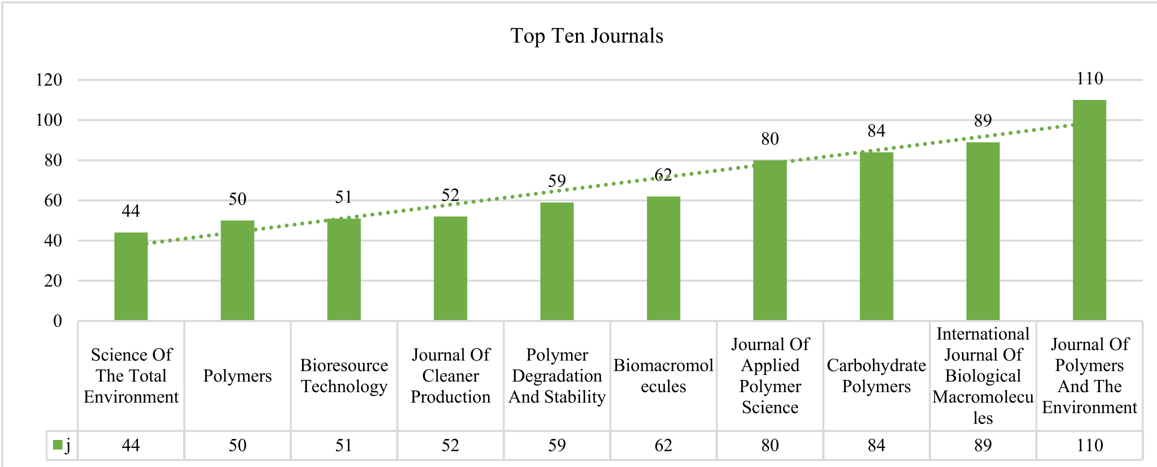

Fig. 4. Publications by journals.

Table 1
Influential journals on bio-based and biodegradable plastics.

Journals	Impact factor (2020)	No. of papers
Journal Of Polymers And The Environment	3.667	110
International Journal Of Biological Macromolecules	6.953	89
Carbohydrate Polymers	9.381	84
Journal Of Applied Polymer Science	3.125	80
Biomacromolecules	6.988	62
Polymer Degradation And Stability	5.030	59
Journal Of Cleaner Production	9.297	52
Bioresource Technology	9.642	51
Polymers	3.426	50
Science Of The Total Environment	7.963	44

4.1.3. Publications by countries

According to Fig. 5, the bio-based and biodegradable plastics literature, the United States published the most articles (567), followed by China (437). Japan and India are next, with 340 and 275 articles published, respectively. Malaysia is ranked 10th, accounting for 119 articles published. The literature on bio-based and biodegradable plastics has clearly shown that Asia, America, and Europe dominate. It's also worth noting that the United States published 16.37% while China published 12.62% of all articles published. This might be attributed to a rise in the knowledge of sustainable environmental practices in these nations, as they are responsible for much of the world's pollution and have consumed a large proportion of synthetic plastics in recent decades.

In related Fig. 5 to new economy bio-based and biodegradable plastics production capacities by region, in terms of worldwide bioplastic production capacity distribution by region between 2020 and 2025, Europe now contains one-fourth of global bio-based and biodegradable plastics production capacity [63]. However, Asia remains the key manufacturing hub in terms of actual bioplastics production and regional capacity expansion. In 2020, Asia generated 46.9% of all bio-based and biodegradable plastics. Production in the Americas has also grown at the same period. In light of this, establishing a European policy framework that ensures equitable access to bio-based resources, establishes measures to support bio-based product market entrance, and accounts for the enabling role of biodegradable plastics in waste stream management is critical. Asia was responsible for 46.9% of global bio-based and biodegradable plastics manufacturing capacity in 2020. Asia's bio-based and biodegradable plastics manufacturing capacity share is expected to fall to 43.2% of world capacity by 2025 [63]. Europe's bioplastics production capacity is predicted to rise dramatically throughout that time period. Figs. 6 and 7 show the region's new economy bio-based and biodegradable plastics production capacities in 2020 and 2025.

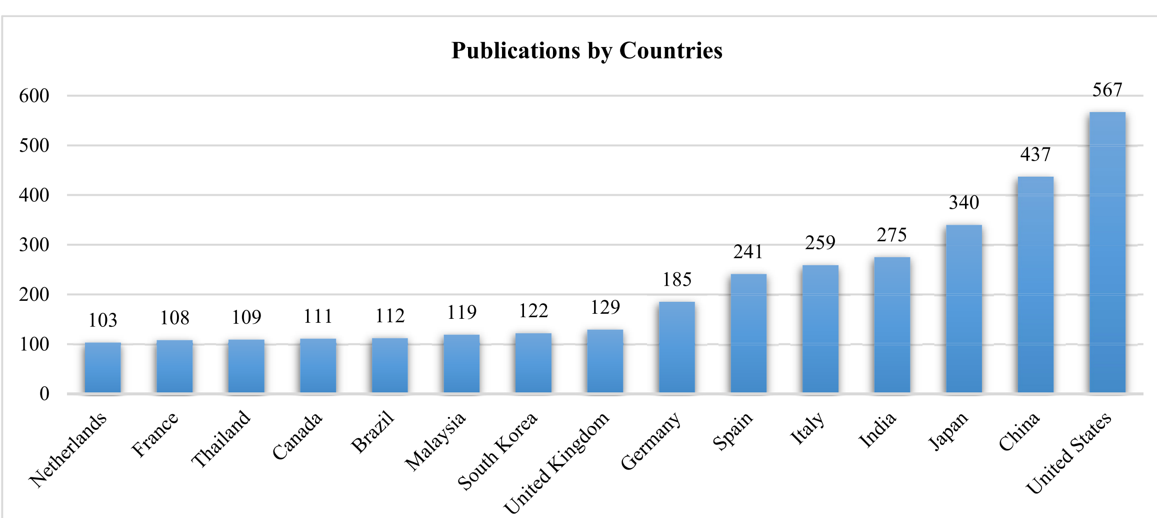

Fig. 5. Top fifteen countries that contributed to bio-based and biodegradable plastics literature.

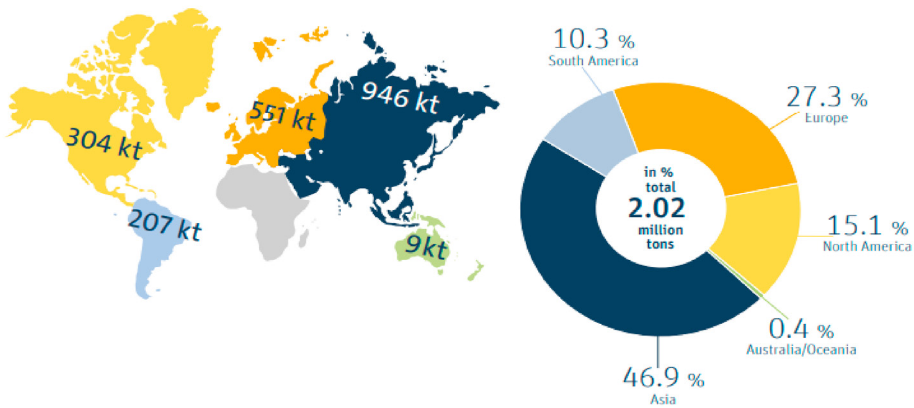

Fig. 6. New economy bioplastics production capacities by region in 2020
Source: Adapted from IFBB [63].

