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Assessing Biopolymer Packaging in the EU Market for Sustainable Bioeconomy Development

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Abstract **– The bioeconomy provides tremendous potential for high-value products like pharmaceuticals, food and feed additives, and biopolymers. The potential for developing bioeconomy is limited to low-value applications such as bulk chemicals, bioenergy, and biofuels. The economic, environmental, and social benefits of a successful transition facilitated by market innovations must be primarily promoted by businesses, government agencies, and consumers. One of the most critical considerations in promoting bioeconomy is evaluating the market potential of biopolymer packaging materials. Leveraging the GE-McKinsey Nine-Box Matrix, a decision-making process was developed to assess the market attractiveness and competitive advantage of the four biopolymer packaging materials in the EU market: cellulose, PHA, PLA, and starch. The approach incorporates novel elements for competitive advantage, such as product sustainability, to deliver value-added benefits that render a product competitive in the market. The research findings indicate that the packaging material made of PLA biopolymer has the most marketing potential. The methodology for selecting biopolymer packaging materials and advancing the bioeconomy through agricultural waste valorization is well-suited for decision-makers.**

Keywords **– Agriculture waste; bioeconomy; biopolymer packaging materials; commercialization; GE-McKinsey matrix.**

1. INTRODUCTION

1.1. Advancement of Bioeconomy

Global transition towards sustainable development has been one of the primary goals in recent years, including developing national and regional bioeconomy strategies [1]. Several national and regional policies show increasing interest in bioeconomy as a solution for sustainable development. Even greenhouse gas emission reduction is one of the critical parts of sustainable development, representing a vital objective of the European Union's sustainsable development [1]. The existing regulatory framework clearly shows the development and intensification of carbon footprint trends. The European Parliament committed to reducing greenhouse gas emissions by 55 % by 2030 and achieving carbon neutrality by 2050. In 2018, the European Commission [2] updated the bioeconomy strategy, stating that the bioeconomy encompasses all systems and industries that depend on biological resources and the principles and functions they provide. It encompasses and connects all economic and industrial sectors that use natural resources and processes to create food, feed,

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bio-based products, energy, and services, as well as all primary production sectors that use and produce natural resources, such as forestry, fisheries, aquaculture, and agriculture. The starting point advancing the bioeconomy is the value pyramid that illustrates the valorization of biomass.

Regarding product value, pharmaceuticals add a lot to the product but in small volumes. In contrast, energy carriers add little to the product value but in large quantities. Agriculture, horticulture, and livestock farming produce the entire value pyramid's products and feedstock. Numerous biobased innovations can be recognized in each tier of the pyramid. However, there is no standardized framework that integrates sustainability, bioeconomy, and agricultural waste valorization consistently. The focus is on prioritizing products based on discussions around sustainable waste management and the need to address plastic waste. This approach has the potential to advance sustainable bioeconomy development and support climate neutrality goals. As per data published by [3], starting from lower value-added products, bioenergy, and bulk chemicals and materials show a fragile line for value-added development from 2008 to 2020. The high value-added products, including food and pharmaceuticals, show enormous value-added development. It is clearly seen that biopolymers seek attention for value-added development even after having a vast potential to drive the bioeconomy sustainably (see Fig. 1).

