sustainability

Article

Evaluating the Perceptions of the Portuguese Population on the Economic Impacts of Biotechnology-Based Technologies

Henrique Vicente [1,2], José Neves [2,3] and Margarida Figueiredo [4,*]

[1] Departamento de Química e Bioquímica, Escola de Ciências e Tecnologia & REQUIMTE/LAQV, Universidade de Évora, Rua Romão Ramalho, 59, 7000-671 Évora, Portugal; hvicente@uevora.pt
[2] Centro Algoritmi/LASI, Universidade do Minho, Campus de Gualtar, Rua da Universidade, 4710-057 Braga, Portugal; jneves@di.uminho.pt
[3] Instituto Universitário de Ciências da Saúde, CESPU, Rua José António Vidal, 81, 4760-409 Famalicão, Portugal
[4] Departamento de Química e Bioquímica, Escola de Ciências e Tecnologia & CIEP, Universidade de Évora, Rua Romão Ramalho, 59, 7000-671 Évora, Portugal
* Correspondence: mtf@uevora.pt

Abstract: Biotechnology-based technologies have the potential to act as catalysts for economic development by fostering innovation, creating new job opportunities, stimulating industry growth, and promoting environmental sustainability. This study aims to evaluate the perceptions of the Portuguese population regarding the economic impacts of using these technologies in areas such as the environment, energy resources, agriculture, industry, and health. For this purpose, a questionnaire was developed and distributed in Portugal to a sample consisting of 559 individuals of both genders, aged between 16 and 82 years old. The findings suggest that, although there is a higher perception of the economic impact of these technologies, participants reveal difficulties in perceiving impacts on health, industry, and energy resources. Moreover, metrics for quantifying participants' overall perception and improvement potential are provided. These metrics are particularly important as they enable the formation of participant groups with similar characteristics, facilitating the development of tailored intervention strategies. Additionally, a model based on artificial neural networks was presented to predict the perceptions of the Portuguese population regarding the economic impacts of using the mentioned technologies. The proposed model performs well, achieving accuracy rates of 93.0% for the training set and 90.9% for the test set.

Keywords: economic impact; biotechnology; sustainability; artificial neural networks

Citation: Vicente, H.; Neves, J.; Figueiredo, M. Evaluating the Perceptions of the Portuguese Population on the Economic Impacts of Biotechnology-Based Technologies. *Sustainability* **2024**, *16*, 3307. https://doi.org/10.3390/su16083307

Academic Editor: George Kyriakarakos

Received: 8 March 2024
Revised: 4 April 2024
Accepted: 10 April 2024
Published: 15 April 2024

1. Introduction

Biotechnology-based technologies have emerged as pivotal drivers of economic growth and innovation across various sectors, reshaping industries, and societies. The integration of molecular biology, genetic engineering, chemistry, and bioinformatics has unlocked unprecedented opportunities to address pressing challenges in agriculture, healthcare, and environmental sustainability, just to name a few [1,2].

The biotechnology-based industry harnesses bio-based raw materials as a substitute for fossil resources to manufacture a diverse array of bioproducts. This type of industry enhances productivity by minimizing resource usage, reducing energy consumption, decreasing emissions (including greenhouse gases), diminishing reliance on fossil fuels, minimizing waste generation, and serving as a crucial tool for waste treatment [1–3]. Within this context, bioremediation has emerged as an environmental restoration method. It relies on the utilization of microorganisms, whose effectiveness can be enhanced through genetic engineering to eliminate pollutants from soil, water, and air. Bioremediation is an environmentally sustainable alternative to traditional cleanup methods such as excavation and incineration. Its application extends to remediating oil spills, industrial waste sites, and polluted water bodies [4–8].

In agriculture, genetically modified crops have demonstrated the potential to enhance yields, reduce environmental impacts, and bolster food security. In fact, genetic modification enables the development of crops with enhanced traits such as drought resistance, pest resistance, and increased nutritional value [9–11]. These modifications not only boost crop yields, but also diminish the reliance on fertilizers and toxic pesticides/herbicides, thereby lessening the environmental impact of chemical usage. Embracing sustainable agricultural practices through genetic engineering promotes biodiversity conservation and safeguards natural resources [12,13].

