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Biodegradable plastic applications towards sustainability: A recent innovations in the green product

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ABSTRACT

The purpose of this study is to investigate the contribution of biodegradable plastics to sustainability in a new and sustainable plastics economy, in which plastics perform their useful function without causing negative externalities. Biodegradable plastics are those that degrade naturally over time. With research carried out across three diverse sustainability principles using the triple bottom line method, a multi-disciplinary strategy is a one-of-a-kind approach (social attitudes, environmental consequences, and economic characteristics). Biodegradable plastics became the initial target, as the position of plastics in the plastics system would inevitably be diminished if it could not be established for biodegradable plastics that give equivalent or improved material properties in contrast with traditional plastics. Therefore, the purpose of this study is to look at the various motives that drive companies to produce biodegradable plastic products, as well as the factors that influence their long-term viability. As a result, the study found that the economic component was the most important element, followed by environmental effects and social attitudes. The research also discusses the variables that influence the adoption of biodegradable plastics, as well as a sustainable framework for improving biodegradable plastics' long-term viability. The findings also assess the effectiveness of the suggested framework, which includes seventeen principles spread over three levels of sustainability. There are nine for the social dimension, eight for the economic dimension, and seven for the environmental dimension. This paper offers a comprehensive and efficient means of evaluating and finding optimal options for industries with biodegradable plastics.

1. Introduction

Human responsibility for the environment has risen over time, in line with recent economic development, especially in developing countries. There are, however, several issues that lift their fears today, which are global warming and the extinction of the diversity of organisms in the world's environment and habitat (Skogen et al., 2018). In terms of environmental consciousness, plastic waste has become one of the main global challenges (Klein et al., 2019). Plastics are versatile, corrosion-resistant, well-insulated, and have a low heat conductivity. As a result, it is widely acknowledged that plastics play an important part in all aspects of human existence (Napper and Thompson, 2019). Plastics' favourable characteristics have prompted the substantial investigation into their potential applications in a wide range of fields. Because of their low cost and adaptability, disposable plastics are frequently utilized in supermarkets, mulch film, and packaging. Evidence suggests that worldwide yearly plastics manufacturing surpassed 3.59 million tonnes in 2018 and will continue to rise (Zhu and Wang, 2020). By 2050, it is estimated that 26 billion tonnes of plastic post-consumer garbage would be created, with half of it being discarded in the environment, posing a perennial waste management problem (Guglielmi, 2017). Nonetheless, if present plastic usage continues to expand at its current rate, the plastics sector will account for 20% of global oil consumption by 2050 (Shen et al., 2020a,b). Because oil-based plastics are made of inert polymer resin, they take hundreds of years to decompose once they leave the natural environment, eventually resulting in an endless build-up. The end of plastics' useful life does not mean the end of their environmental effect. There is a possibility of toxic chemicals being released from plastic waste and the environment deteriorating (North and Halden, 2013) (see Table 1).

The vast accumulation of end-of-life plastic has put the ecosystem under unprecedented strain. According to investigations, roughly

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Table 1
Descriptions of biodegradable categories.

Types of Materials	Composition	Degradation Pathway	Suitable Environments for Degradations
Biodegradable (starch-based polymers)	Starch-polyester (PCL, PLA, PBAT or AAC) blends	Hydrolysis occurs due to the hydrolytic scission of the ester bonds in the chain backbone.	Biodegradable, compostable, and marine degradable. Suitable for controlled composting, activated sludge (sewerage treatment), and soil deterioration.
Biodegradable (polyesters)	Polylactic acid (PLA)	The hydrolysis of the ester bonds in the chain backbone is accomplished by hydrolytic scission of the ester bonds.	In addition to composting at a temperature of <60 °C for the typical period of time,
Controlled degradation (masterbatch additives)	Polyethene with a pro-degradant additive	It is necessary to understand that the two-stage process involves oxidative degradation, which is typically abiotic in the first instance, followed by biodegradation of the oxidation products in the second instance.	Although there is limited data, it appears to decay slowly in compost and landfill. In the open air, the fragments disintegrate into the fine residue.

12,000 plastic particles were discovered per litre of sea ice in the Arctic in 2018 (La Daana et al., 2018). As a result, it's not unexpected that plastic particles were found in the stomachs of almost 90% of seabirds (Wilcox et al., 2015). However, the ocean is being harmed by plastic, and the land and freshwater are not immune to the effects of plastic contamination (Rochman, 2018). The two major tactics for dealing with environmental plastics challenges are front control and terminal treatment. Several countries have moved to prohibit the sale of plastic bags, imposing fees or levies on customers or retailers (Convery et al., 2007). In 2018, China, the world's largest producer and user of plastics, prohibited certain plastics' imports. Consumers and manufacturers are trying to discover alternative materials to replace plastics and microplastics, and biodegradable plastics have emerged as a viable option (Zhu and Wang, 2020). Theoretically, investments in biodegradable plastics, better than traditional plastic composition, were undertaken by a more extensive range of plastic producers, and therefore two concerns were created. The big concern is adoption and how it can be handled globally (Mehta et al., 2021). Due to the cost of biodegradable plastics, most consumers are stopped from patronizing them (Yaguchi et al., 2020). This may seem to be because most people don't know enough about biodegradable plastics' utility and protection.

These days, biodegradable plastics manufactured from renewable biomass are a hot topic. Plastics manufactured from renewable raw ingredients such as cellulose, bioethanol, starch, and lignin are commonly used in biodegradable products (Steven et al., 2020). Polylactic acid (PLA), poly (hydroxy alkenoates) (PHA), poly (hydroxybutyrate) (PHB), poly (hydroxybutyrate-*co*-valerate) (PHBV), and poly (hydroxy valerate) (PHV) already exist on the market as the most common biodegradable and commercially available natural polymers (Zhu and Wang, 2020). Biodegradable plastics can be biodegraded without causing any negative consequences due to their perseverance. Biodegradable plastics are now being used effectively in several industrial and environmental initiatives (Haider et al., 2019).

Investments in biodegradable plastics, better than traditional plastic composition, were undertaken by a more extensive range of plastic producers, and therefore two concerns were created. The big concern is adoption and how it can be handled globally. Due to the cost of biodegradable plastics, most consumers are stopped from patronizing them (Yaguchi et al., 2020). This may seem to be because most people don't know enough about biodegradable plastics' utility and protection. As a result, most plastics firms will not be interested in economic research to help select biodegradable plastics that are economically cost-effective (Wu et al., 2020). Despite the fact that some biodegradable plastics have demonstrated excellent mechanical, degradable properties and physicochemical in various industrial use, it is widely acknowledged that biodegradable plastics are not yet a viable replacement for synthetics plastics (Rujnisokele and Pilipovi, 2017). With the rise of biodegradable plastics, there is a need to address a knowledge gap in this field. As a result, it is still debatable whether biodegradable plastics can be a viable long-term option for achieving sustainable development goals for plastics manufacturing and reducing global plastic pollution. It is the purpose of this study to address both sides of the debate over biodegradable plastics (Mehta et al., 2020). The opportunities and challenges of solving environmental plastic pollution and factors driving the uptake of biodegradable plastics perspectives are also raised. Different aspects of biodegradable plastics will be discussed, ranging from economic benefit, social responsibility, and environmental protection.

The remainder of this article is formulated in the following way. Section 2 develops the research materials and methods, and the literature is analyzed in section 3. Environmental risks associated with the use of biodegradable plastics is analyzed in section 4. Opportunities and challenges for biodegradable plastic are stated in section 5, and some discussion and management implications are in conjunction with the results. Finally, in addition to recommending more research directions, discuss the study's conclusion and limitations in section 6.

2. Research materials and methods

2.1. Search and selection process

Finding and extracting articles relevant to the research has been accomplished using aggregator databases such as Scopus and publishing databases such as Elsevier, Taylor & Francis, Springer, and Google Scholar. The terms biodegradable plastic, bioplastic, sustainability, bio-based plastics, and triple bottom line (TBL) approach were often used simultaneously. As a result, while the database's use of this level of granularity (aggregator and publisher level) resulted in a certain degree of correlation between the two domain tiers, it also confirmed the aggregate searches that were conducted to collect all relevant material from published literature (Bastas and Liyanage, 2018). All papers included in the study were peer-reviewed journal articles, conference proceedings and books to guarantee that the academic subjects were included under the investigation of the most reliable materials and publications with outstanding management impact (Thornhill et al., 2009). There were only publications written in the English language in these collections.