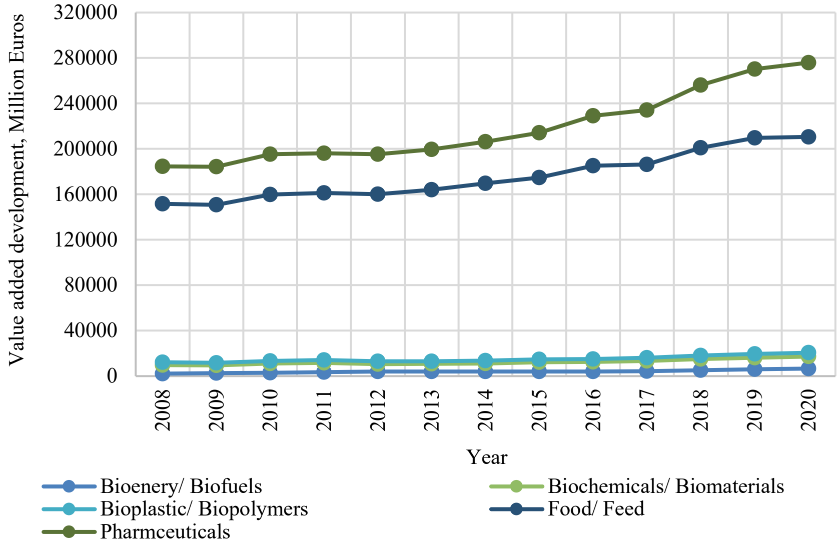

Fig. 1. Bioeconomy added value share of distinct levels of products from agricultural waste [3].

The most recent market data gathered by European Bioplastics indicates that worldwide biopolymer production capacity is expected to rise from 2.2 million tons in 2022 to 6.3 million tons in 2027 [4]. The data shows that the industry is progressing toward a sustainable future with less environmental impact, but it also goes beyond that. It is also anticipated that over the next few decades, the emerging biopolymers sector will reveal enormous economic potential [5]. The biopolymer markets are expanding, encompassing consumer electronics, toys, packaging, horticulture/agriculture, consumer electronics, automotive, and textile industries. In 2022, packaging will continue to be the largest segment of the global bioplastics market, making up 48 %. Biopolymers are used in a range of products, including keyboards, beverage bottles, and car interior parts [6], [7].

Moreover, another concern for the value-added development of biopolymers is to make the right investment choice for biopolymer packaging materials, ensuring their sustainability and profitability in the market. In order to be sustainable, a business model must show society or customers how biopolymers will advance in the future. Companies must establish business models that effectively close the biopolymer life cycle, confront the potential impacts on agricultural production that may surpass those associated with processing and use, and establish industrial standards to guarantee that biopolymer companies promote sustainability throughout the product life cycle [8], [9].

1.2. Agriculture Waste Valorization to Biopolymers Packaging Materials

Agriculture wastes are a core of the bioeconomy as they are a significant sector. In EU-27, almost 70 % of the biomass is of agricultural origin, which makes agriculture the largest source of biomass. The vital use of agricultural waste to produce value-added products is an excellent approach to complying with EU regulations. The "resource, recovery, and recycle" paradigm must be imposed to bring about the industrial revolution in the agricultural sector. The technological, social, economic, and environmental aspects of agricultural waste can all be more harmoniously balanced by the bioeconomy. Additionally, by utilizing waste, fostering economic growth for waste, and striking a balance between production and consumption, the bioeconomy promotes sustainable agricultural sector growth [10].

A more concentrated area is biopolymer production from agricultural waste because it promotes sustainable development. Agricultural crop residues, lignocellulosic feedstocks, and organic wastes are significant biopolymer resources from agricultural byproducts and edible food waste [11], [12]. Agricultural crop residues are highly efficient for producing biopolymers because they require less land and yield more material. Easy access to these residues is essential for effective biopolymer production. The total available agricultural residue in Europe is 72 529 kilotons/year [13]. Country-specific annual available agriculture residues are shown in Fig. 2. Crops produce large amounts of agricultural residues, which vary based on farming practices, crop types, and crop rotation. The quantity of residues depends on the crop yield and the area cultivated. The availability of these residues is influenced by their competition for industrial or agricultural use and the need to retain some on the land to preserve soil fertility [14].