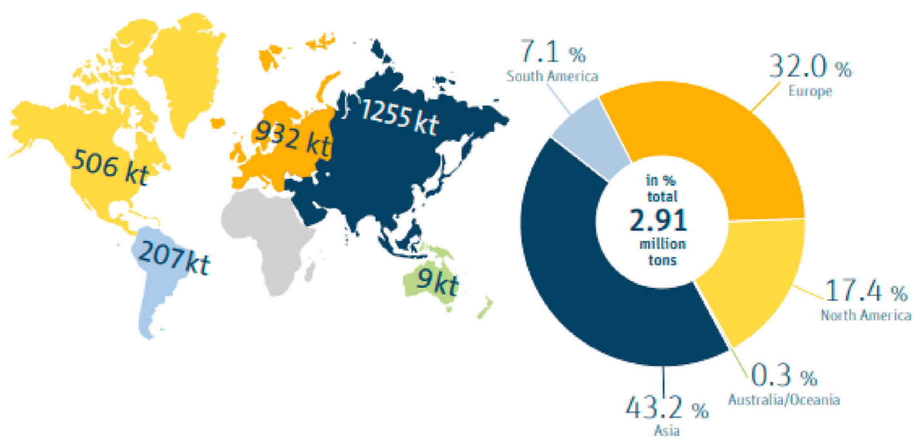

Fig. 7. New economy bioplastics production capacities by region in 2025
Source: Adapted from IFBB [63].

4.1.4. Contribution by subject area

The relevance and acceptability of bio-based and biodegradable plastics in the academic arena is demonstrated by using several disciplines in the literature. Fig. 8 shows that materials science with (16%), environmental science with (12%), chemistry with (12%), and chemical engineering with (11%) of disciplines produced the most articles. Although materials science dominates the literature on bio-based and biodegradable plastics, other disciplines are becoming more interested in the subject. This might be due to the issue of environmental deterioration, which is very important in today's economic world. Firms are under carefully and critically pressure from the government and pressure from environmentally concerned consumers and suppliers due to environmental degradation. Because bio-based and biodegradable plastics increase environmental sustainability, numerous disciplines have contributed to the literature on bio-based and biodegradable plastics, resulting in a wide range of topics of interest.

4.1.5. Publications by institutions

Fig. 9 shows authors' affiliations who have published on bio-based and biodegradable polymers. As seen in Fig. 9, Universidad de Sevilla and Ministry of Education China published the most articles in the bio-based and biodegradable plastics literature, accounting for 11% each. Only two institutions publish 22% of the total number of articles published. Chinese Academy of Sciences comes in third with the most articles published with 10%, followed by the National Institute of Advanced Industrial Science and Technology with 8% total number of articles published. Since educational institutions are recognised based on the work of their authors, a specific institute may rise to the top if its workers produce more articles.

5. Bio-based and biodegradable plastics: some observations and findings

This section provides information based on an impartial review of 174 Scopus and Web of Science papers. The following sections summarise the classifications of papers in the bio-based and biodegradable plastics literature into three basic groups before constructing a conceptual framework based on the present literature. The literature has been divided into five categories: Assessment/evaluation on the Sustainability of biodegradable plastics, Biodegradable plastics applications, end-of-life for bioplastics and Factors driving the uptake of biodegradable plastics.

5.1. Assessment/evaluation on the sustainability of bio-based and biodegradable plastics

In this study, articles from Web of Science were evaluated for their capacity to give new insights and future perspectives for researchers exploring the environmental, economic, and social aspects of biodegradable plastics, with a particular emphasis on the long-term sustainability of bio-based or biodegradable plastics, respectively. The triple bottom line (TBL) of bio-based or biodegradable plastics was studied. In comparison to environmental LCA studies, social and economic factors receive significantly less attention in the literature [64,65]. Because the upstream processes of these product systems are equivalent to

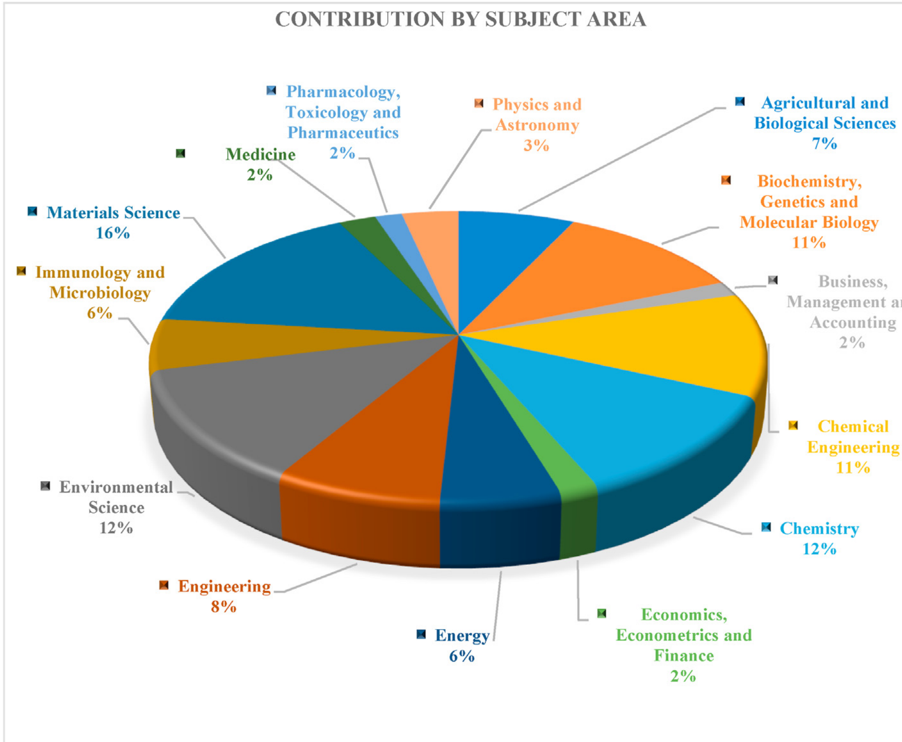

Fig. 8. Contributions of bio-based and biodegradable plastics papers by subject area

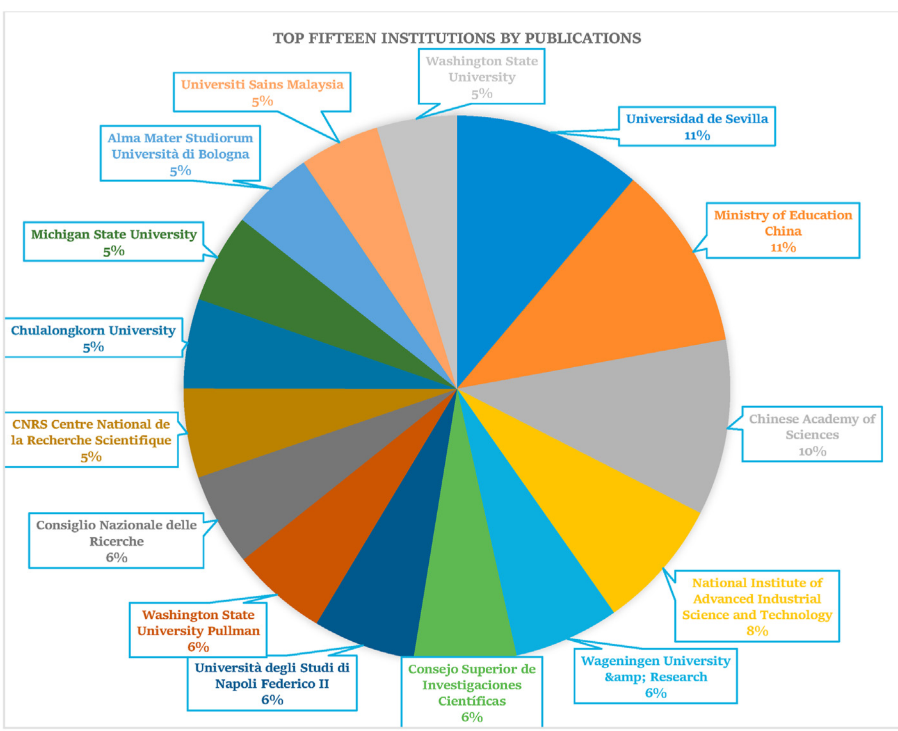

Fig. 9. Top fifteen institutions by publications

biodegradable plastics, the study was expanded to include social, environmental, and economic studies on bulk bio-based or biodegradable plastics, as seen in Table 2.