Biotechnology's impact on environmental preservation is notably underscored by the advancement of biofuels. These renewable alternatives to fossil fuels, sourced from organic materials like plant biomass or algae, represent a significant stride in sustainable energy solutions. Leveraging genetic and metabolic engineering techniques, it is possible to enhance the efficiency and affordability of biofuel production, further bolstering their potential as a green energy source. Indeed, biofuels play a dual role in combating climate change by reducing greenhouse gas emissions and lessening the reliance on fossil fuels, offering a sustainable energy solution [14–16].

Similarly, another area where biotechnology-based technologies have a significant impact is medicine, leading to the development of new drugs, vaccines, medical devices, and diagnostic tools aimed at improving patient outcomes, preventing diseases, and enhancing overall healthcare delivery. Examples of biotechnological innovations in healthcare include personalized medicine, gene therapy, regenerative medicine, targeted drug delivery systems, and advanced diagnostic imaging techniques. These innovations have the potential to revolutionize healthcare by providing more effective, precise, and tailored solutions to medical challenges, minimizing side effects [17–21].

Given the accelerating pace of biotechnological innovation and its increasing prominence in economic strategies worldwide, it is imperative to understand the public's perceptions of the economic impacts of biotechnology-based technologies. In fact, public perceptions can influence market dynamics and consumer behavior. Positive perceptions of biotechnological advancements may enhance consumer acceptance of biotech-derived products, leading to an increased demand and market growth. Conversely, negative perceptions or misinformation can erode consumer trust, resulting in market resistance, reduced adoption rates, and even boycotts of biotech products. Therefore, understanding public perceptions is essential for companies seeking to navigate market complexities and maintain consumer confidence in their products and services [22,23]. Furthermore, biotechnological advancements often involve complex scientific processes, ethical considerations, and potential risks. In this context, understanding public perceptions of biotechnology-based technologies and openly addressing their concerns can aid in fostering trust and transparency in scientific innovation, promoting responsible innovation practices. Public engagement in discussions about the economic impacts of biotechnological innovations can foster a more inclusive and democratic approach to technology governance [22–24].

According to McCluskey et al. [25] the beliefs of populations influence both their perception of risk and how they interpret new information from the media or other sources. Therefore, it is crucial to enhance public understanding of the benefits and risks associated with biotechnology-based technologies. Decision makers should invest in proactive education to establish a framework which enables the population to assess risks effectively when specific events occur. Preemptive risk communication can help to mitigate potential negative consequences. Companies, scientists, and governments must be prepared to disseminate information during crises. Neglecting to do so could lead to alarmist reporting by the media.

Malyska et al. [23] point out that, in a highly mediated society, there is a requirement for a fundamental change in how the dissemination of knowledge about emerging technologies in society is planned and designed. Connecting with the public goes beyond promoting research solely after its completion. It should be an integral part of the research process from the beginning and adapted to the different stages of research development. Communication must be comprehensive, carefully strategized, and conveyed in a manner easily grasped to mitigate misconceptions. Effective communication entails offering concrete examples of applications when discussing innovative techniques, using clear and concise language that is easily understandable, and addressing social concerns in a thoughtful and respectful manner. Thus, it is crucial to identify both the benefits and potential risks while also effectively communicating plans regarding biosafety measures. Interactive seminars could provide an ideal setting for this type of commitment, centered on dialogue rather than straightforward knowledge dissemination [23].

According to Jimenez et al. [24], interactions between researchers and communities promote critical thinking, cater to community needs, offer broad-ranging responses, and foster mutual trust. The authors describe various types of initiatives that authorities and the scientific community can undertake with the aim of engaging the public. These initiatives include (1) informal education (which takes place outside of the traditional classroom setting and includes museums, community events, festivals, and extracurricular programs, just to name a few); (2) initiatives related to citizen science and community participatory research; and (3) policies that align with the public's values and provide opportunities for public input. The authors also highlight the role that regulatory agencies can play in developing education and outreach policies targeted at communities. These policies aim to effectively communicate the social, economic, environmental, and human health benefits of biotechnology-based solutions, alongside the associated risks and methods of risk assessment and mitigation.