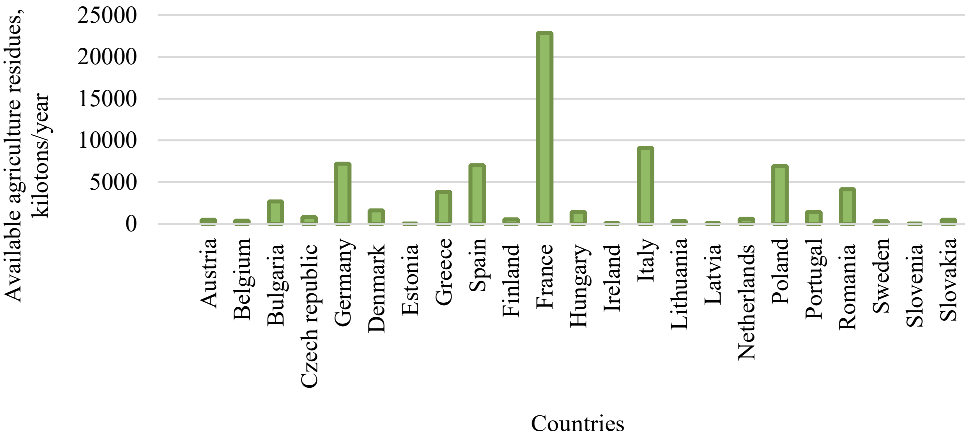

Fig. 2. Availability of agriculture residues in EU [13].

Over the past few decades, the pathway for valorizing agricultural waste has evolved to produce value-added products. As reported by [15], polylactic acid (PLA) production from agricultural residues using a solid-state fermentation technique provides cost-effective, eco-friendly, and large-scale production. Besides, PLA can be produced from multiple agricultural residues such as milled corn cob, sugarcane bagasse, food waste, and cassava [16]. The viable crops for starch-based packaging materials are maize, wheat, cassava, and potato. The most standard method to build starch-based packaging materials is injection molding. This environmentally friendly method uses efficient machinery and durable thermosetting polymer [16].

Enzyme hydrolysis can produce Polyhydroxyalkanoates (PHA) packaging from agricultural residues like fruit peels, bagasse, and food crops. This process creates packaging that is both renewable and biodegradable. It is considered a green method because it can be used in mild environments and does not require harsh chemicals [17].

Cellulose is the most abundant biopolymer packaging material, primarily derived from various agricultural residues such as seeds, grasses, stalks, woody vegetation, sugarcane bagasse, and rice straw. Among them, sugarcane bagasse and rice straw are economic crops and can be obtained from general agro-waste. The most standard step-by-step method to produce cellulose biopolymer packaging material is extraction, pretreatment, and emulsification-diffusion techniques. PLA, PHA, starch, and cellulose biopolymers are the most topical and competitive biodegradable polymers. These biopolymers are linked to using renewable raw materials derived from agricultural resources, such as proteins and polysaccharides [18].

Sustainable packaging is one of the industries with the most incredible growth rate. As such, it must be prioritized by both the market and consumers [19]. However, producing such products is not feasible if they do not have adequate viability. Conducting feasibility studies to produce such innovative products from renewable biomass resources is essential. So that it would be commercially viable in the future to drive a commercial business, a fundamental methodology should be designed to evaluate the new products, as by implementing the GE-McKinsey matrix, we can estimate the current condition of the product's portfolio [20].

Many studies have supported the GE-McKinsey matrix for the corporate business portfolio. For instance, a Russian oil and gas production enterprise has used this method to identify the potential of the business [21], Indonesian university modified and used this method for prioritizing resource allocation by following the mapping the market position of the study programs [22], Italian fashion industry has used it to evaluate the investment opportunities for product portfolio management [23], Chinese case study has used it to determine the sustainable urbanization performance [24], and a market attractiveness of different fruits in agroforestry system has been investigated by using this method [25]. A positive outcome emerged from this research on the market's attractiveness and business strength. To prioritize the biopolymer comprehensively in the bioeconomy, assessing the market opportunity for decision-making in commercializing the packaging materials is imperative.