This outstanding success in global sustainability activities was acknowledged in 2005 with the approval of the Kyoto Protocol. The vast majority of sustainability integration research, which is in line with the research purpose of this analysis, was conducted in accordance with the Kyoto Protocol (Rajeev et al., 2017). It was decided that the search period for this analysis would be from 1995 to 2021, based on the most significant achievements in the fields of renewable energy, global sustainability and sustainability management, biodegradable plastics, bio-based plastics, and the triple bottom line (TBL) approach, as well as the collection of current state-of-the-art publications.

Because of this, a systematic review has been conducted to meet the objectives of this study and give synthesis findings. In their prior work, Lu and Liu (2014) operationalized the overarching structural study strategy that was proposed. It is necessary to deal with the research difficulties unambiguously from the beginning of the systematic analysis and as part of a stated approach in Stage 1, which seems to classify a topic or analytic challenges (Khan et al., 2003). In order to satisfy the requirements of the review, it was necessary to identify the keywords for the investigation. A large number of keyword patterns in the sample are required to ensure that the review field of research is covered. In accordance with data sources, phase 2 calls for thorough and accurate examinations of the relevant publications and archives in question (Moshood et al., 2021).

It is also necessary to be aware of and select an acceptable research field to have access to various related data and methods. Furthermore, Step 3 entails using keywords in descriptions, scopes, and keywords to research a certain region (Moshood et al., 2020). The keyword for this research is processed, integrated into the known, and then selected from a list of publishers and journals, among other things. Valid research should be conducted without regard to linguistic constraints, and study questions should be open to revision if necessary. Ke et al. (2009) argued that compatibility might be maintained using a minimal parameter analysis.

As part of Step 4, the analysis must be subjected to a quality assessment to ensure that the technique is accurate. In order to provide an accurate assessment, the material received for analysis and improvements must also be confined to the preferred features. It is necessary to clean up certain data conditions from the previous search query since they were incorrect. Naturally, the preceding step 3 search would turn up many mainstream queries and articles to choose from. Therefore, an in-depth examination of the contents of the article is necessary (Moshood et al., 2020). The evidence is compiled and presented in Step 5, which is the last step. The systematic review will be conducted here to characterise and integrate the high-quality polished publications, which will be based on papers that are largely linked to the areas of interest. As a result, a field and meaning or form are provided to extract the information (Lu and Liu, 2014). The reports are typically examined and summarised by the parameters of the analysis, the existence of the analysis, and the results (Moshood et al., 2021).

2.2. Analysis process

This article provides one possible strategy of applying qualitative research to textual results, which is described in detail. Various steps in the creation and research of biodegradable plastic, the sustainability life cycle, and the triple bottom line (TBL) methodology are covered in detail in this article. As a result of this structure, each stage of the assessment phase is divided into parts that include procedures, results, and discussion, allowing the reader to get a deeper understanding of how data are reviewed as well as the ramifications of each process and the resultant data (Chang and Hsieh, 2020). Following the completion of the specified systematic literature review technique, the found articles were screened, filtered, and confirmed for inclusion in the analysis using an iterative selection method, as depicted in Fig. 1.

During this procedure, duplicate papers were removed, eligibility was confirmed from abstracts, and the whole content of an outstanding article was checked in the context of the research concerns to decide on the final judgement regarding the biodegradable plastic, sustainability, and triple bottom line (TBL) approach areas under consideration (Shamseer et al., 2015). According to this study's comprehensive literature evaluation procedure, the 115 publications were reviewed and verified to be legitimate before inclusion.

3. Literature review

3.1. Overview of the biodegradable plastics sector

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 (Wang et al., 2016). 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%) (Kolybaba et al., 2003). They contain chemicals that can pose a risk to the atmosphere, and they need more resources to manufacture (Marsh, 2003). The accumulation of plastic waste obstructs water and oxygen flow, causing harm to the atmosphere

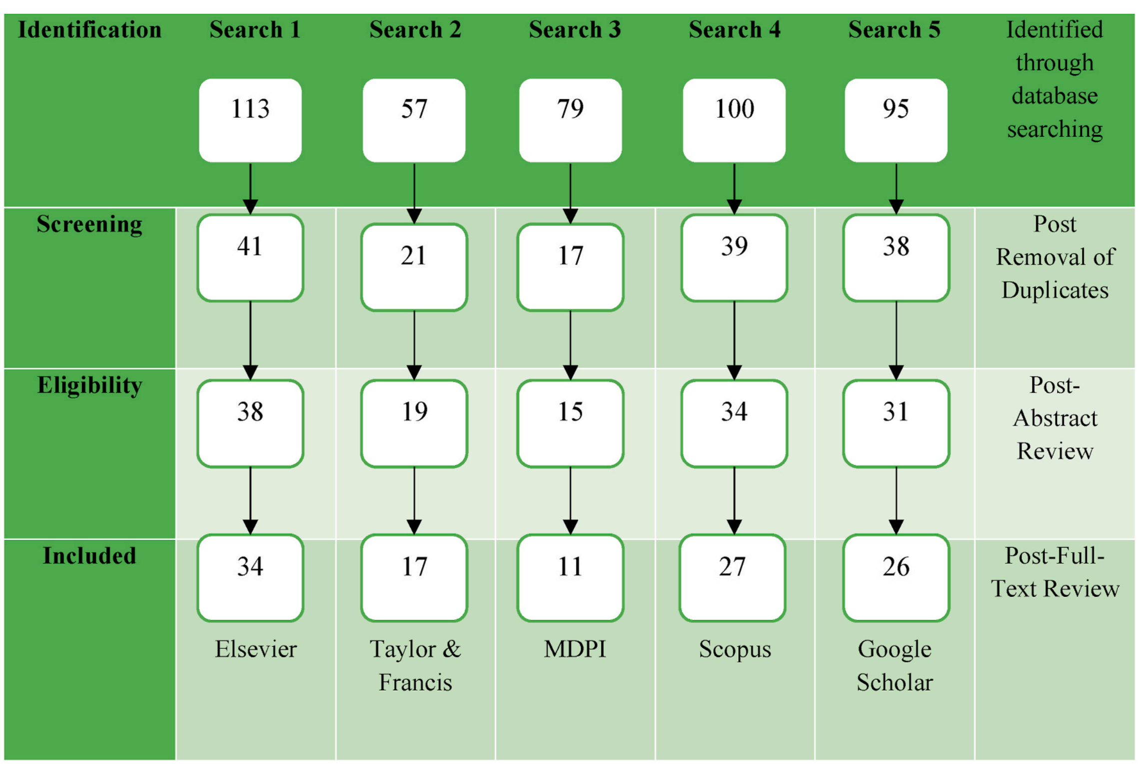

Fig. 1. Overview of paper identification, selection, and inclusion process.

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 (Widiastuti, 2014). Even if it is possible to make the reuse of plastic materials environmentally friendly, further tests should be done to ensure that the content achieves the appropriate consistency. Recycling also has a number of 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 (Zoungranan et al., 2020). Dust and toxic gases (CO_2, NOx, and SOx) are released into the atmosphere as traditional plastic composites are recycled (Wang et al., 2016). 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. A novel way out of the increasing rate of demand for plastic packaging is to adopt biodegradable plastics (Widiastuti, 2014).

Many misconceptions still abound concerning the word 'bioplastics.' It is erroneously believed that any product produced from biomass is supposed to be biodegradable. Nevertheless, using feedstock's that are bio-related should not be assumed that the completed product must be biodegradable in nature (Pant et al., 2019). Therefore, it is vital to state that bio-based plastics are not constantly recyclable and that recyclable plastics are not constantly bio-based. There is a mixed-up between biodegradable plastics and plastics that are bio-based. Both are considered eco-friendly plastics; both are not similar concerning the original concept (Rujnic and Pilipovic, 2017). Biodegradable plastics production is from the biodegradability perspective, while biomass is adopted as the raw material in place of oil in bio-based plastics production (Iwata, 2015).