The scope of the research under consideration, as shown in Table 2, differs in terms of product systems, measurement processes, and indicators that are being studied, among other things. As a result, this research focuses on identifying important problems with biodegradable plastics' sustainability, such as social, environmental, and economic hotspots, as well as the metrics used to measure their sustainability [67]. This will necessitate a thorough examination of both procedures and scopes, which is outside the scope of this research [85]. Additionally, the following search phrases were used for a complete search of

Table 2
Sustainability dimensions and indicators for biobased and biodegradable plastics.

References	Types	Method	Dimensions	Indicators
Mendes and Pedersen [66]	Observation/Document Review	Life cycle assessment	Environmental	Climate Impacts, Recycling, Environmental Effects, Carbon Emissions, Waste Management.
Bishop et al. [67]	Systematic Literature Review	Life cycle assessment	Environmental	Waste Management, Biogenic Carbon Cycling, Carbon Emissions.
Salwa et al. [68]	Observation/Document Review	Life Cycle Assessment	Environmental	Environmental Impacts, Waste Management.
Amasawa et al. [69]	Experiment	Life Cycle Assessment	Environmental	GHG Emissions, End-of-Life Scenarios, Energy Recovery, Waste Management.
Kabir et al. [70],	Literature Review	Life Cycle Assessment	Environmental	Production, Waste Management, Distribution, Use, And Disposal.
Adekomaya et al. [71],	Observation/Document Review	Life Cycle Assessment	Environmental	Saving Fossil Energy and Reducing GHG Emissions, Waste Management.
Spierling et al. [72]	Meta-Analysis	Life Cycle Assessment	Environmental	End-of-Life Assessment, Global Warming Potential, Waste Management.
Walker and Rothman [49],	Literature Review	Life Cycle Assessment	Environmental	Energy Consumption, Carbon Emissions.
Bałdowska-Witos et al. [73],	Meta-Analysis	Life Cycle Assessment	Environmental	Eco-System Integrity, GHG Emissions.
Venkatachalam et al. [74],	Quantitative Survey	Life Cycle Assessment	Environmental	Carbon Emissions, Waste Management.
Beigbeder et al. [75],	Experiment	Life Cycle Assessment	Environmental	End-of-Life, GHG Emissions.
Dilkes-Hoffman et al. [76],	Systematic Literature Review	Life Cycle Assessment	Environmental	Energy Consumption, Carbon Emissions.
Martinho et al. [77],	Quantitative Survey	Survey Questionnaire	Environmental	GHG Emissions, Water Usage, Energy Consumption, Waste Generation.
Pires et al. [78]	Quantitative Survey	Life Cycle Assessment	Environmental	Energy Consumption, Waste Generation.
			Environmental,	Waste management.
Dijkstra et al. [79],	Systematic Literature Review	Triple Bottom Line	Economics	High Costs.
			Social	Society, Product Responsibility, Health and Safety.
Filiciotto and Rothenberg [80],	Meta-Analysis	Material Flow Analysis	Environmental	Climate Change, GHG Emissions.
			Economic	Financial Performance.
			Social	Empowerment, Responsibility to the Community.
Wellenreuther and Wolf [81],	Literature Review	Life Cycle Assessment	Environmental	Environmental Performances, Cost Efficient.
			Economic	Cost, Technical Impact.
Gerassimidou et al. [82],	Systematic Literature Review	Multidimensional Perspective	Environmental	Global Warming Potential.
			Economic,	Financial Impact, Eco-Efficiency
			Social	Participation, Accessibility, Health and Safety.
			Environmental,	End-of-life, Materials, and services
Blanc et al. [83],	Quantitative Survey	LCA, LCC, and ExA	Economic	Transformation, Sale, costs.
			Social	Consumption, Health and Safety
			Environmental	Environmental Management, Pollution, Dangerousness.
Xu, Jiang, and Wu [84],	Systematic Literature Review	Fuzzy Analytical Hierarchy	Economic	Reliability, Responsiveness, Flexibility, Financial Performance.
			Social	Human Rights, Societal Commitment, Customers Issues.

biodegradable items' social, environmental, and economic aspects: commodities manufactured from renewable resources. There are social elements of biodegradable products, biodegradable plastics sustainability indicators, the economic aspects of biodegradable plastics, and the environmental aspects of biodegradable plastics.

However, while there has been substantial study into plastic film, most of it has been on the products' environmental impact. Leceta et al. [86] conducted an environmental evaluation of bio-based films made from agro-industrial by-products and marine leftovers to maximise the value of these wastes. Siracusa et al. [87] used a life cycle assessment technique to assess the environmental harm caused by a bi-layer film bag for food packaging throughout its life cycle from an environmental standpoint. Toniolo et al. [88] utilised the life cycle assessment technique to compare the environmental benefits of two recycled plastic packagings, one of which was recyclable after use and the other which was not. Results showed that using a comparative LCA application was a useful way for determining the extent to which an innovative recyclable package was ecologically superior to an alternative non-recyclable package when comparing two different types of packaging. According to Barlow & Morgan [89], concentrated their attention on packaging in the meat and cheese industries, examining the impact of films and bags, as well as the influence of packaging on the levels of waste and energy consumption elsewhere in the food system.

Regarding promoting packaging sustainability through eco-design tools, Martinho et al. [77] focused on the factors that impacted consumer product purchase and recycling behaviour concerning sustainable packaging. The sustainable variable was environmental awareness, which included purchasing and disposing of items following environmental regulations. Some analyses have concentrated on two aspects: the economic and environmental dimensions, or the environmental and social dimensions, while others have focused on three dimensions. According to Pålsson et al. [90], an assessment model for selecting packaging solutions in supply chains was established from the standpoint of sustainability. The estimates for the environment were based on carbon emissions, and the calculations for the economy were based on expenses. Grönman et al. [91] followed a systematic methodology for sustainable food packaging design that included SWOT analysis and the Life Cycle Assessment approach for evaluating environmental and economic functions. Pires et al. [78] investigated sustainability parameters, which were aggregated using a multi-criteria decision-making technique on two dimensions: environmental aspects connected to life cycle assessment and social aspects related to environmental information on the packaging. They found that the packaging had a positive impact on both environmental aspects and social aspects. Jiuping Xu et al. [84] provide sustainability criteria for plastic film supply chain management based on a triple bottom line approach (economic profit, environmental protection, and social responsibility).

Academic and corporate interest in biodegradable plastics for sustainability has exploded in recent years. This paper assessed biodegradable plastics for sustainability using the TBL technique (economic benefit, social responsibility, and environmental protection). In general, biodegradable plastic film assessments have focused on the product itself, with little thought given to analysing biodegradable plastics sustainability from the perspective of TBL and determinants. As biodegradable plastic usage rises, more companies focus on long-term sustainability.

As a result, both rich and developing nations have a large body of literature on organisational variables [4]. To the best of our knowledge, only small research has used the TBL technique for biodegradable plastic film sustainability, and few assessments of biodegradable plastic film sustainability have been conducted. This study aims to assess the long-term viability of biodegradable plastics, and the study indicated above can help. A vital component of creating sustainable plastic is the establishment of sustainability aspects, assessment procedures, and performance measurement indicators. Furthermore, past research has paid less attention to crucial aspects impacting the biodegradable plastics market's long-term viability. From a commercial standpoint, this research would uncover variables that are driving the acceptance of biodegradable plastics to aid operation managers, government agencies, and organisations.