In our two prior studies, we used an evolving approach to improve the value of biopolymers in the bioeconomy pyramid. Where [26] assesses the biopolymer alternatives in accordance with sustainability criteria and indicators, and [27] provides the system innovation pathway by developing a carbon footprint tool for product packaging meant for online marketplaces. The current study aims to develop a methodology for employing the GE-McKinsey analysis to determine the market potential of biopolymer packaging materials that offer innovative transfer to the market. The study contributes to developing a market opportunity for decision-making in commercializing packaging materials. A case study has been developed for four packaging materials: cellulose, PLA, PHA, and starch.

2. MATERIAL AND METHODS

A successful transition toward bioeconomy is about to emerge through radical innovations promoted primarily by stakeholders, businesses, or government organizations. Fig. 3 shows the strategic scheme for the market innovation transfer of biopolymer packaging materials produced from agricultural waste to advance the bioeconomy.

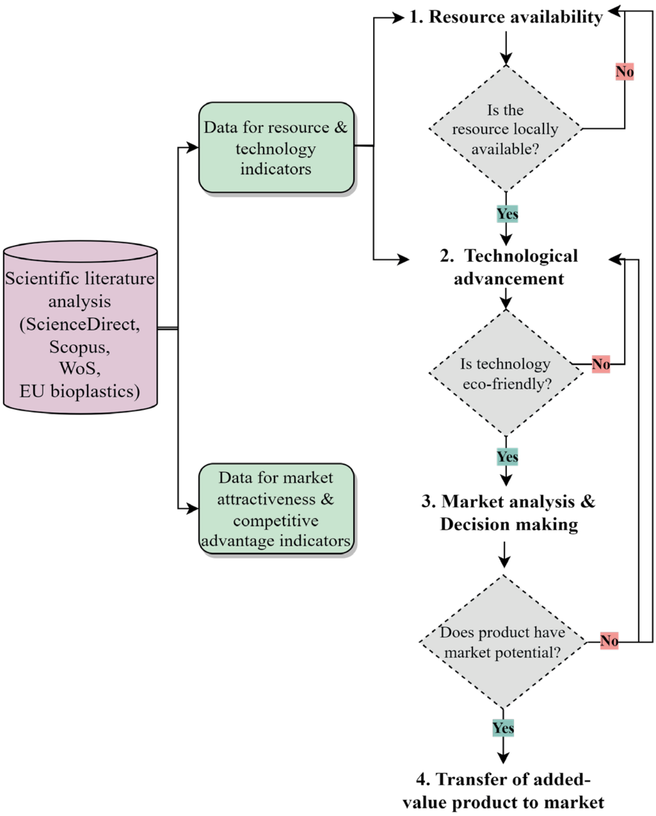

Fig. 3. Methodology algorithm.

This study performs a market analysis for the four different biopolymer packaging materials from agriculture crop residues.

Step 1: The first stage in fostering agriculture valorization is the availability of resources; these resources should be locally sourced and not rely on imports. In this case, the evaluation is based on the availability of resources.

Step 2: Technology must be eco-friendly. Even if technology is innovative, it should be widely accessible. If not, then it goes to the first stage.

Step 3: The GE-McKinsey matrix, utilized for market evaluations, is the decision-making matrix in this scenario. Data on the economy, technology, market competitiveness, and products have all been gathered for calculations. The data are entered into the matrix for decision-making when the findings have been obtained. A positive calculation result may not necessarily reflect the actual situation; in most cases, matrix visualization is required. Scientific articles, current plant data, and yearly reports serve as information sources for the matrix. Based on the information gathered, data is analyzed and shown in two dimensions (market attractiveness and product competitive advantage) on the GE-McKinsey matrix. The primary data are gathered from information sources such as scientific research articles.

Step 4: is the last step, visualization of results and suggestions for further investigation into the manufacture of new products in the nation or place where they are now produced and where local resources are available.