The term "biobased" refers to the origin of the substance, which might be partly or completely biobased. Conventional plastics are fossil-based, made from non-renewable natural resources (Zoungranan et al., 2020). Renewable biomass, or plants, is used to make biobased polymers. Sugarcane, cassava, and corn are some of the most popular plants utilized to produce bioplastics. Some biobased polymers are biodegradable. However, not all biobased plastics are. The term "biobased" solely refers to the material's manufacturing process (Moshood et al., 2021). It does not refer to what happens to it at the conclusion of its existence. Biodegradable simply implies that the material may be converted back into natural components such as carbon dioxide, biomass, and water through a chemical process carried out by microorganisms in the environment. In the case of biodegradable plastics, the environmental conditions must typically be fairly precise for them to degrade properly. Some biodegradable polymers are fossil-based, whereas others are biobased (Widiastuti, 2014).

Biodegradable plastics are easily disintegrated plastics by living organisms' activities, which are commonly known as microbes in the water. This type of plastics can be substituted for plastics that are non-degradable to minimize 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 (Widiastuti, 2014).

After being disposed of, biodegradable plastics are naturally reduced into nontoxic constituents in a manufacturing composting location (Holden, 2011). The rate at which plastic materials are being adopted in packaging has led to the emergence of biodegradable plastics. The use of polymers materials in packaging products meant to be used within a short time is deemed unnecessary. Thus, biodegradable packaging was adopted because it disintegrates very fast in a manufacturing composting location. It can be created through either synthetic or natural resin (Kolybaba et al., 2003). Petroleum-based products are used in the production of synthetic biodegradable plastics, a non-renewable resource.

In contrast, natural biodegradable plastics can be primarily produced from renewable resources or synthesized from renewable substances. Because renewable-based biodegradable plastics are being produced from plants, they have received more attention because of the great benefit industries will derive from them. Besides, bio-based polymers can reduce the total dependence on petroleum supply, which will curtail carbon emissions into the atmosphere (Widiastuti, 2014).

Different types of biodegradable biopolymers are used for numerous packaging purposes. According to their source, there are three groups of natural biodegradable polymers:

- Biomass products such as starches and lignocellulosic products,
- Polymers obtained by extraction of microorganisms such as poly (hidroxyalkanoate) (PHA),
- Polymers synthesized from renewable materials such as polylactides (PLA)

Plastics made from starch may be totally decomposed and have good tensile straightness, according to the experiment of Orenia et al. (2018). Biodegradable plastics made from agricultural waste may also be used for packaging and salt containers, fibre and plastic components manufacturing, as well as possibly replacing non-biodegradable and petroleum-based polymers, such as polyethylene terephthalate (PET) (Mostafa, Farag, Abo-dief, & Tayeb, 2018). Polyhydroxyalkanoates (PHA) are another example of a biodegradable plastic that has been utilized for many years (Wang et al., 2014). According to Davis and Song (2006), expanding the usage of biodegradable plastic and packaging is a way to reduce landfills and support a holistic waste management strategy by using recyclable and more sustainable resources instead of petroleum (Moshood et al., 2021).

The most considered bio-based and eco-friendly plastic resources examined currently are PLA and polyhydroxyalkanoates (PHAs) (Ipsos, 2019). 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 (Sudesh and Iwata, 2008). 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. Bio-based and biodegradable plastics, including PLA and PHA, are commonly called eco-friendly and renewable, decreasing 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 (RameshKumar, Shaiju, & O'Connor, 2020). 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 together with its copolymers to produce recyclable sutures and matrices intended to coordinate the drug's delivery (Lam Ho-Ching Dennis, 2013).

3.2. Market dynamics of biodegradable plastics

The study provides the necessary business insight to key industry players and lets them understand the biodegradable plastic market's future. The evaluation includes a forecast, a description of the business structure, competitors' market shares and market dynamics, market demands, market drivers, market barriers, and product analysis. The key growth opportunities are further identified in this report while also outlining the key obstacles and potential risks. The main areas of interest are the types of products in the biodegradable plastic industry and their unique uses at various stages of operations.

According to a biodegradable plastic industry study by the Malaysian Investment Development Authority, the biodegradable plastics market is expected to rise from US$3.02 bil in 2018 to US$6.12 bil by 2023 at a CAGR of 15.1 percent (Malaysian Investment Development Authority, 2020). Market development is due to growing demand in developing economies such as Malaysia, India, China, and Brazil for biodegradable plastics in various end-use industries. Also fuelling the industry is the growing acceptance of major players' strategies such as new product releases and mergers, acquisitions, and alliances. According to MIDA (2020), while the market for plastic packaging products has reached 300 million tons per year, biodegradable plastic has a manufacturing capacity of approximately 2.5 million tons per year. The cost of processing and the selling price of biodegradable plastics are on the high side because of this disparity between supply and demand (Malaysian Investment Development Authority, 2020).

Biodegradable plastics or bioplastics are generally classified into polyhydroxyalkanoates (PHA), polylactic acid (PLA), polybutylene succinate (PBS), and polycaprolactone (PCL), according to the product type. According to the application segment, the packaging industry is the leading employer of biodegradable plastics. As global packaging equipment in food & beverage, fabrics, pharmaceuticals, and consumer goods, rising demand for biodegradable plastics due to strict regulations is set to hit the market with sufficient demand (Döhler et al., 2020). Along with an environmental understanding of biodegradable plastics' introduction, these criteria have augmented the packaging market with a CAGR of about 15.1 percent through 2023 (Malaysian Investment Development Authority, 2020). Cargill Incorporated, Mitsubishi Chemical Corporation, and NatureWorks are some of the leading players operating in the biodegradable plastic industry profiled in this data analysis report.

There are a few studies that provide the bioplastic market with estimates. An annual report on the bioplastics industry's growth is released by the Institute for Bioplastics and Bio-Composites (2019), which also provides projections on the development of global production capacities for bioplastics (Döhler et al., 2020). The growth of global production capacity for the next five years (2018–2023) is seen in the latest IFBB survey. Projections for both bio-based and biodegradable plastics are included in the study. Bio-based resources that are usually recyclable and obtained from renewable resources are bioplastics. Bioplastics have been identified as a possible resolution to prevent fossil-based conventional plastics' negative effect on the environment (Comaniţă et al., 2015). Bioplastic production is associated with the mixtures of bio-starch and starch, the fermented products of bioplastic products and petro-chemically produced bioplastic.

The production of biodegradable plastics is done by using polymers (i.e., macromolecules), a substance that is easily identified by enzymes existing in nature (Razza and Innocenti, 2012). It is essential to stress that the production of raw materials does not necessarily determine plastics' biodegradability. Other things determining biodegradability are the chemical composition, the final product's makeup, and the expected condition for the product's biodegradation (Briassoulis and Dejean, 2010). Not all bio-based plastics are recyclable, the structure of the particular polymer determines biodegradability. For this reason, it takes a few weeks for some polymers to disintegrate while other polymers still exist for several months before they can disintegrate under similar conditions (Rujnic and Pilipovic, 2017).

The high price of biodegradable plastics is one of the most critical barriers to the biodegradable plastics industry. Complex engineering processes push increased costs along with the volatility of raw materials used to manufacture biodegraded plastics. However, policymakers take aggressive steps to remove environmentally-friendly plastics in different markets. Several groups have been formed to confirm that environmentally meaningless plastic waste is being disposed of and that in most industries, biodegradable plastics are being recycled. The great concern for biodegradable plastics is initiated due to the fact that the packages made from non-biodegradable plastics have constituted a serious waste disposal problem. Consequently, many investigations have been done to develop packaging materials made from biodegradable plastics over the past three decades. The combination of the different biopolymers, biosynthetic and chemosynthetic polymers, have been identified as being used for various packaging purposes (Iwata, 2015).

Therefore, the suitability of biodegradable plastics for the packaging of food requires the following: Appropriate power and adaptability, non-poisonous, non-absorbable by oxygen, strong ability to resist moisture, ability to be constant in a diverse range of temperature in storage, and economical for both the starting of the material and the technical processing. These stringent criteria have prevented the newly developed biodegradable plastics from receiving general recognition. Thus, the growing greenhouse gas emissions caused by global climate change led to the zero-emission concept, thus developing biodegradable plastics produced from renewable resources. While numerous novel methods are being investigated regarding bio-based and biodegradable plastics production, the stringent criteria to be met at the last uses of these materials must not be ignored (Sudesh and Iwata, 2008a,b).