5.2. Sustainability of biodegradable plastics

The term "sustainable" was initially used in forest areas in Germany in the 1840s, and Gifford Pinchot et al. introduced it to the United States. While the term was originally used for natural resources, it has now come to refer to a set of procedures that allow resources to be utilised and maintained at specific rates [92]. Later, the concept was transferred to agriculture and indicated a changing paradigm [93]. The first of the economic framework's principles on sustainability is that changes in consumer behaviour should contain some forward-thinking [94]. Consumers who spend so much now may be termed "irrational" to ensure future well-being. At this point, it has become apparent that estimating consumers' present plastic usage without causing them to become destitute in the future is necessary.

Sustainable growth is commonly recognised as a key strategic goal of today's global policy. The concept's most well-known exposition defines sustainable development as development which meets present-day needs without jeopardizing generations to come' (World Commission on Environment and Development) [95]. This appears to be a very straightforward idea, which lies at the core of the link between economic growth, preservation of the environment, and social wellbeing. But operationalizing these ties poses a major challenge for a wide variety of stakeholders, including the government, NGOs, companies, community groups, and individuals [96].

When the term "sustainability" was first employed in the perspective of the future of the human being in Goldsmith [97], book, it came to the forefront as a normative idea [98]. Sustainability, which was also on the agenda at the United Nations Conference on Human Environment in Stockholm [92], was described as an approach that seeks to satisfy today's needs in a way that ensure the satisfaction of people and to realise these by protecting natural resources while considering the interests of future generations [92]. Later decades saw the notion of sustainability broadened in a variety of ways. Economic growth and development within the largest borders of ecology was realised through reciprocal contact and sustained over time, according to Ayar and Gürbüz [92]. "Sustainable consumption" was defined by the Roundtable [99] as "consumption that meets basic needs while minimizing the use of natural resources, toxic materials, waste emissions, and environmental pollutants throughout the product or service's life cycle," while also "bringing a higher quality of life and greater use of services."

Furthermore, the broad definition of sustainability allows individuals with various viewpoints to find common ground. When the literature is examined historically, it is seen that academic circles are primarily concerned with issues related to environmental protection. Many researchers have looked at material issues such as pollution and trash [100], worries about acid rain, recycling [101], and greenhouse gas emissions [102] in an attempt to identify answers. According to Thakur et al. [103], from the consumer's perspective, the quickly growing technology and production possibilities in the twenty-first century, on the one hand, diminish natural resources, increase environmental damage. Humanity becomes more and more injured as a result of this scenario. Environmental consciousness has developed thanks to communication channels that make customers more sensitive to social concerns and have started to shift to products or services that do not hurt nature and people. In addition to environmental concerns, the concept of sustainable consumption encompasses many other issues, such as the preservation of natural resources, the fight against poverty, industrial efficiency, and the advancement of economic development, health, education, and the overall quality of life.

Walkera & Rothmana [85] underlined the purposes of sustainability are entrenched in the following tripartite: economic prosperity, social fairness, and protection of the environment. Achieving well enhanced and sustained results of biodegradable plastics rests on minimizing the plastics processes. The objective of social economics and environmental sustainability consideration in biodegradable plastics is based on resource management and effective environmental protection. Fig. 10 depicts the stages of a packaging's life cycle where sustainability may be enhanced and which parts of these stages can be addressed.

5.2.1. Social sustainability

Basically, many researchers concluded that social sustainability includes effective social capital management [104,105]. The social capital can be seen as a long-lasting commodity of an organization that is not used depreciated, but instead refined and has to be held on a long term basis [106]. Social capital creation within an organization involves management establishing a desirable working atmosphere, where workers improve social skills and other skills. This can be achieved by changing aspects like investing in human resources, enhancing workforce ability, fostering a collaborative working community, networking opportunities, access to the information available, and gaining new knowledge more productively and efficiently [107]. Social capital also helps an organization increase the standard of education at a larger scale, eliminate development, and tackle hunger and other public severe problems at the systemic level [105].

5.2.2. Economics sustainability

In order to assure the economic consequences of long-term biodegradable plastics, techniques that can conserve cost-effectiveness, the environment, human, and social capital for a long time should be explored [108,109]. The capital strategy will provide the theoretical strategy for measuring all shared resources in various units, which will afford stable, hypothetically comprehensive, and policy-relevant assessments among countries [96]. The establishment of jobs and enterprises for the general public is a good indicator of the economic impact of using biodegradable plastics. When employment is established, it is relatively straightforward to add taxable bases and physical goods [46]. Furthermore, using sustainable materials can reduce energy consumption, waste disposal, and manufacturing costs throughout operations [18].

5.2.3. Environmental sustainability

During the development of products or services, it may be necessary to monitor resource depletion and technical contamination to determine the environmental sustainability of biodegradable plastics [110]. The depletion of resources includes the use of land, energy, water, fossil fuel, and so on. The emission of effluence includes climate change, greenhouse gas emissions, water pollution, air contamination, the release of a fatal chemical, poisoning humans, the release of cancer-causing agents, the production of summer smog, acidification, eutrophication, and so on. When developing environmentally friendly products and services, it is critical to conduct environmental assessments using strategic methods [111]. This strategy will ensure the development of policies, procedures, and packages that are sensitive and favourable to the environment [112,113].

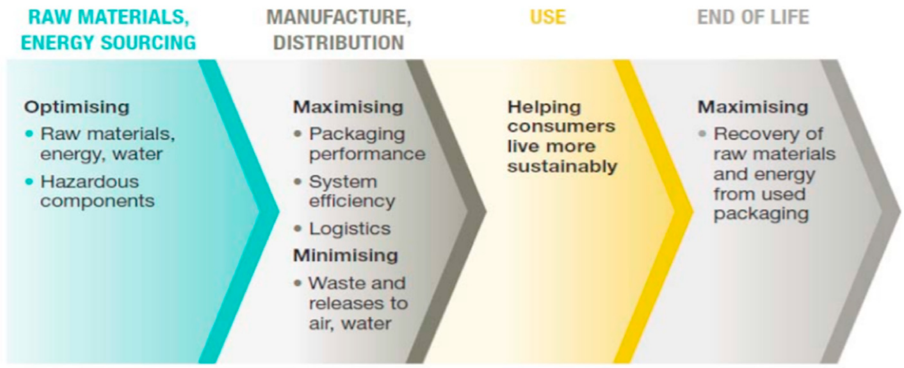

Fig. 10. The concept for sustainability for biodegradable plastics packaging and product systems.

5.3. Substrates for the sustainability of biodegradable plastic in planning practice

According to the principle of social sustainability, job creation should be regulated by social justice standards, according to the principle of "social sustainability." To connect these, an enabling environment must be built to maximise resource use, prioritize resource allocation, and promote fair resource distribution [114]. In practice, environmental sustainability theory offers a planning approach that permits human civilization to survive within the biophysical environment's constraints [115]. One method to putting the concept of "economic sustainability" into reality is to use an urban design technique that meets the social service needs of the general public, particularly the urban poor, while also enhancing the authenticity of the urban environment [116,117]. This is already a great feature, but they may still be made to lower environmental effects and be more environmentally friendly [118]. Biodegradable plastic packaging is an essential component of sustainability since it is the trash that a customer must deal with and dispose of on their own [117]. Fig. 11 depicts the stages of a packaging's life cycle where sustainability may be enhanced and which parts of these stages can be addressed.