2.1. Data Collection and Evaluation Technique

The market analysis is carried out using primary qualitative data. The literature analysis is performed to collect the data for each indicator in the GE-McKinsey analysis. The first two steps address the indicators for resource availability and technological advancement, which are considered for the market competitive advantage to provide value added benefits. Resources play a central role in a business's environmental performance to establish efficiency in the process [28], and the eco-friendliness of technology significantly addresses a business's sustainable practice [29]. For the market attractiveness, six key indicators are evaluated market size, market growth rate, market profit, price sensitivity, access to raw materials, and production cost [30]. The market competitive advantage is evaluated based on the six critical indicators, including demand, market share, availability of resources, selling price, environmental ease of technologies, and product quality [30].

The Likert scale is a commonly used scale that displays the preferences for outcomes derived from quantitative indicators [31]. A decision-maker can also use the Likert Scale to assess and contrast the outcomes of various projects. For market attractiveness, the evaluation is done based on a five-point scale, where 1 is very unattractive, and 5 is very attractive. Six indicators are selected, including market size, market growth rate, market profitability, price sensitivity, access to raw materials, and production cost. Each indicator is evaluated differently based on the external importance scale, which indicates the position on the scale. Market size is determined based on the potential clients or buyers in a packaging market, where the external importance scale is set from little (1) to great (5) market size. The market growth rate is determined based on the growth of the packaging industry by 2030, where the external importance scale is set from a low (1) to a high (5) growth rate. Market profit is determined based on the economic factors that the business pulls in after accounting for all expenses, and the scale is set from low (1) to high (5). Price sensitivity is determined by the price of a product that affects the consumers' purchasing decisions, which is evaluated on a scale from high (1) to low (5). Access to raw materials indicates the availability of raw materials required for primary production, which is determined based on the scale from difficult (1) to easy (5). Lastly, production cost includes a variety of expenses such as raw materials, labour, manufacturing supplies, and general overhead, which is determined based on the scale from high (1) to low (5).

For market competitive advantage, the evaluation is also done based on five-point ratings. Where 1 represents a very low competitive advantage, and 5 represents a very highly competitive advantage. Each indicator is evaluated individually. Higher demand for the product is weighted as 5, and lower demand is weighted as 1. Market share is evaluated as 1 represents 1–20 %, 2 represents 21–40 %, 3 represents 41–60 %, 4 represents 61–80 %, and 5 represents 81–100 %. Regarding the availability of resources, 1 represents that the resource is difficult to access, and 5 represents that the resource is easily accessible. The selling price is rated as 1 for lower and 5 for higher selling price. The environmental ease of technology is evaluated based on its impact on the environment during the manufacturing process, where 1 represents a little or no positive environmental impact and 5 represents a very positive environmental impact of technology. Lastly, the quality is evaluated based on the melting point of the biopolymer, where 5 shows a high melting point of biopolymer with a very highly competitive advantage, and 1 shows a low melting point with a very low competitive advantage.

2.2. GE-McKinsey Market Analysis

The GE-McKinsey Matrix technique includes nine modules or boxes to designate market aspects for possible new bioproducts. The GE-McKinsey matrix approach has been altered to consider factors and limitations, including environmental protection requirements for the manufacturing process and product sustainability. It displays the competitive attractiveness of a specific product rather than the company's competitive standing. This matrix shows a similar approach to the Boston Consulting Group matrix. For product development and evaluating competitive scenarios, the GE-McKinsey matrix is frequently employed [23]. Fig. 4. shows the GE-McKinsey matrix, where products that fall in the green boxes are high performers with commercialization potential. Products that fall in the gray boxes must be analyzed and improved until they appear in the green boxes [24].