3.3. *Sustainability of biodegradable plastics*

Sustainable growth is commonly recognized as a critical strategic goal of today's global policy (Moshood et al., 2021). The concept's most well-known exposition defines sustainable development as development that meets present-day needs without jeopardizing generations to come (World Commission on Environment and Development) (WCED, 1987). 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 well-being. But operationalizing these ties poses a significant challenge for a wide variety of stakeholders, including the Government, NGOs, companies, community groups, and individuals (Wu et al., 2020). According to Wang et al., (2008), sustainability purposes are entrenched in the following tripartite: economic prosperity, social fairness, and protection of the environment. Achieving well-enhanced and sustained biodegradable plastics results in minimizing the plastics processes. The objective of social economics and environmental sustainability consideration in biodegradable plastics is based on resource management and adequate environmental protection (Katrina Rogers and Barclay Hudson, 2015).

The plastic industry's contribution to ecosystem degradation, climate change, and several interdependent issues call for a focus on the principles of social, economic, and environmental sustainability to address the fundamental ecological loads of biodegradable plastics projects (Rujnic and Pilipovic, 2017). The Triple Bottom Line, which was conceptualized (also known as TBL) in 1994, considered environmental protection, financial performance, and social performance in project execution (Tate and Bals, 2018). This principle submits that sustainability would be attained in biodegradable plastics, including economic, social, and environmental performance. Considerations are given to the environment and human society without jeopardizing the financial gains.

The principle of sustainability is well-grounded on the belief that society is expected to adopt an existing and realizable scale, which the upcoming generations can also adopt. Therefore, the development that will be successfully sustained needs the adoption of rigorous efforts concerning different aspects of society and the activities of a human being to achieve this objective (Wang et al., 2008). Sustainable development of biodegradable plastics is basically about managing the association between human and environmental needs such that non-renewable resources that have grave restrictions on the environment are not needlessly surpassed (Tomás et al., 2016). At the same time, the current ethics of societal fairness and fundamental civil privileges are not prevented. It could also mean avoiding environmental and societal failure to ensure the survival of the current society and upcoming generations (Plessis, 2007).

The elements required to adopt sustainable, biodegradable plastics include social, economic, biophysical, and technical qualities and a set of all-encompassing, process-oriented principles (Hill et al., 2010). In their study, social sustainability was intended to refine human life quality, execute training, and bring fair and equitable social costs of biodegradable plastics in quest of intergenerational equity that provides cultural diversity in plastics productions. Sustainability's economic aspect pursues affordability to the bioplastic's projects' target groups. It also includes boosting employment generation, increasing competitiveness, utilizing environmentally conscious workers, and sustaining biodegradable plastics projects' required ability to meet future needs (Tate and Bals, 2018). The biophysical features of sustainable, biodegradable plastics cover extraction of renewable resources beyond their slow rate of rejuvenation, dropping the consumption of four generic resources, which are materials, power, water, and land; expanding resources reuse or recycling; giving preference in place of renewable resources, reducing the pollution of air, land, and water, preserving and refurbishing ecological vitality and diversity, and lessening damage to sensitive land (Álvarez-chávez, Edwards, Moure-eraso, & Geiser, 2012). Technical sustainability concerns durability, reliability, and functionality in biodegradable plastics. Fig. 2 shows the proposed framework for the biodegradable plastics sustainability life cycle.

According to the previously assessed literature, the suggested framework for the biodegradable plastics sustainability life cycle shown above was developed with the help of several professionals and practical proof provided by the literature (Inês Ribeiro 2020). Biodegradable plastic products and the bioplastic industry require earth's assets contributions. These contributions are the materials for development, including the epitomized energy of utilized materials (Osman et al., 2021). The bioplastics organizations' accountability to the constructed environment should consider asset management as a vital administrative instrument to decrease, reuse, and recycle non-inexhaustible assets (Moshood et al., 2021). These assets assume fundamental job development activities.

There are so many available grades of biodegradable plastics with various features. Nevertheless, biodegradable plastics are purposely and presently used in making packaging for food, food package ware for food, bags meant for shopping, and agricultural uses (Kumar, 2011). The usage of the aforementioned features determines how biodegradable plastics can be sustained. The best way or method to which it is put into use is determined by its features (Martien van den Oever et al., 2017). Nevertheless, the bio-based plastic products' appearance is always similar when it is compared to the conservative fossil-based plastic products. This situation is also applicable to biodegradable against

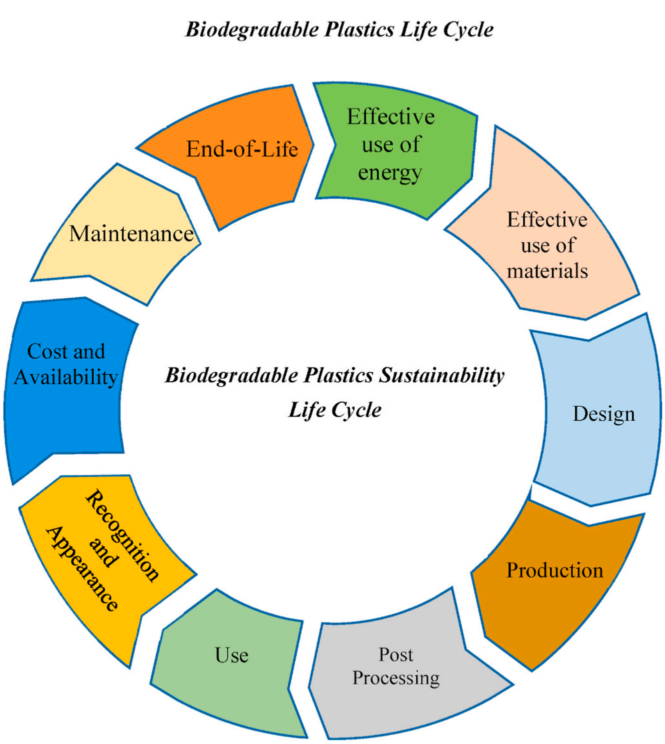

Fig. 2. Proposed framework for the biodegradable plastics sustainability life cycle.

non-biodegradable products. The identification, composability, and disposal of bio-based plastic should be indicated on the logos and labels so that consumers can easily see and read. Some recommendations, such as biodegradable,' are not clearly explained. Therefore, linking the logos and labels to a standardized and certified system is necessary. Besides, the fact that plastic is biodegradable does not suggest that the materials disintegrate fast in the environs (Martien van den Oever et al., 2017).

The manufacturing abilities of bio-based and biodegradable plastics in 2015 took almost 1% of plastics' entire production globally. There is a great expectation that biodegradable plastics will be highly marketable in the future (Bio-PET, PBS, and PLA) while there will be great consolidation of other plastics (CA and Bio-PA). Generally, there has been a high expectation that bio-based and biodegradable plastics' share will rise to 2.5% of relic plastics manufacturing by 2020 (MIDA, 2019). Numerous dealers have been making many bio-based and biodegradable plastics available, and they have been more costly than fossil-based plastics regarding their weight. Nevertheless, precise physical features can bring about the reduction of costs after it has been used. Many biodegradable plastic products are now cost-competitive (Martien van den Oever et al., 2017). Besides, the fluctuation in the prices of oil determines fossil-based plastics prices. In most situations, the stability of biomass prices determines biodegradable plastics' prices. When the production economic scale is encouraging, there is an expectation of decreasing biodegradable plastic prices.

The biodegradable plastic kinds, the market size, the use and obtainable set, and infrastructural processing determine how it can be disposed of after use. The choice of disposing of the biodegradable plastics hinges on how it has been completely used and the infrastructure's availability where the product's recovery is to be done. Biodegradable plastics have different features of an extensive range. The best way to dispose of biodegradable plastic is determined by its use (Martien van den Oever et al., 2017).

3.4. Sustainability principles identification for biodegradable plastics

Sustainability principles identification for biodegradable plastics is crucial for contemporary management prominence on sustainable growth (Boukherroub et al., 2015). The triple bottom line concept typically differentiates three dimensions intended for biodegradable plastics sustainability assessments: environmental protection, economic performance, social responsibility (Moshood et al., 2021). Stimulated by earlier studies and professional views, the recommended classical has twenty-six principles through the three scopes of sustainability. The nine for the social, economic, and environmental dimensions have eight (see Fig. 3).