The assessment of public perceptions of biotechnology-based technologies has been explored through various studies carried out in different countries. According to findings from the 2019 Food Safety report [26], 72% of European citizens showed an awareness of food and beverage additives. The overwhelming majority in Sweden (98%), the Netherlands (95%), and Estonia (87%) claimed "most likely" to be acquainted with these additives. Among Europeans, 60% were familiar with genetically modified additives in foods or drinks, while only 21% had heard about genome editing. The respondents from Sweden were "most likely" to be acquainted with genetically modified additives in food and drink (83%), while those from Finland (62%) and Estonia (57%) exhibited the highest awareness of genome editing [26]. When considering socio-economic factors, the report noted that participants familiar with genetically modified additives in food and drinks tended to be adults aged 20 and above, self-employed, or holding managerial positions [26].

The 2019 Food Safety report [26] also highlighted that 43% of Europeans were of the opinion that food products contained harmful substances. This perspective was particularly prominent in Cyprus (66%), France (63%), Croatia (61%), and Poland (52%). Conversely, Finland (17%), Sweden (24%), and Germany (29%) exhibited the lowest levels of agreement with this assertion.

According to the Special Eurobarometer 505 [27] the primary drivers guiding Europeans' food purchases encompass taste (45%), food safety (42%), and cost (40%). Additionally, 34% prioritize the food's origin, while 33% focus on its nutrient content, and 20% consider its shelf-life. Concerns regarding food processing and animal welfare were cited by 16% of participants, while considerations about the product's environmental and climate impact were mentioned by only 15% of participants. Taste ranks among the top three most cited factors in 21 EU Member States, emerging as the primary factor in eight of them, namely in Portugal (59%), Poland, and Slovakia (both 55%). In Czechia and Belgium, it is the predominant aspect mentioned, together with cost with percentages reaching 58% and 47%, respectively [27]. Food safety also emerges as one of the top three most mentioned factors in 24 countries. However, it takes precedence as the primary factor only in five nations, with Italy (58%), Greece (55%), and Cyprus (51%) reporting the highest proportions. Cost ranks among the top three most mentioned factors in 17 EU Member States. Portugal leads with 70%, followed by Lithuania (61%), Latvia (60%), and Estonia with percentages ranging 61% and 55% [27].

The Special Eurobarometer 516 [28] reveals a favorable opinion among Europeans toward emerging technologies. It highlights that 86% of participants anticipate a positive impact from vaccines and efforts to combat infectious diseases over the next 20 years, while 70% hold similar optimism regarding biotechnology and genetic engineering [28]. Across EU nations, the range of respondents foreseeing a positive outcome concerning biotechnology and genetic engineering varies from 93% to 82% in Portugal, Estonia, Finland, and Sweden, to 55% to 60% in Romania, Austria, and Croatia [28].

Woźniak et al. [22] examined the evolving perspectives of Europeans towards biotechnology and genetic engineering over the last two decades. The results of various public opinion studies reveal an increasingly positive trend regarding the impacts of scientific and technological advancements on humanity. The authors emphasize that there has been a discernible, albeit slight, shift towards the acceptance of biotechnology. Particularly, high expectations are highlighted regarding medical advancements, improvements in the quality of life, and the potential they represent for future generations. On the contrary, social acceptance remains lower, particularly regarding genetically modified products, namely genetically modified crops. In fact, the adoption of these types of crops faces some resistance from society, despite allowing for the reduction in greenhouse gas emissions, exhibiting greater resistance to pests, insects, or adverse environmental conditions, demonstrating higher productivity and nutritional value for both humans and livestock, and providing greater economic returns for farmers [22].

Woźniak-Gientka et al. [29] conducted a comprehensive study to gauge the prevailing public sentiment among Poles regarding biotechnology and genetic engineering. The research, undertaken in 2019, surveyed a sample size of 1008 respondents comprising Polish residents aged 15 and above. The survey was distributed across all 16 administrative divisions of Poland. The primary objectives were to assess: (1) the level of awareness concerning products derived from genetic engineering techniques, (2) public opinions regarding various applications of biotechnology and genetic engineering, and (3) the overall stance on genetically modified feeds. The study findings showed that over half of the Polish population acknowledged the presence of products derived from genetic engineering techniques in the market. Despite apprehensions surrounding research in biotechnology and genetic engineering, between 39% and 69% of Poles expressed support for these endeavors, depending on the specific area of research. Additionally, 62% of respondents opposed genetically modified feeds, citing concerns over potential harm to human life and health [29].