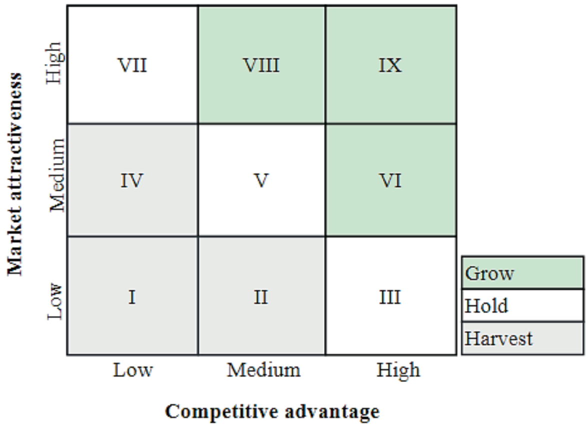

Fig. 4. The GE-McKinsey Matrix example [26].

A green box is a growing area, meaning the product has strong competitiveness and attractiveness for the market. If a product is categorized in the "hold" area of a matrix, it indicates that the product requires careful management to sustain its current value and position in the market. This typically involves maintaining its performance and addressing any issues to prevent decline. On the other hand, if a product is in the "harvest" area, it signifies that the product has low competitive advantage and market attractiveness [32]. This matrix has the benefit of accounting for a greater variety of variables than the Boston Group matrix and being more straightforward to comprehend visually. The nine fields and three times three grids provide the GE-McKinsey Matrix with larger dimensions. The Boston Group matrix, in contrast, only contains four fields and a two-by-two grid [33].

2.2.1. Market Attractiveness

Market attractiveness replaces market growth as the measurement of industry attractiveness. It refers to the profit possibilities in a product's market or industry. Market attractiveness can be calculated as following Eqs. 1 and 2.

$$M_a = (z \cdot k), \tag{1}$$

where

M_a market attractiveness total score;

Z estimated total rating score;

k coefficient.

$$k = \frac{100}{(f \cdot B_{\max})}, \tag{2}$$

where

k coefficient;

f number of factors;

$B_{\max}$ max rating score.

2.2.2. Market Competitive Advantage

Market competitive advantage refers to a scenario or event that offers a business a competitive or superior position in the marketplace. In this study, a competitive advantage is evaluated for a product. A relative competitive advantage can be calculated by Equation 3.

$$R = \left(\frac{B}{B_{\mathrm{comp}}} - 1\right) \cdot 100\%, \tag{3}$$

where

R relative indicator of product competitive advantages;

B new product score estimation;

B_{comp} strongest competitor score estimation.

3. RESULTS AND DISCUSSION

The most available and easy-to-access resource considered is agriculture residues, and the eco-friendliness of the conversion technique is considered according to the type of packaging materials. The market is set for Europe, and the products chosen are biopolymer packaging materials, including PLA, PHA, starch, and cellulose. The evaluation rating results for market attractiveness are presented in Table 1. Since all market attractiveness indicators are equally important, every indicator was assigned a weight of 16 %.

The evaluation rating results for market competitiveness advantage are shown in Table 2. The weight was set for the market competitive advantage indicator in percentage, considering the importance of the indicator. The highest weights are 20 % for the availability of resources and environmental ease of the technology. As per our developed methodology, these two indicators are crucial for a strong business portfolio. The rest of the indicators are evaluated for the 15 % of weights.

TABLE 1. EVALUATION RATING RESULTS FOR MARKET ATTRACTIVENESS

Indicators	**Weights**	**External importance scale**	**Very unattractive** **1**	**Unattractive** **2**	**Neutral** **3**	**Attractive** **4**	**Very attractive** **5**	**External importance scale**	**Source**
Market size	16.6 %	Little	C	P2	S	P1		Great	[4]
Market growth rate	16.6 %	Low		C	S	P2	P1	High	[6], [34]–[36]
Market profit	16.6 %	Low		C	S	P2	P1	High	[4]
Price sensitivity	16.6 %	High		C; P2	S		P1	Low	[37], [38]
Access to raw material	16.6 %	Difficult					C; S; P1; P2	Easy	[39]–[41]
Production cost	16.6 %	High		P2		C; P1	S	Low	[42]–[44]