Aside from the types of plastics concerned, the scope of the agreement must take into account the whole lifetime of plastics and maintain sustainability across the various stages of production, manufacture, consumption, and waste disposal (see Fig. 11). Sustainable plastics in design, manufacture, chemical application, and end-product are critical. This necessitates openness in plastics production and treatment and transparency in the use of resins, products, waste materials, and chemical

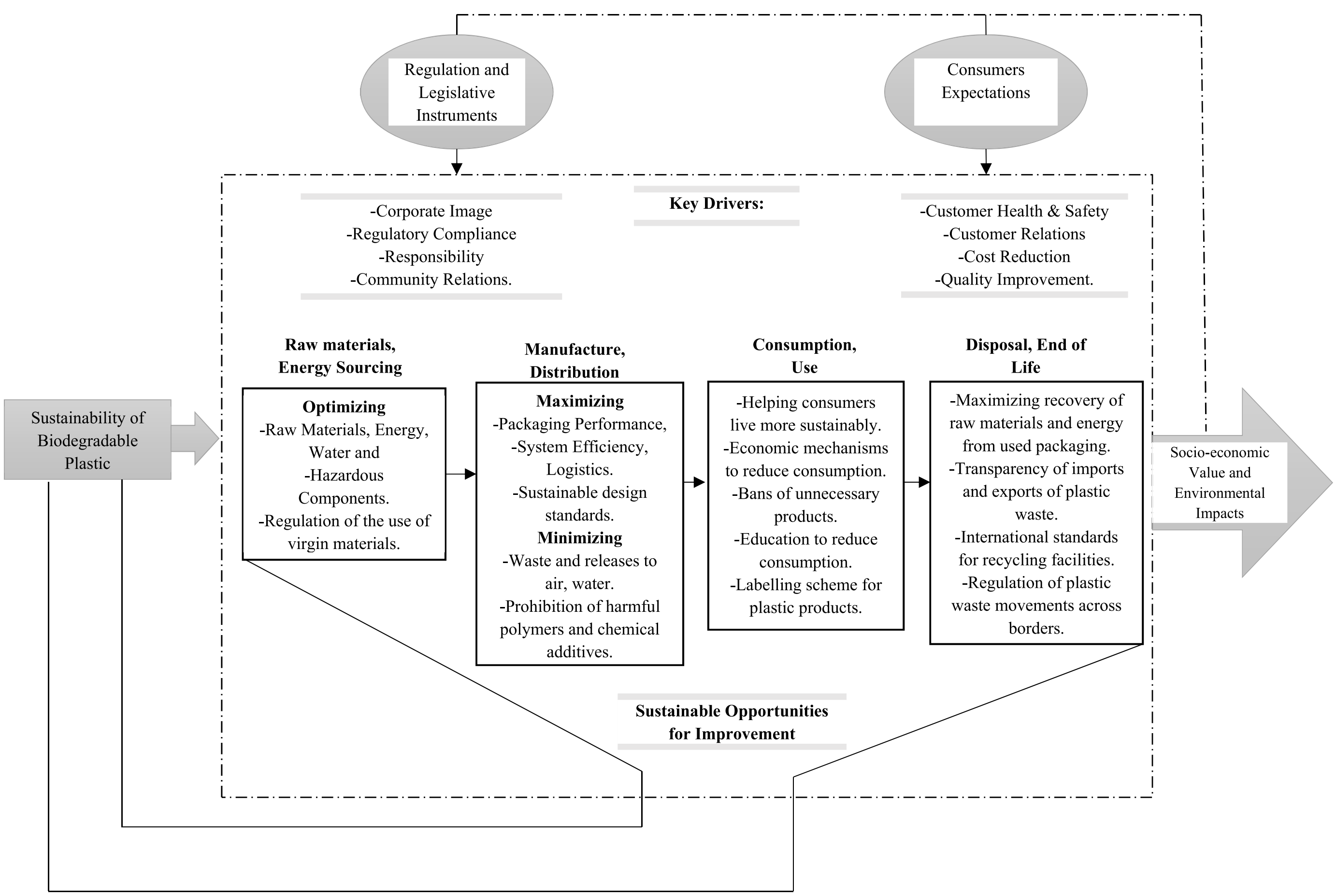

Fig. 11. Concept for sustainability and extended policy on biodegradable packaging towards production systems priorities.

components [119]. Global industrial standards must contain functional definitions, environmental criteria for all lifecycle processes, Extended Producer Responsibility (EPR) schemes, labelling systems showing recycled content, suitable disposal, and danger potential, as well as other requirements [120]. Despite several recommendations, the issue remains in determining how to tailor them to distinct local situations. Simon and Schulte [121] restate the Global Ocean Commission's request to eradicate plastic pollution through "time bound, quantitative reduction objectives" and "better waste management" for the treaty design, based on identifying the amount of garbage that is not properly collected and establishing a goal to raise waste collection rates, as the quantity of waste that enters the ocean is far more difficult to assess. Two different approaches are proposed by Raubenheimer [122],: a "Waste Reduction Approach" as a short- and medium-term solution for a more integrated waste management system, and a "Usage Reduction Approach" as a long-term solution for lowering per-capita virgin material consumption and closing the loop.

An innovative worldwide certification method for sustainable design may be used to encourage the use of sustainable design [123]. The international initiative "Operation Clean Sweep" provides the best pellet, flake, and powder containment practices. However, it is presently only available on a volunteer basis [119]. Plastic types that meet international quality requirements for quality may be produced in smaller quantities, and the management of inferior plastics and controlled chemicals can be made more efficient [120]. As a result, there is a pressing need for more comprehensive training in chemical synthesis and green chemistry to be included in university curricula and training courses for professionals such as scientists, professors and regulators, as well as industry personnel, particularly in developing countries [124]. Pressure from the community and the possibility of legal responsibility, on the other hand, might motivate businesses to develop their environmental and social performance [119]. Unquestionably, when public pressure results in stringent environmental legislation, businesses are more likely to enhance their environmental performance. Companies may push for rules on their own behalf if they have created environmentally friendly materials and feel that mandating their technology will provide a competitive edge in the marketplace. Researchers in strategy and public policy [119–121] argue environmental legislation's long-term costs and advantages. Many of the early conversations regarding sustainable products centred on the trade-offs that must be made between environmental protection and social-economic competitiveness.

Therefore, the principles for the sustainability for biodegradable plastics packaging and product systems, as developed by this organization, include: Reduce the number of raw materials, finished goods, and packaging that is utilised, reducing the use of single-use products that cannot be recycled or composted; avoiding the use of fossil fuel-based materials in favour of materials and products derived from renewable feedstocks; and addressing sustainability throughout a material's life cycle: from feedstock production to the manufacturing of biomaterials and final products to use and disposal of the material after it has served its purpose. Environmental, health, and social and economic justice are all included in the definition of sustainability. Reusable, recyclable, and compostable items are encouraged, as are agricultural systems benefit farmers, the environment, farm workers, and the local community. Specifically, this means removing hazards of concern during feedstock production; conserving soil; protecting and building soil; conserving nutrient cycles; protecting air and water access and quality; promoting biological diversity; reducing overall energy consumption and its impacts; reducing transportation impacts; developing and certifying a comprehensive sustainable agriculture plan; protecting workers' health and safety; and providing fair compensation. Farms owned and run by small to mid-sized families should be supported; Genetically Modified Organisms (GMOs) should not be used in agricultural feedstock production, and chemicals should adhere to the 12 Principles of Green Chemistry should be used in their manufacture. These principles aim to limit the potential for health and environmental risks in the design and manufacturing of chemicals [125], avoid engineered nanomaterials and chemicals that have not been evaluated for environmental and public health impacts across the life cycle, and decentralise production and buy locally to reduce the environmental footprint of production, transportation, and consumption.