Kooffreh et al. [30] evaluate the level of knowledge, interest, and perception of biotechnology among secondary school students. The study encompassed a sample of 304 students in senior secondary classes from eight secondary schools within the Calabar metropolis, aged between 16 and 20 years old. The findings indicated that 34% of students possessed limited knowledge regarding medical biotechnology, genetic engineering, and genetically modified products. Among the students, 30% acknowledged biotechnology as the utilization of living organisms to generate goods and services, while 33% recognized it as an emerging technology rooted in biology. Only 20% of the participants were open to embracing biotechnology applications, while 50% expressed doubt regarding its ability to enhance services for mankind. Meanwhile, 30% revealed a lack of knowledge about biotechnology applications. The findings also revealed that 25% of students exhibited a very low interest in pursuing biotechnology at a university level. Overall, secondary school students in Calabar demonstrated low levels of knowledge, perception, and interest in biotechnology, and the authors stress the urgent need to promote awareness and emphasize the applications of biotechnology among secondary school students [30].

Klop and Severiens [31] conducted a study on the attitudes of Dutch secondary school students towards biotechnology. In this study, the concept of attitude encompasses levels of knowledge as well as cognitive and affective evaluations and behavioral intentions.

The main goals were examining the types of cognitive and affective evaluations and the behavioral intentions evident in students' attitudes, to investigate the interrelationships between them, and to distinguish different attitude patterns. Out of the 634 students involved, only 574 surveys were considered, with 147 from secondary vocational education, 147 from general secondary education, and 280 from pre-university secondary education. The authors explored the possibility of identifying subgroups within the entire student population and successfully identified four clusters. Cluster 1 comprised 22.6% of the students and encompassed those who declared embracing biotechnology in their daily lives. They exhibited confidence regarding their future intentions to become consumers of biotechnological products, ranging from consuming genetically modified foods to undergoing genetic testing during pregnancy. Cluster 2, comprising 41.6% of the students, includes those who neither strongly oppose nor strongly support biotechnology. They maintain positive views about biotechnology but express some reservations about its developments. Despite this, they show intentions to consume biotech products, especially if certain critical or environmental conditions are fulfilled. They also demonstrate appreciation for its medical applications. Cluster 3, representing 18.3% of the students, consists of individuals who have significant skepticism and concern regarding biotechnology. They are apprehensive about its impact on nature and do not view it as a natural progression of society. They have no intention of engaging with it now, or in the future. Finally, cluster 4 comprises 17.5% of students. They hold highly negative views towards biotechnology, limited knowledge about the subject, pessimistic beliefs, and reluctance towards using biotech products. Only their attitude towards the applications in health is slightly less negative [31].

Artificial neural networks (ANNs) are inspired by the cognitive capabilities of the human brain, aiming to replicate its intricate learning mechanisms. Comprised of the interconnected nodes resembling neurons, ANNs discern patterns, learn from data, and make decisions. Each node is fed by inputs from other nodes or external sources, these signals are modified through activation functions, before being transmitted as outputs. The network's performance is optimized through continual adjustment of connection weights during training, refining its ability to recognize patterns and make predictions. One of the most popular architectures is the MultiLayer Perceptron (MLP), which organizes nodes into layers with connections that flow in only one direction. The design of MLPs often involves trial-and-error, and various techniques have been suggested to accomplish this objective, including methods based on hill-climbing algorithms, which iteratively refine the initial architecture to reduce an internal error metric [32–34]. In recent years, ANNs have demonstrated success across diverse domains, spanning environmental sciences [35–38], healthcare [39–41], or image reconstruction [42,43], just to name a few.

2. Methodology

This section succinctly outlines the study design, data collection procedure, instruments employed, cohort characteristics, and the methods used in data analysis. Additionally, ethical considerations observed during the research are mentioned.

2.1. Study Design

The use of biotechnology-based technologies serves as a catalyst in areas like economic development, innovation, job creation, industry growth, and environmental sustainability, just to name a few. Despite advancements in biotechnology, there still exists apprehension and resistance from the public regarding its potential social, health, and environmental risks. To address this challenge, it is important to improve the understanding and acceptance of biotechnology, which requires active involvement from the population. Thus, this study aims to assess the perception of the Portuguese population regarding the use of these technologies in the fields of the environment, energy resources, agriculture, industry, and health. It also aims to evaluate the economic impacts of these technologies and establish a predictive model. Hence, it is intended to provide insights into the subsequent research questions:

- What is the population's perception of the impact of biotechnology-based technologies on the environment, energy resources, agriculture, industry, and health?
- What is the population's perception of the economic impact of biotechnology-based technologies?