Note: C-cellulose; P1- PLA; P2- PHA; S-starch

TABLE 2. MARKET COMPETITIVE ADVANTAGE EVALUATION RATINGS RESULTS

Indicators	**Weights**	**Very low competitive advantage**	**Low competitive advantage**	**Moderate competitive advantage**	**Highly competitive advantage**	**Very highly competitive advantage**	**Source**
		Rating scale					
		1	**2**	**3**	**4**	**5**	
Demand	15 %		S	P1	P2	C	[34]–[36], [45]
Market share	15 %		C	S	P2	P1	[4]
Availability of resources	20 %					C; S; P1; P2	[39]–[41]
Selling price	15 %		C; P2	S		P1	[37], [38]
Environmental ease of technology	20 %				P1; P2	S; C	[46], [47]
Quality (based on melting point)	15 %			P2	P1; S	C	[48]–[51]

Note: C-cellulose; P1- PLA; P2- PHA; S-starch

Table 3 demonstrates the weighted scores for the market attractiveness and competitive advantages. The visualization of GE-McKinsey results is shown in Fig. 5. The results in the matrix show that PLA has a substantial potential for market attractiveness (4.65) and competitive advantage (4.15) because PLA has the lowest market price (1.50–2.09 USD/kg) [37] with the highest production capacity of 37.9 % [4] compared to other packaging materials. PHA packaging material has the weakest position in the market competitive advantage (3.15).

TABLE 3. RESULTS FOR BIOPOLYMER MARKET ATTRACTIVENESS AND COMPETITIVE ADVANTAGES

Market attractiveness evaluation									
Weights of importance					**Weights**	**Weighted scores**			
Indicators	**Biopolymer packaging materials**								
	Cellulose	**Starch**	**P1- PLA**	**P2- PHA**		**Cellulose**	**Starch**	**P1-PLA**	**P2-PHA**
Market size	1	3	4	2	16.666 %	0.166	0.498	0.664	0.332
Market growth rate	2	3	5	4	16.666 %	0.332	0.498	0.83	0.664
Market profit	2	3	5	4	16.666 %	0.332	0.498	0.83	0.664
Price sensitivity	2	3	5	2	16.666 %	0.332	0.498	0.83	0.332
Access to raw material	5	5	5	5	16.666 %	0.83	0.83	0.83	0.83
Production cost	4	5	4	2	16.666 %	0.664	0.83	0.664	0.332
Total	16	22	28	19	100 %	**2.66**	**3.65**	**4.65**	**3.15**
Market competitive advantage evaluation									
Weights of importance					**Weights**	**Weighted scores**			
Indicators	**Biopolymer packaging materials**								
	Cellulose	**Starch**	**P1- PLA**	**P2- PHA**		**Cellulose**	**Starch**	**P1-PLA**	**P2-PHA**
Demand	5	2	3	4	15 %	0.75	0.3	0.45	0.6
Market share	2	3	5	4	15 %	0.3	0.45	0.75	0.6
Availability of resources	5	5	5	5	20 %	1	1	1	1
Selling price	2	2	5	2	15 %	0.3	0.3	0.75	0.3
Environmental ease	5	4	3	1	20 %	1	0.8	0.6	0.2
Quality (based on melting point)	5	4	4	3	15 %	0.75	0.6	0.6	0.45
Total	24	20	25	19	100 %	**4.10**	**3.45**	**4.15**	**3.15**

To strengthen the position, PHA should focus on reducing costs, improving material performance, expanding range of applications, and enhancing market visibility. On the other hand, cellulose material shows the least market attractiveness (2.66), which can be improved by increasing the market size growth rate and potentially giving a better price. The market share for cellulose is only 1.5 % [4]. Starch packaging materials show an average position for market attractiveness (3.65) and competitive advantage (3.45). However, improving both ratios can lead to a higher position for starch material.