3.4.1. Economic dimension

The economic results will significantly affect biodegradable plastics products, indicating market operations quality. Measurement analysis has traditionally included five indicators: flexibility, reliability, financial efficiency, responsiveness, and quality (Boukherroub et al., 2015). Reliability relates to distribution success in the supply chain of bioplastic film, i.e., placing the right product in the correct position, suitable condition, proper standard packaging, and the right customer's documentation (Spierling et al., 2018). The responsiveness relates from the biodegradable plastic products' point of view to the quality of content flows, evidence flows, and monetary flows from source to customer point. Flexibility is the potential of the supply chain for biodegradable plastics to react or acquire or preserve competitive advantages over market shifts towards sustainability (Xu et al., 2016). Flexibility ensures that the film of biodegradable plastics must adapt and develop continuously with changes in time and conditions. The financial recital is a widespread concept that includes the cost and management of assets, including acquisition costs, design costs, cost of procurement, manufacturing costs, cost of the supply chain, cost of returning, cost and return on investment costs and added assets (Chardine-Baumann and

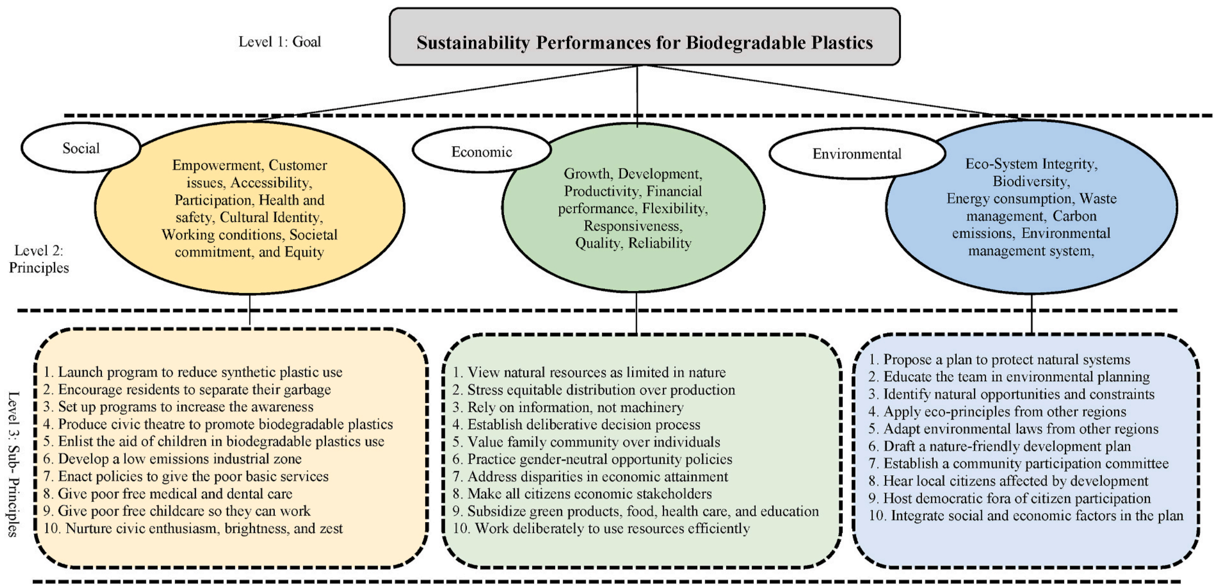

Fig. 3. Categorized assembly of sustainability presentations created on the triple bottom line (TBL) method.

Botta-Genoulaz, 2014), as well as cost variances in normal or contract cost variances. The customer-seller partnership is one crucial feature of quality. The poorer output influences the financial results and prestige of the focal company. Quality is measured as customer satisfaction and service quality in the biodegradable plastics market (Xu et al., 2016).

Implementing taxable bases and tangible possessions becomes very simple when jobs are created. Sustainable materials are also used to minimize energy, waste, and production prices during operations (Dilkes-Hoffman, 2020). Metallic objects, glass, wood, plastics, paper, waste oil and inks, and manufacturing fluids need to be recycled to reduce the enormous and dangerous waste at disposal sites. Besides, this will reduce the costs involved in waste disposal. Also, while the production prices of plastics can be reduced when biodegradable plastics are used, if lower energy pumps, vehicles, and lighting fittings are used, energy costs will be reduced in the process of producing plastics (Saint Akadiri et al., 2019). Montini (2020) clarified the misconception that sustainability theory does not mean the deterioration of economies. Economies are far more than anything substantial. Yet, subtle and competitive maintenance markets, qualitative development, sharing, sweetness, and natural constraints are required. It is an economy that is healthier than a larger economy. In a business sense, the words economic viability is an increase in the valuation of short- or long-term owners and maintaining a stable financial basis for sustainable business existence.

3.4.2. *Environmental dimension*

Environmental evaluation tests the environmental awareness of plastics that can be biodegraded (Chardine-Baumann and Botta-Genoulaz, 2014). Still, the social and environmental consequences are not agreed upon as it depends on the industry and the area in which the practices occur (Boukherroub et al., 2015). Several international standards, for example, International Organization for Standardization (ISO) 26,000, OECD guidelines (Organization for Economic Co-operation and Development) (Gordon and Mitidieri, 2005), ISO 14, 001, GRI, SA 8000 (Curkovic and Sroufe, 2011), and research study have been recommended by a range of more or less generic requirements. However, these standards cover not all sustainability. Five environmental areas of biodegradable plastics management are isolated in this article, including Carbon emission, energy use, environmental management systems, and waste management systems (Xu et al., 2016).

Consumption of energy is one of the most commonly used environmental factors. Energy usage commonly means electricity, energy sources, and natural gas utilized in the manufacturing and processing stages in the plastics biodegradable industry. Since climate change has now become recognized as a grave concern to contemporary communities, reducing carbon emissions in the last decade to reduce climate change has become a significant global issue (Xu et al., 2016). Concerns surrounding the greenhouse gas emissions from the packaging and logistic phases must be minimized within the biodegradable plastics sector (Blanc et al., 2019). Waste management often represents industrial development. The use of waste disposal of biodegradable plastics typically includes discontinuation of goods from waste dumps, recovery of products to raw materials, and the replacement of the product, refunds, or remanufacturing for future use (Xu et al., 2016). The environmental management framework promotes decisions that allow organizations to improve environmental efficiency, ensure sustained progress, and avoid adverse environmental effects (Chardine-Baumann and Botta-Genoulaz, 2014). The biodegradable plastics industry's environmental protection framework involves concerns like environmental approval, environmental budgeting, environmental reviews, and environmental compliance (Xu et al., 2016). Correctly designing waste management systems for bio-based products is essential for both the environment and utilization of these wastes as resources in a circular economy.

Although the loss of capital includes the usage of soil, the use of oil, the use of water, the use of fossil fuels, etc., the pollution of effluent consists of climate change, GHGs, water degradation, air contamination, lethal material leakage, human toxicity, the release of cancer-causing agents, the production of summer smog, acidification, eutrophication, etc (Fouad and Farag, 2019). Strategic environmental assessment is crucial to developing sustainable goods and services through strategic means (White and Noble, 2013). This approach would ensure that strategies, practices, and packages are established that are environmentally responsive and favourable (Reichert et al., 2020). In terms of ecological management, the focus is on managing the negative environmental impact of business operations. Recent environmental sustainability study, unrestrained industrial growth, according to Kopnina (2017), is one of the most critical threats to the natural world and ecological processes. Kasayanond, Umam and Jermsittiparsert (2019) define environmental sustainability as preserving and renewing future generations' present biosphere and the biosphere. Global problems are recent environmental threats such as climate change, global warming, deforestation, deforestation, and biodiversity loss. Consumers are increasingly pushing corporations to adopt environmentally friendly strategies to improve their effectiveness (Kabir et al., 2020).

3.4.3. Social dimension

The global metric used to calculate corporate social success is social responsibility. It measures the organization's operations' social impacts on its players (Chardine-Baumann and Botta-Genoulaz, 2014). Sustainable operations involve personnel and culture who are sustainable. A socially conscious initiative to strengthen the community and maintain its worker's and consumers' well-being. The researcher assesses this factor in this paper's five parameters: safety and health, employment, social commitment conditions, and customer issues. The most critical social conditions are jobs (or job formation and wealth) (Xu et al., 2016). Companies seek to raise living conditions by complete and healthy jobs. As social metrics in this study, the number of biodegradable plastic products and employee turnover positions is included.