5.4. Applications of bioplastics

Bioplastics are frequently utilised in the food packaging, pharmaceutical, and medical equipment industries. PLA, PHA, and nanocomposites might be used to make bioplastics. However, starch is the most often utilised substance in the production of bioplastics [23]. Corn or potato starch is used to make it. Starch was chosen because it has a biodegradable natural properties and can be manufactured in large quantities at a reasonable cost. It is said to be one of the most promising options for bio-plastics manufacturing. PLA, PHA, and nanocomposites are the most popular types of bioplastics utilised in packaging applications.

PLA is used in various packaging materials, including cups, bottles, films, and containers [23]. It also works in the textiles business, producing shirts, furniture fabrics, and diapers. Due to the stereo complex, Mazda and Teijin developed heat-resistance PLA for automotive materials. Spun fibres and biaxially stretched film are two possible characteristics of PLA. Another kind of PLA that Synbra, Sulzer, and PURAC created is foamed PLA, which is utilised for expanded polystyrene (EPS) foam as a bio-based alternative. PLA is also used to strengthen the casing of mobile phones with kenaf fibre [53]. PHA has a wide range of applications in the industry. Medical implant materials, medication delivery carriers, and even granule surface proteins were all covered. PHA has been synthesised into various structures to fulfil these goals, including PHB, PHBV, P4HB, and P3HO. Sutures, repair devices, repair patches, tendon repair devices, artificial oesophagus, and wound dressings are researched. PHA oligomers have also been discovered to have nutritional and medicinal properties [23].

Furthermore, because of its biodegradability, biocompatibility, and breakdown through surface erosion, PHA is also employed as a drug carrier. Moreover, PHA monomers have been produced as RHA, which has significant uses as initiators in synthesising acceptable compounds such as antibiotics, vitamins, aromatics, and pheromones. R3HB, a different PHA monomer, has also been utilised to make carbapenem antibiotics and macrolides [23].

5.4.1. Food packaging

Plastic wrapping problems, which constitute a whole sector in and of itself, have been the major focus of the food industry in recent years [7]. In order to meet the needs and criteria of the food production business, this sector is constantly evolving. Its emphasis on developing innovative polymer-based packaging is essential for the whole food industry's long-term sustainability and quality standards, resulting in cleaner and more sustainable supply chains from production facilities and their internal storage systems to transportation facilities, among other things [126]. In addition to meeting the requirement for high-standard storage qualities, compostable or degradable biomaterials may also satisfy the desire for packaging that is inexpensive in cost, has a minimal environmental impact, is easy to customise, and has a low environmental footprint [127]. Still, effective packaging applications in the food business are limited compared to other areas and need to be expanded; however, today's most prominent food distribution organisations are aware of the issue and appear eager to convert to bioplastics as much as feasible [128]. The importance of remembering that different food items require various packaging features when designing this type of material necessitated the development of multiple technologies such as multi-layer films, modified environment packaging, and intelligent and active packaging when creating this type of material [129]. Water and oxygen resistance are two of the most highly desired qualities in food packaging. But creating bio-based multicomponent synthetic coatings to serve as a barrier is not difficult, there is a disadvantage in terms of recycling, because single-component materials can be recycled while multicomponent coatings cannot be recycled [7].

5.4.2. Agricultural applications

PHA-based bioplastics are used in various agricultural applications, including nets, grow bags, and mulch films. Using bioplastics-based nets as a substitute for high-density polyethene (HDPE), which has traditionally been used to increase crop quality and output while protecting it from birds, insects, and the weather, is becoming more popular [7]. Grow bags, also known as planter bags or seedling bags, are made mostly of low-density polyethene, which is readily available. On the other hand, grow bags made of polyhydroxyalkanoate (PHA) would be biodegradable, root-friendly, and non-toxic to surrounding water sources. To conclude, bioplastics in mulch films are necessary to maintain excellent soil structure, moisture retention, weed control, and pollution avoidance to replace fossil-based plastics in the mulch film [130]. Bioplastics are often used in agriculture and horticulture [131]. Putting flowers or plants in a biodegradable container saves the buyer money because they don't have to throw it away. It may be planted beside the bloom and will ultimately decompose [118]. The mulching film, flower bulb packing, attaching technologies, fertiliser rods, and pheromone traps are some of the other uses in this field.

5.4.3. Medical applications

Bioplastics are utilised in various medical applications, including medical equipment, gloves, and blood containers. Because of their biodegradability, they're also employed in implants. The plastic will ‘disappear' on its own and will not need to be removed [118]. Cardiovascular, burn, wound dressings, medication delivery devices and dental implants are among the other uses. Advances in biomedical applications of biodegradable plastic materials lead to the development of novel drug delivery systems and tissue engineering therapeutic devices, such as implants and scaffolds [132]. Polymers are used in various medicinal and biological applications [133]. These areas can benefit from cellulose as the primary green bioplastic. Cellulose has been extensively researched in the domains of implants, tissue and neural engineering and due to its nontoxicity, lack of mutagenicity, and biocompatibility in medicines [134]. Cellulose fibres are formed by the arrangement of fibrils, which are the fundamental structural units with cell widths of 10 nm, in a macroscopically organised manner. Bacterial cellulose is being utilised to create cellulosic membranes used in tissue healing scopes.

These membranes have holes ranging from 60 to 300 μm in diameter. Additionally, bacterial nano-networks and modified cellulose matrix have been investigated [7]. Any green plastic research on the manufacture of medical implants, whether in the dentistry, orthopaedic, or biomedical areas, rely heavily on nano cellulose and their composites. In more recent investigations, 3D printing and magnetically sensitive nanocellulose-based materials are being developed [135]. Another use that deserves to be mentioned is wound dressing nano-cellulosic membranes, which provide benefits such as reepithelialization acceleration, wound pain reduction, infection reduction and extruding retention. Bioprocess®, XCell®, and Biofll® are examples of patented goods of this type that are currently on the market [7]. Another benefit of using PHAs is that they are biocompatible, making them suitable for a wide range of medical applications, including cancer detection and therapy, wound healing dressing, post-surgical ulcer care, and bone tissue engineering [132].

5.5. Bioplastics end-of-life management

End-of-life management scenarios were created for this research to see if upgrading the EOL management system might reduce the environmental effect. Approximately 75% of plastic trash is now disposed of in sanitary landfills, with the other 25% being recycled [136]. In landfills, bioplastics can decompose anaerobically, producing methane, a powerful greenhouse gas. Bioplastics may be turned to compost with suitable composting facilities. Bioplastics, on the other hand, are theoretically recyclable [137]. When biobased and biodegradable plastics are used more often, disposal must be considered. There are no issues with using drop-in biobased polymers like bioPE because they are chemically similar to their petroleum-derived equivalents and can be recycled in the same stream [138].

On the other hand, Biodegradable plastics are a new class of materials that are chemically different from existing plastics. Most individuals (62%) said they would recycle biodegradable plastic in their usual recycling container if they could identify it [139]. Recycling, organic recovery, and energy recovery are the most advantageous end-of-life options for fibre and bio-based packaging materials since they avoid landfilling [140]. The recovery chain must include the following stages to adhere to this hierarchy in a long-term manner: (a) collection – creating appropriate collection methods based on the source of packaging waste; and (b) sorting – adequate categorization for each end-of-life solution following the quality standards [141]. The main objective for bioplastic goods at the end of their intended usage is to close the loop, cycling the product back to be reutilized at the end of its life [136]. Reduce, reuse, recycle, and compost are the preferred methods of disposal at the end of a product's life cycle.