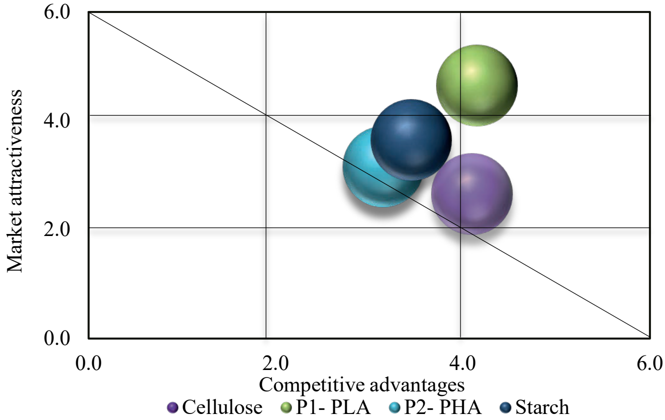

Fig. 5. GE-McKinsey matrix results for biopolymer packaging material alternative.

The agriculture industry is a comprehensive source of biomass resources and biomaterial suppliers with significant potential for producing biopolymer packaging materials [52]. Over the time, market demand for biopolymer packaging materials should be raised to ensure environmental safety. According to the recent report from European Bioplastics 2022, 48 % of biopolymers are used as packaging applications in Europe [4]. Despite the significant market potential, biopolymer packaging materials often use less cost-effective strategies compared to synthetic polymers [53]. The results of our study show that cellulose has the second highest position in terms of market competitive advantage but the weakest market attractiveness. However, it is not always straightforward to determine if the product is fully sustainable and has high market potential. Market potential seeks economic benefit more than environmental benefit [54]. The results of this study strongly favour the production of PLA packaging materials with both market attractiveness and competitive advantage. Moreover, biopolymer packaging material investment opportunities bring an advantage to acting towards climate neutrality by complying with the global environmental policy to decrease CO_2 emissions by increasing agricultural residues and sharing biobased products in the market.

4. Conclusions

The valorization of agriculture residues for developing bioeconomy and businesses is suitable for Europe. Business strength and attractiveness are also assessed through the systematic step-by-step approach. Also, this business portfolio analysis provides sustainable business solutions for investment or expansion of the business. It assists producers and businesses in expanding their business growth through the originated information. The approach employed here is broadly adaptable and suitable for various products. It can be applied to both novel and existing bio-products produced from agricultural biomass. The study covers four primary attractive biopolymer packaging materials having market attractiveness and competitive strength. The methodology has been demonstrated to be a practical framework for acquiring knowledge of the market for different biopolymer packaging materials.

The GE-McKinsey matrix proved to be an excellent tool for decision-making of a products readiness level to enter the market. Whether the product is sustainable and economically beneficial or requires significant changes in terms of technology used, resource availability, market attractiveness, and competitiveness, it can be modified for various scenarios and parameters. PLA biopolymer packaging material would be an ideal investment option, followed by cellulose, starch, and PHA packaging materials to attract the market. Nowadays, the policies and regulations are more focused on the environmental impact of the businesses. In such cases, this study would help businesses to make a viable choice.

While the study was currently being conducted, certain constraints were identified that might broaden the focus of future research, including a) the absence of extensive data on the biopolymer industry's market size, growth rates, and competitive environment, particularly for biopolymers produced from agricultural waste, could render accurate evaluation challenging, b) evaluating possible growth in the market and competitive advantage could prove challenging when there is a degree of uncertainty regarding the scalability, efficiency, and cost-effectiveness of the technique utilized to create biopolymers from agricultural waste, and c) demand and pricing estimates could become more difficult to determine because the biopolymer industry is rapidly changing competitive dynamics, market trends, and customer preferences.

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