Health & safety measure the effect of a procedure or substance on staff and customers' safety and health (Chardine-Baumann and Botta-Genoulaz, 2014). To avoid work injury and guarantee that consumers do not benefit from low-quality goods, the aim is to encourage and maintain a high level of physical, intellectual, and social well-being for workers and clients. Employment terms include many aspects of satisfaction for workers, wages and benefits, times of rest, working hours, growth of human resources, seasonal celebrations, leave of absence and administrative procedures, and maternity leave (Xu et al., 2016). The company's corporate contribution applies to the local society's social obligation and stakeholders and cultural, educational, health, technical, and social investment upgrades. Customer complaints apply to any problems involving each customer individually. Their emphasis is primarily on consumer care and safety, customer data security and privacy, marketing and consumer information provision and other vital resources.

The production of eco-friendly goods should be actively targeted (Döhler et al., 2020). Biodegradable plastic materials, either biodegradable or as replacements for manure, have been developed to minimize litter produced by recycled plastics. Bio-gradable plastics have been established as being commonly used in disposables packaging and are used in agriculture where biodegradability is recommended. Non-biodegradable plastics (bio-PE and bio-PET) that have recently been better produced can be used in food packaging (Martien van den Oever et al., 2017). Actually, there is increasing awareness of the societal effect of "Biodegradable Plastics" packaging items. Many people in society are eager to move to an alternate packaging material with a lower perception of pollution or made by renewable energy. This condition has been the primary reason for enhancing the handling of biodegradable plastics to reduce plastic waste in our society (Wang et al., 2020).

Societal capital tackles culture or communities' topics, such as poverty, inequality, human rights, corruption, community development, welfare, family concerns, and lack of schooling, public health, youth activity problems, and democracy. Developing corporate capital encourages trust in the company and its stakeholders, thus enhancing a company's credibility with its stakeholders (Reichert et al., 2020).

4. Environmental risks associated with the use of biodegradable plastics

Biodegradable plastics are another type of plastic that has an unavoidable environmental impact when used. When biodegradable plastics are discarded carelessly, they have two environmental outcomes: accumulation and disintegration. Like conventional plastics (PE and PP), Biodegradable plastics may break down into microplastics and nano-plastics. With the progressive knowledge of BPs biodegradable plastics, scientists have recently begun investigating the effects of biodegradable microplastics (BMPs). Shruti & Kutralam-Muniasamy (2019) went over the environmental implications of biodegradable microplastics in great detail. Limited forms of biodegradable microplastics have been studied for their possible impacts on aquatic life. Green et al. (2016) have shown that biodegradable microplastics (PLA) have negative impacts on diversity and benthic community growth richness. The high concentration stress and rise in respiratory rate generated by PLA in flat oysters and the high-dose response of PLA in sandy sediments have shown similar findings in the respiratory rate of *Arenicola marina* L. (Shen et al., 2020).

According to Straub et al. (2017), the adsorption and function of biodegradable microplastics (PHB) and polymethylmethacrylate microplastics (PMMA) in the freshwater amphipod *Gammarus fossarum* were investigated. As a result of the experiments, it was discovered that both microplastic treatments with varying particle sizes (32–250 μm) had a substantial impact on the assimilation efficiency of the amphipod *Gammarus fossarum* and decreased the growth in wet weight. González-Pleiter et al. (2019) investigated the possible ecotoxicological effects of secondary PHB nano-plastics (25–100 mg. L^{-1},200 nm) on three typical aquatic species *(Daphnia Magna, Anabaena* sp. *and Chlamydomonas reinhardtii)*. According to the findings, secondary PHB nano-plastics caused a statistically significant reduction in cell development as well as alterations in relevant physiological parameters in all three aquatic creatures examined (Shen et al., 2020). The scientists also pointed out that the PHB nano-plastics generated due to the abiotic breakdown of PHB microplastics were harmful to the aquatic species subjected to the tests. According to the findings of the aforementioned investigations, biological exposure to conventional and biodegradable microplastics and nano-plastics has similar ecotoxicological effects on test organisms as exposure to conventional microplastics and nano-plastics.

It is possible that the effects of induced alterations will suggest that biodegradable plastics are not entirely safe for the environment (Shen et al., 2020). Besides, biodegradable microplastics can serve as vectors for transmitting microorganisms and chemical contaminants. Several studies have demonstrated that microplastics are key vectors for transmitting microorganisms and chemical pollutants. Frère et al. (2018) investigated the microplastic bacterial communities in the Bay of Brest; Hartmann et al. (2017) investigated the microplastics as vectors for environmental contaminants, while Koelmans et al. (2016) examined microplastic as a vector for chemicals in the aquatic environment. Pittura et al. (2018) investigated microplastics as vehicles of environmental PAHs to marine organisms; Shen et al. (2019) went over the recent advances in toxicological research of nanoplastics in the environment and Ziccardi et al. (2016) examined microplastics as vectors for bioaccumulation of hydrophobic organic chemicals in the marine environment. Biodegradable microplastics have a significant adsorption and enrichment potential for chemical contaminants and microorganisms due to their comparable particle size features, excellent fluidity, and good stability. Zuo et al. (2019) examined the adsorption and desorption of poly (-butylene adipate co-terephthalate) (PBAT, 2338 ± 486 μm), polystyrene (250 μm), and polyethene (2628 ± 623 μm) for conventional organic pollutants, and the results were published recently (phenanthrene). Based on the results, it was discovered that the adsorption and desorption capacities of PBAT BMPs were much greater than those of PS and PE microplastics.

Therefore, when compared to typical microplastics, the scientists found that microplastics' were a more effective vector of phenanthrene. Unfortunately, due to a lack of evidence in this domain, it is still too early to declare biodegradable microplastics' danger (whether there is a threat or not). The influence of biodegradable microplastics on a limited number of aquatic creatures has only been discovered in a few research investigations to date. Many studies on the possible consequences of biodegradable microplastics have not been conducted. It is uncertain whether they will be conducted on a series of animals raised for human consumption. Consequently, it is difficult to assess the more precise danger that biodegradable microplastics may represent to the health of creatures, ecosystems, and humans. As a result, Future generations should be concerned about the ecological impact of biodegradable microplastics on the ecosystem. It is vital to analyse and incorporate the impact of biodegradable microplastics on human food safety and health by studying the possible impacts of biodegradable microplastics on diverse species and ecosystems.

5. The benefits and drawbacks of using biodegradable plastics

Biodegradable plastics are extremely important for conserving the environment on a worldwide scale. The creation of biodegradable plastics is an unavoidable prerequisite for the environment's long-term sustainability in the twenty-first century (Steven et al., 2020). As a result, it is a shared objective for all governments worldwide to intensify research into biodegradable plastics and encourage the creation of biodegradable plastic products. This alternate potential must be promoted where the difficulty lies (Shen et al., 2020). This study identifies various perceived and actual challenges to the widespread use of biodegradable plastic in the future, which may limit their commercial acceptance. Organizational considerations are among the most significant roadblocks (regulation and legislative instruments, financial strength, supply chain and sourcing, performance and material quality, market penetration and availability, technology cost, communication and awareness).

Interestingly, existing policies, regulations, and standards have been promoted to counteract some of these barriers; however, there appears to be a disconnect between what the policy landscape seeks to accomplish in this regard and the impact of actual implementation on the industry and consumer levels (Andrade Almeida et al., 2021). In light of the ongoing conversation over the efficacy of biodegradable plastic products and in recognition of the critical (and often overlooked) role that stakeholders, producers, non-governmental organizations, and governments play in resolving complex and intertwined issues. Fig. 4 shows the challenges and opportunities of using biodegradable plastics, indicates which policy instruments should (theoretically) be used to address those problems.

Overall, research is needed to comprehend better, establish, and encourage the uptake of materials with desirable characteristics in the context of end-of-life options that make use of alternative feedstock sources that are expandable, readily available, and sustainable, and that can help to reduce greenhouse gases emissions at the sectoral level of the economy. In order to do this, it is necessary to have a policy and practice alignment (Andrade Almeida et al., 2021). Therefore, there are some crucial factors to be considered: Technology/material properties issues, regulatory, financial considerations, managerial considerations, and customer considerations.