The end-of-life options for bioplastics include; recycling, renewable energy recovery (incineration), compost/biodegradation, anaerobic digestion and feedstock recovery. Bioplastics may be recycled; however, they must be separated into distinct streams [142]. Suppose biodegradable material is introduced into the conventional plastics stream and fully degrades throughout the recycling process. In that case, the features and specifications of the traditional material with which it is mixed may be altered. Furthermore, if it does not entirely decay, it may do so in the completed recycled product, causing premature failure [143]. Though the technology for separating bioplastics from ordinary plastics exists, it is still in its infancy. It will be practical soon as commercial quantities rise enough to pay the necessary investments. Because of the large quantity of heat created by plastics, energy recovery is worldwide [144]. PLA and other biodegradable plastics created from renewable resources typically include carbon, oxygen, and hydrogen atoms, with no chlorine atoms. They do not develop dioxins during combustion or incineration since they contain chlorine atoms. Bioplastics have always lacked heavy-metal additions [145]. As a result, they may generally be properly burned without producing dioxins or heavy metals [139]. End-of-life alternatives such as recycling, composting, and anaerobic digestion should be prioritised above energy recovery because of the great potential for other choices such as those mentioned above [146]. Even though biodegradability is the primary goal of bioplastics, they should be the least desired end-of-life choice because there is a great possibility for alternative end-of-life alternatives such as recycling, composting, and anaerobic digestion [147].

The bioplastic may not only be melted and turned into granules for new use during recycling but it can also be broken down into its chemical building block in some circumstances [148]. Lactic acid, for example, may be extracted from PLA and utilised to create PLA resin once more. Chemical recycling is another term for it [149]. The product that has been certified biodegradable or compostable and the difference between the two must be well understood [150]. Biodegradable products are always compostable, whereas compostable products are not necessarily biodegradable. In order to be biodegradable, a product must satisfy specific standards (time, environmental conditions, quality of compost produced). Composability is a feature of several bioplastic materials [151]. However, this composability will only occur under the strict supervision of industrial composting facilities [152]. At the moment, the approach of utilizing waste from biodegradable plastics in bio-gasifiers to turn it into useable methane is also being used on a small scale. When coupled with composability, anaerobic digestion of bioplastics offers a lot of potential for more effective waste management [153].

5.6. Factors driving the uptake of biodegradable plastics

Biodegradable plastics' achievement rates and position are influenced by their sustainability credentials and clients, as well as rules, technology, and resources (Shen, 2009). There are a few brief instances:

➢ Materials Related Factors

The material-related factor may directly impact biodegradable plastics manufacturing, and the cost of the product can be significant [155,156]. Selection time, type of materials, and affordability of the commodity in the local market are all risk factors correlated with materials. Build engineering, marketing, logistics, reliability, aesthetics, and efficiency place life-cycle standards on materials and manufacturing processes. The content group may have a discernible impact on cost and timeliness. Material uncertainties are factors that can affect the cost and duration of a biodegradable plastics industry production exhibition [157]. Delays in supplier payment, inflation/market fluctuation, supply price increases, sponsor/client funding, deviation demands, and a poor financial/capital climate are all material-related risk factors. This list lists the delay factor content classes where producers score high, and owners score low. The general idea that influenced academia and industry is that a lack of materials and machinery needed for production is a reality in developing countries' manufacturing sectors.

➢ Technology Factor

Technology cost includes the cost of equipment, machinery, and failure in the system, a mistake in the estimation, crash, and injuries. The site location and connectivity and new technology malfunction are other threats in this group. The parties' numerous activities and operating processes are a technological risk for local-foreign joint projects that might occur. Technological hazards include something that stops businesses from making the commodity they desire [158]. This could involve capital indecision and content obtainability, preliminary site survey, the adequacy of requirements, and the initial design. These risks are expected when the project's complexity and specifications change and if design mistakes or overviews occur [158,159]. Moser et al. [160] note that technology is a world view that needs to be considered in developed countries' strategic strategies. Purohit and Kumar [161] concluded that sufficient biologically degradable technology could be calculated by the existence of local fabrics, the magnitude of local materials and the usage of local risk management services, and professional workforce resources.

➢ Regulatory Environment

The regulatory environment is widely acknowledged as a significant factor influencing green products. Although overly stringent government policies may result in lower levels of technological innovations [162], we see it differently regarding implementing green products. Organisations would be more likely to subordinate ownership to an agency outside their company if more stringent regulatory climate. The relentless challenge of adapting to legal standards can positively impact the acceptance of green goods.

➢ Social Factor

The plastic pollution issue was narrowed down into three main root causes: low environmental concern of people, less awareness towards the environment, and low perceived value towards the environment. Based on the study by Ahmad, Juhdi, & Awadz [163], regardless of the consumer's education level, most of them still lacked information on environmental terminology and concepts. Plus, research by Dyehouse et al. [164] explained that many people only have general knowledge of the environment but lack understanding about the deeper issue and idea towards the environment. Moreover, according to Ramayah, Lee, & Mohamad [165], people with less educated and low income refuse to prioritize environmental issues since they give greater inducement towards their own family and household. Rezai et al. [166] stated that lack of understanding and consciousness towards the advantages of eco-friendly products explains the decline of positive attitude towards eco-friendly products. There is only minimal knowledge about Malaysian customers' preferences about greening, their views about these green initiatives and campaigns, and their plan to go eco. Businesses can take advantage of cost advantages and produce more revenue at slightly lower (unit) costs by expanding production volume for bioplastics. Currently, bioplastic manufacturing volumes are comparatively low, with production costs being high. Customers' desire to pay for green products grows as awareness of natural resources and environmental conservation rises. This will have a positive impact on bioplastic production.

➢ Financial Related Factor

Financial strength includes interest rate fluctuations, credit ratings, capital supply, cash flows, and pension coverage. Local items risk durability because their reliability and affluence depend on the biodegradable plastics involving locally-based stakeholders such as consumers and manufacturers. Rise, local taxes, payment and obtainability delays, and foreign exchange fluctuations are some of the financial challenges you may face while handling green products [167]. The primary causes of increased privatized costs in developing countries are political uncertainty and corruption, currency volatility, interest rates, labour market, and commodity demand uncertainty. Liu and Cruz [168] observed that the key factors to cost overruns in the provision of high-rise production are unpredictable climate, inflationary commodity prices, imprecise quantity start-up, project location and type uncertainties, labour cost fluctuations, and local control.

➢ Customer’s Attitude

In reaction to an external event, an established mood, emotion, or opinion is referred to as an attitude [169,170]. An attitude can be transitory or can develop into a long-term state that affects a consumer's efforts to evaluate a product, service, or the like, where he or she may develop an attitude toward the thing being measured [169]. External cues influence one's attitude toward something, allowing for the formation of certain behaviours [170]. In other words, the functional definition of attitude is a consumer's assessment of their likes and dislikes based on any external inputs [171]. According to Yadav and Pathak [172], attitude is the consequence of behavioural beliefs that the person relies on the influence of such acts and the outcome evaluations of a positive or negative choice on the repercussions of a particular activity. In addition, four criteria were used to assess the attitude: name, good, interest, and making the right decisions [171]. The factors influencing demand for biodegradable plastics are depicted in Fig. 12.

Therefore, as previously stated, the many influencing factors are challenging to quantify to employ in a system for forecasting bioplastic demand [19]. The information on bioplastic needs is derived from a time series of linked data on crude oil prices, feedstock costs, and GDP. Several technical prospects are being produced across the literature and throughout this study [24] since there is a high degree of misunderstanding in the prospective application of these aspects. It is also challenging to estimate policy measures that can be implemented in the future because there are various policy interventions with varying outcomes [173]. Furthermore, implementing national and international policies will be problem-sensitive, resulting in different outcomes. The perceptual impact will be significantly more difficult to implement [19,174].