First and foremost, technological advancements have significantly impacted the acceptability of biodegradable plastics (Klein et al., 2019). It is possible to increase biodegradable polymers' thermal stability and mechanical strength by combining them with inorganic materials using currently available technologies, but further research is required. It will also result in an increase in degradation products as well as a decrease in the rate of degradation (Shen et al., 2020). The decomposition of macromolecules into micro molecules by environmental microorganisms is

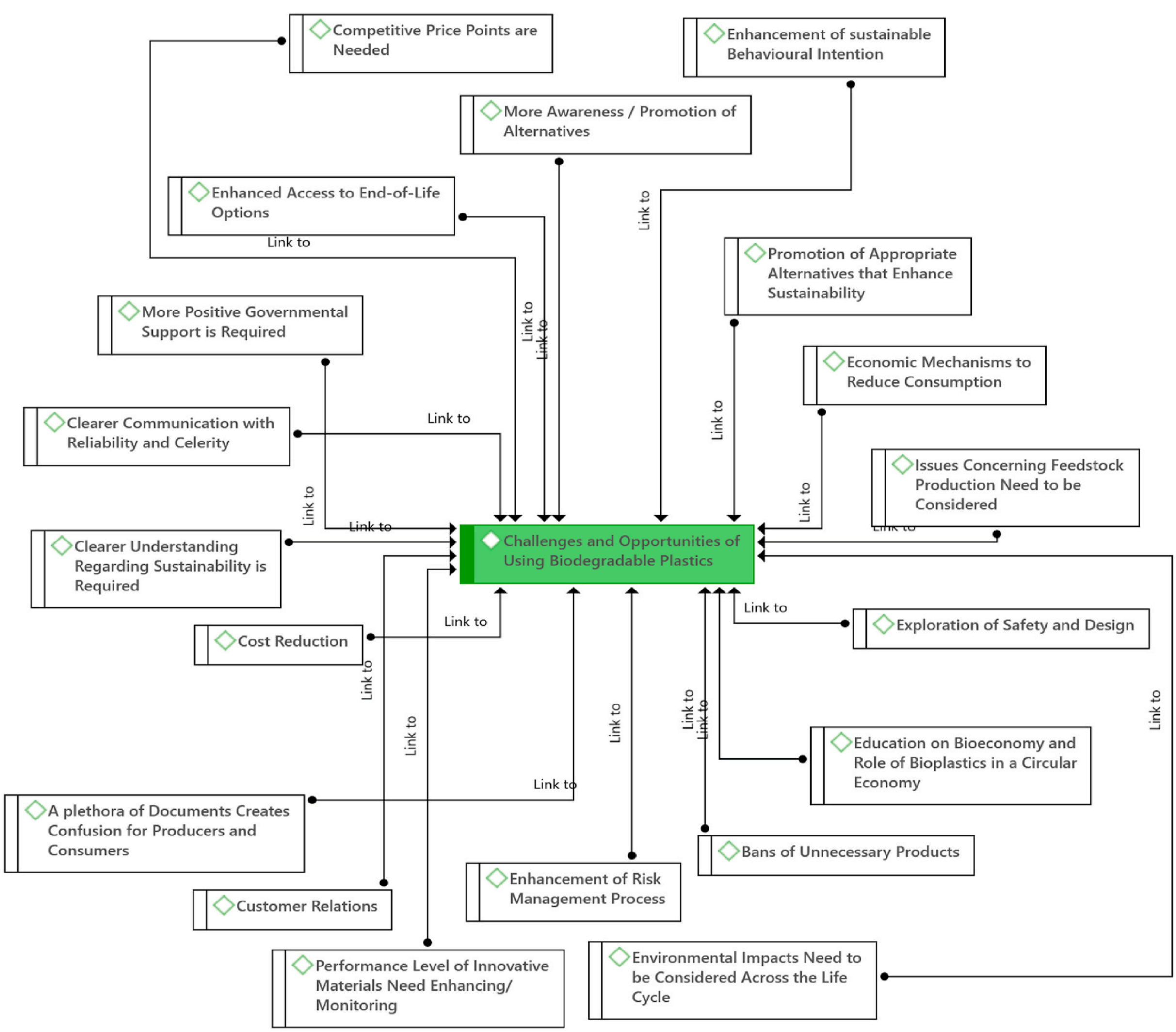

Fig. 4. Challenges and opportunities of using biodegradable plastics.

responsible for the biodegradation performance of biodegradable plastics. This degradation process is extremely sluggish, particularly in the case of resin molecular materials (Copinet et al., 2004). In addition to the difficulty of recycling discarded plastics, there has been little research on whether or not deteriorated items may harm the environment. Additionally, the disposal of biodegradable plastics on a big scale must be considered (Skogen et al., 2018). It will be possible to treat biodegradable plastics in compost facilities due to improvements in the composting infrastructure, such as compost categorization and biodegradable plastic recycling, which will be implemented (Andrade Almeida et al., 2021). The adoption and sustainability of biodegradable plastics focused on two technology areas – materials production and waste management. On the waste handling line, first.

The improved composting infrastructure, including compost sorting, would make it easier to treat biodegradable plastics in the composting plant (Gross and Kalra, 2002). Improved, financially feasible sorting technology would also mitigate recycling issues. Fluorescent markers are a viable technology in this field (Dilkes-Hoffman, 2020). Fluorescent markers include an entail labelling of the resin that generates a light that can be sensed and used to sort products when irradiated. Other firms are developing the performance and durability of plastic sorting machines (e.g., Tomra) (Körner et al., 2005). One crucial point regarding material properties is that biodegradable plastics with the same characteristics as traditional plastics can be developed to ensure competition in the market. In order to address the problem of plastic deposition in the environment, waste management and public behavioural awareness are vital factors to take into account. Still, they are not sufficient in and of themselves. The advancement of technology, as well as the creation of new materials, will be taken into consideration in the future.

Secondly, policy and intervention will dramatically alter the rate at which bio-based polymers are used (Shen et al., 2009). In contrast with biofuel development supporters, bioplastics suffer from a lack of favourable government policies (Philp et al., 2013). 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.

Thirdly, financial constraints significantly impact the development of biodegradable polymers. Producing biodegradable polymers is more expensive than conventional plastics since the raw materials are more expensive and the technological process is more difficult to master (Shen et al., 2020). In order to offset this, the final product price is substantially more than the price of conventional plastics (Hopewell et al., 2009). When it comes to determining whether or not a product can be applied to many people, the cost of the product has traditionally been a crucial factor. Prices of agricultural raw materials should be strictly regulated to guarantee that they stay competitive with fossil fuels, which will help stimulate the shift from conventional to biodegradable building material and other materials.

Furthermore, new equipment and synthesis methods should be developed to bring the cost of biodegradable polymers down to an acceptable level. Boosting the function of synthetic biodegradable plastic materials such as cellulose, starch, and shell and expanding the usage of materials is a critical step toward lowering prices (Shen et al., 2020). In order to promote the switch to biodegradable materials, fiscal policy initiatives would be required. This includes funding for low GHG 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) (Shen, 2009). The innovative techniques in economics are shown by the example of two of the best recycling/incineration countries (Hopewell et al., 2009): The Netherlands (where waste is expensive due to being near to the sea) and Japan, where waste excavation includes burial into hard volcanic rock.

Fourthly, there is a lack of a favourable management framework in the biodegradable plastic business. Plastic garbage may be managed in three ways: through recycling, burning, or disposal in a sanitary landfill facility (Shen et al., 2020). It has become difficult to dispose of plastic trash due to the disorganised collecting system for conventional plastics and biodegradable plastics. Chemically, biodegradable polymers may be burnt in the same way as ordinary plastics, and their energy content is comparable to traditional plastics (Dilkes-Hoffman, 2020). But when it comes to waste disposal, conventional plastics and biodegradable plastics are very different. The decomposition of conventional plastics in a landfill is complicated. Methane, a greenhouse gas with a larger global warming potential than CO_2, can be created during the decomposition of biodegradable polymers in landfills. Biodegradable plastics that have reached the end of their useful lives are being managed through the use of industrial composting and anaerobic digestion, among other methods. The collection and separation of compostable plastics appropriate for composting and anaerobic digestion through separate collection systems and the transportation of these materials to industrial composting and digestion facilities must take place first.

Fifthly, increasing environmental awareness among the general population is necessary to promote biodegradable plastics (Shen et al., 2020). Non-biodegradable plastics is not only a big source of concern for the general population, but they are also an issue that has to be addressed (Dilkes-Hoffman, 2020). Biodegradable plastics (bags, containers, and other materials) should be labelled with identifying numbers to make them easier to distinguish from other recyclable materials. Local education on the identification and handling of biodegradable plastics must be linked with this effort to ensure a successful outcome. As long as proper labelling and specialised garbage collecting procedures are implemented, biodegradable plastics are unlikely to negatively influence waste management.

6. Discussion

At this point in time, the accumulation of plastics on the earth is a significant concern. The severity of this problem will exponentially worsen if global plastic production and use continue to grow at their current rates. It is thus necessary to take steps to slow the rate of plastic build-up and the environmental consequences that will inevitably result from this unavoidable accumulation. Biodegradable plastics have the potential to significantly enhance and safeguard the environment, as well as significantly accelerate the development of environmental protection. The production of biodegradable plastics, on the other hand, appears to be far less difficult than their treatment. The performance of biodegradable polymers has been called into serious doubt. There is no definitive answer to the question of whether biodegradable plastics can be a hopeful solution to waste management and global plastic pollution problems. Many parts of biodegradable plastics are still in their early stages of development. In order to alleviate the problem of plastic build-up in the environment, there is no one answer, and it is critical to identify the most effective mix of remedies. For the time being, biodegradable plastics should be considered a component of the solution, although a minor portion of the solution. It is important not to underestimate the impact of biodegradable polymers on the accumulation of plastic waste. Biodegradable plastics are of essential relevance to the world economy in view of the urgent need for energy saving and emission reduction. First, we need to ensure that all biodegradable plastics can replace non-biodegradable plastic products with the same or similar performance; everyone in the world can dispose of biodegradable plastic waste in accordance with regulations and laws; that these collected biodegradable plastics can be biodegraded on a large-scale; and that the biodegradation by-products can be returned to the environment.

In addition to being a source of limitations and regulatory compliance, our findings show that environmental regulations may give opportunities for plastic reduction, profitability, and image preservation, as well as the development of new companies. Incorporating environmental sustainability considerations into product development and company operations has been shown to have several benefits, including increased resource efficiency, profit margin, higher sales, and creation of new products, enhanced company image, product diversification, and strengthened competitive edge, according to the literature. It was also noticed from the literature review that most plastic film evaluations considered only one dimension of sustainability (Martinho et al., 2015); few considered two dimensions (Pires et al., 2015); and very few considered three dimensions (Xu et al., 2016). Academic and industrial interest has grown dramatically in biodegradable plastics towards its sustainability in recent years. This report's triple bottom line method (economic benefit, social responsibility, and environmental protection) was employed to assess biodegradable plastics towards their sustainability. In general, biodegradable plastic film analyses have concentrated on the product itself and have scarcely contemplated evaluating biodegradable plastics' sustainability from (economic benefit, social responsibility, and environmental protection) viewpoint. As biodegradable plastic film sustainability grows, organizations are gradually focusing on sustainable assessment from an (economic benefit, social responsibility, and environmental protection) viewpoint.

Therefore, both developed and developing countries have a vast volume of literature on biodegradable plastic products. A little study has incorporated the triple bottom line approach for biodegradable plastic towards its sustainability to the best of our understanding (Xu et al., 2016). Few assessments have been made on the management of biodegradable plastic products can also be derived from this that the biodegradable plastic film industry is currently not adequately integrated and mature since the TBL approach restricts the completely detailed examination of the policy environment for the biodegradable plastic film business. This research aims to improve these inputs by creating a policy structure for a sustainable performance evaluation of biodegradable plastic products. The structure was developed and improved with the parallel evaluation principle of TBL sustainable dimensions. This study further establishes basic sustainability requirements for managing biodegradable plastics products for which the above analysis can be beneficial. It is clear that these measurements of sustainable plastic products include sustainability dimensions, evaluation methods, and performance monitoring indicators.

An important innovation in this modern day is bioplastics. They are products intended to be used for different purposes to make life very comfortable for the public (Iles and Martin, 2013). Food, beverages, and edible things are being obtained through the use of harmless, lightweight, and various packages produced from plastics. Because of the lightweight bioplastics, it is straightforward to dispose of other heavier wastes. Nevertheless, plastics can constitute a lot of nuisance in the environment, such as taking up many spaces, thereby causing great difficulty for waste management while handling wastes. A great deal of landfills can be taken over by lightweight plastics, thus becoming a jumble of mess on land and sea. Though plastic debris may become so uncontrollable for the next generation, they should be educated and trained to handle it. The next generation needs to be educated and qualified in the various means through which plastic products can be produced and utilized adequately to prevent them from constituting a great nuisance in the environment. They can be further informed that it is possible to produce and use products in a manner that the waste, greenhouse gases, and pollution can be greatly reduced. Presently, resources such as corn, soy, sugarcane, potato, and other renewable materials can be used to produce bioplastics. Producing petroleum plastics from materials that can be recycled can make sustainable products. Also, the process of production can equally be sustained. Biodegradable plastics and bioplastics can restrict recycled materials from lesser power and low carbon impression (Greene, 2014). Because sustainable plastic materials can be recycled after usage, they can comprise bio-based, biodegradable, and reprocessed plastics.

It is developing biodegradable plastics that can be sustained influence the environment. Such effects include the usage of raw materials, sources of energy, and economic influence. The economic impact has to do with creating trade, employment, and manufacturing companies in society. The process involved in designing products and services should integrate ways through which products can be sustained to prevent the negative effect of the products on the environment, social life, and economy. The triple bottom line program should be adopted as a tool that will ensure sustained products that will totally reduce the negative impacts on the environment, social life, and economy.

7. Conclusion and future outlook

This research looked into the long-term viability of biodegradable plastics that are committed to environmental protection. The study employs a triple bottom line approach to highlight the unpredictability of the biodegradable plastic development process, which encompasses macro and micro environmental issues. This study adds to our understanding of bioplastic product development and green product innovation. A triple bottom line analysis approach may be used to examine the social, economic, and environmental repercussions of biodegradable plastic innovation at each step. This study's conclusions have a wide range of implications. This information can be used to help build a theoretical framework for future studies. The biodegradable plastics industry may significantly address increasing environmental issues by incorporating environmentally sustainable activities in their business activities.

Social, economic, biophysical, and technological aspects, as well as a set of all-encompassing, process-oriented principles, are all necessary for the adoption of sustainable, biodegradable plastics. The goal of social sustainability was to improve human life quality by implementing training and introducing fair and equitable social costs of biodegradable plastics in the pursuit of intergenerational fairness and cultural diversity in plastics manufacturing. The economic component of sustainability is to make bioplastics initiatives affordable to the target demographics. It also entails expanding job creation, enhancing competitiveness, employing environmentally conscious personnel, and ensuring biodegradable plastics projects can fulfil future demands. The biophysical characteristics of sustainable, biodegradable plastics include extracting renewable resources beyond their slow rate of rejuvenation, reducing consumption of four generic resources (materials, power, water, and land), expanding resource reuse or recycling, prioritizing renewable resources over non-renewable resources, reducing pollution of air, land, and water, and preserving and refurbishing. Technical sustainability in biodegradable polymers refers to their durability, dependability, and functionality.

Plastics derived from bio-based resources, and in particular biodegradable plastics derived from bio-based resources, account for a minor proportion of total plastic manufacturing. Because of this, it is illogical to foresee a near-term situation in which biodegradable polymers outnumber all present plastic production methods. It is also questionable whether or not this is a true advantage. The use of biodegradable plastics in the future plastics system should be expected, provided that: annual demand is increasing; they attract public attention; they provide opportunities for the use of non-fossil feedstocks; there are many biodegradability-required niche applications (particularly in the agricultural and related industries), and these plastics are capable of doing the same. In the first instance, when describing the scope of possible analysis, there is an exercise in deciding which applications are suitable for 'design for deterioration' where biodegradation will benefit as a disposal option, solving a problem for which there is no obvious alternative solution. Time and energy may be spent more wisely in the process of developing the material qualities and designing the larger structural framework necessary for the applications that are being developed. Bringing existing material up to date would be a wonderful place to start this project. Instead of examining the replacement potential of all plastics, the focus would be better positioned to evaluate the replacement potential applications that would benefit from biodegradable plastics this time. One of the objectives would be to consider the functional aspects of biodegradable plastics.

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Declaration of competing interest

I have no conflict of interest to report.

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