6. Discussion

The study discusses bio-based and biodegradable plastics and then assesses the existing research. This research systematically evaluates the

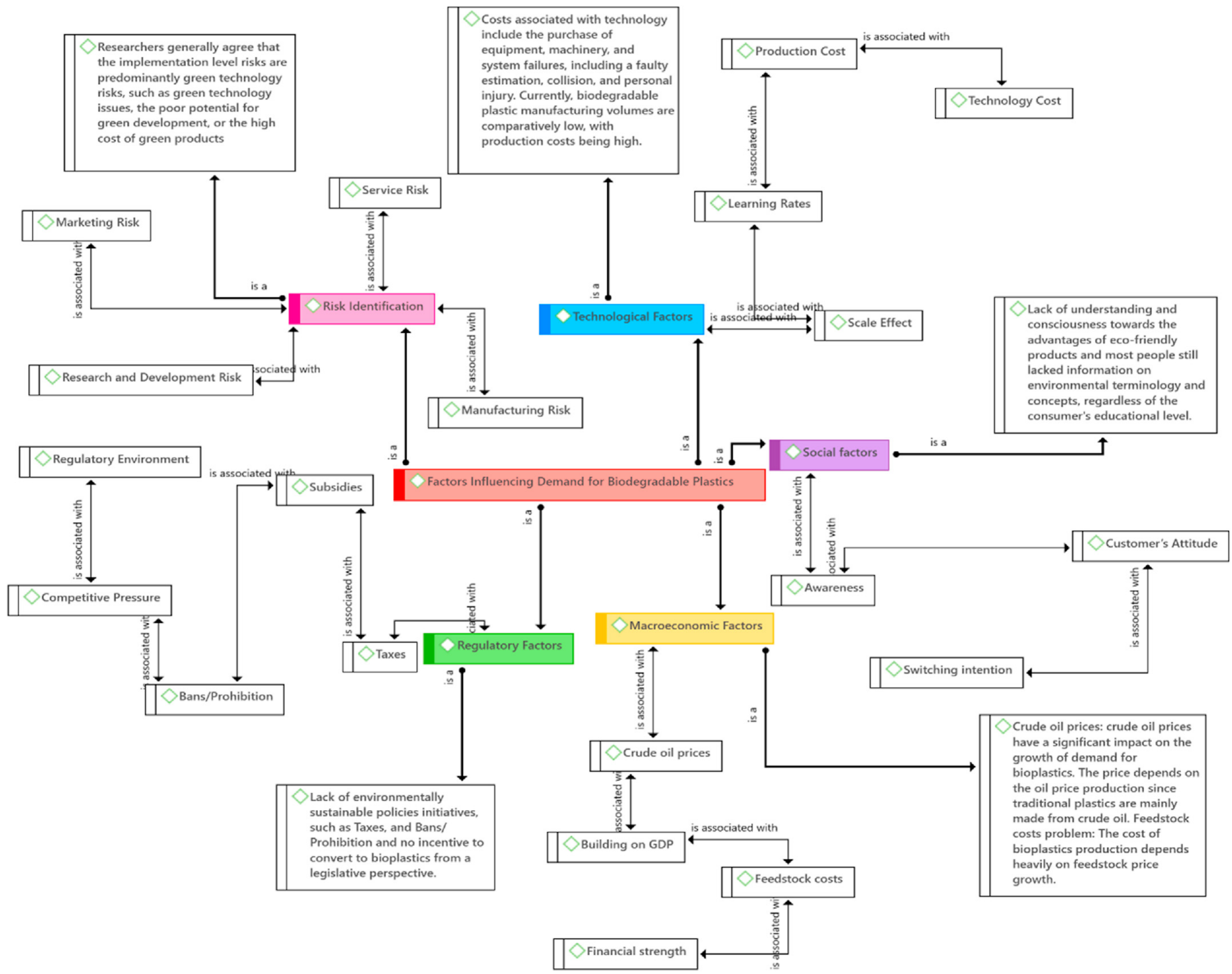

Fig. 12. Factors influencing demand for biodegradable plastics.

literature on bio-based and biodegradable plastics. The information was gathered from reputable databases. Metadata analysis reveals notable journals, publications by year, top contributing nations, institutions, and areas. In addition, according to the influence and number of papers published, Journal of Polymers and the Environment is the most prominent journal in this topic. The Science of the Total Environment was revealed to be among the top 10 journals in the area at the same time. According to the report, the United States and China lead this subject in terms of significance and publication volume. Furthermore, the research reveals that materials science, chemistry, and chemical engineering account for a large share of the literature on bio-based and biodegradable plastics. Following that, the study presents findings based on Web of Science shortlisted publications. Based on content analysis, the findings were provided. The shortlisted articles were grouped into five categories for the content analysis. The categories consist of assessment/evaluation on the sustainability of bio-based and biodegradable Plastics, sustainability of biodegradable Plastics, biodegradable plastics applications, end-of-life for bioplastics and factors driving the uptake of biodegradable plastics. The content analysis reveals that most bio-based and biodegradable plastic film evaluations considered only one dimension of sustainability [77,86,89]; few considered two dimensions [78], and very few considered three dimensions [84]. Biodegradable plastics have seen a tremendous increase in scholarly and industry attention in recent years. This paper evaluated Biodegradable polymers using the triple bottom line technique (economic benefit, social responsibility, and environmental protection). TBL and determinants evaluations of biodegradable plastics' long-term sustainability have received little attention in previous biodegradable plastic film investigations. Sustainability is becoming increasingly important as the usage of the biodegradable plastic film develops. It also sheds light on the condition of applying factors that influence biodegradable plastics sector sustainability in an organisational setting and identifies challenges associated with this. This study has presented an accurate assessment of the sustainability of biodegradable plastics, based on the general history of the relevant companies, and including environmental complexity into the overall picture. The suggested findings of this study would also enable biodegradable plastics firms achieve a variety of benefits, including increased awareness of sustainability and expanded knowledge of sustainability through the adoption of TBL and its associated methods.

Studying biodegradable plastics' current strengths and problems from a sustainability perspective was a primary goal for this research. Bioplastics look biodegradable and beneficial to our environment; however, progress toward sustainability is still sluggish due to biodegradable plastics production technological limits and biodegradability application in natural environments. Increasing competition with the bioenergy industry for feedstock might restrict food supply, which would be a problem for future generations if basic grain prices rose. Additionally, it also expands the agricultural and chemical industries' revenue and job opportunities. There is a dearth of awareness about biodegradable plastics and how to dispose of them among consumers. Because biodegradable plastic objects are rarely used in the plastic market, there isn't much drive to ensure correct disposal. However, adopting biodegradable plastics without a sustainable product design for the whole life cycle would be worthless. When sustainability techniques are followed, biodegradable plastics may become more sustainable, such as increasing the lifespan of biodegradable plastics' lifespan and introducing new additives to entirely compostable, biodegradable plastic. These TBL and system thinking techniques will also educate organisations on the finest sustainable methods to ensure long-lasting product development and fulfil market expectations.

An examination of biodegradable plastics production and the creation of a vision for future biodegradable plastics in a sustainable society identified several leverage points for increasing sustainability in the biodegradable plastics industry. These points included environmental policies, production of feedstocks, and manufacturing stages. Several restrictions apply to the study. Scopus and Web of Science databases, including all articles, were used in the study's data collection process. Because of this, several papers have been excluded, which might raise questions regarding generalizability. This study was based on objective keyword searches rather than a subjective screening and shortlisting procedure. Even while subjective judgement might be useful in some situations, this method has the potential to provide biased results. For this reason, the study restricts itself to metadata and content analysis alone. Citation and network analytic software may be used in the future for more study.

7. Conclusion

Biodegradable plastics can be used to replace conventional plastics to improve the environment while also ensuring the long-term availability of petroleum resources. Biodegradable plastics have shown to be quite useful in irradiating medical devices and food. Many issues might be handled, and a green environment could be preserved for a long time, thanks to the manufacture of biodegradable plastics. The main difficulties that must be effectively solved are the high production costs and low performance of some biodegradable plastics, which require more study to prevent competing with other environmental effects.

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Further reading

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