Bearing in mind these research questions, a questionnaire was crafted, validated, and administered in Portugal to a diverse cross-section of individuals encompassing both genders, a wide range of ages, and varied educational backgrounds. The questionnaire considered the impact of biotechnology-based technologies on five central themes (i.e., the environment, energy resources, agriculture, industry, and health). Additionally, it examined the economic impact of these technologies. The questionnaire was structured to allow for the application of the methodology proposed by Fernandes et al. (2016) [44] for converting non-numerical data into numerical data. Further insights on these points are described in Sections 2.2–2.4.

2.2. Data Collection

The selection of a questionnaire survey method stemmed from a careful analysis of technique options, with the decision reinforced by the simplicity and versatility it offers. In fact, questionnaire surveys, although they may lack depth and context, offer efficiency, standardization, and anonymity. Other techniques like interviews, focus groups, observation, experimental research, and case studies provide richer insights, but may be resource-intensive, subject to bias, and have limited generalizability. Moreover, the questionnaire survey boasts a clearly delineated structure, facilitating the conversion of participants' qualitative feedback into quantitative data [45–48].

The questionnaire crafted for this study is structured into three parts. The initial part gathers sociodemographic details, including age, gender, and educational background. The subsequent part of the questionnaire involves a series of assertions (Table 1) concerning the core themes of the research (i.e., the impact of biotechnology-based technologies on the environment, energy resources, agriculture, industry, and health), for which participants were invited to provide their viewpoints. Finally, the latter part of the questionnaire features a series of assertions related to the economic impact of biotechnology-based technologies (Table 2). Differing from the descriptive nature of the initial answers, subsequent sections make use of a five-level Likert scale (i.e., strongly agree, agree, disagree, strongly disagree and I do not know).

As per Bell's recommendations [49], a team of experts critically assessed the questionnaire, suggesting modifications that were incorporated into an updated version. The validity and clarity of the modified questionnaire were then assessed, utilizing a limited group of participants distinct from the main sample. To assess the instrument's reliability, Cronbach's alpha was calculated. The obtained value for the 28 questions in the second section of the questionnaire was 0.84.

The modified questionnaire was personally handed to each participant in the sample in a hard copy format. All 600 distributed questionnaires were returned, resulting in a 100% return rate. The data collection period spanned from November 2022 to July 2023.

Table 1. Systematization of the assertions in Part II of the questionnaire by themes.

Impact on the Environment	A1	The use of biotechnology contributes to the reduction of environmental pollution.
	A2	Biotechnological innovations positively contribute to climate change mitigation efforts.
	A3	Biotechnological processes must prioritize sustainable resource management.
	A4	The responsible application of biotechnology contributes positively to the conservation of biodiversity.
	A5	Biotechnology has positive effects on overall environmental sustainability.
	A6	Biotechnological advancements should be subject to strict environmental regulations.
Impact on Energy Resources	A7	Biotechnology plays a significant role in the development of sustainable energy sources.
	A8	The use of biotechnology facilitates the development of cleaner and greener energy solutions.
	A9	The use of bio-based energy sources contributes to decrease carbon dioxide emissions.
	A10	Biotechnology plays a role in improving energy storage technologies.
	A11	Biotechnological advancements contribute to the decentralization of energy production.
	A12	Biotechnology enhances energy security through diversified and sustainable sources.
Impact on Agriculture	A13	Biotechnology positively contributes to increased crop yield and food production.
	A14	The use of biotechnology promotes pest-resistant and drought-tolerant crop varieties.
	A15	The use of biotechnology in agriculture enhances soil health and fertility.
	A16	Biotechnological advancements support the development of environmentally friendly pesticides.
	A17	Biotechnology supports precision farming, reducing environmental impact.
	A18	Genetic modification in agriculture is a viable method for enhancing nutritional content in crops.
Impact on Industry	A19	Biotechnology positively influences sustainable product design and development.
	A20	Biotechnological advancements contribute to the development of eco-friendly materials.
	A21	Responsible biotechnological practices contribute to minimizing industrial waste.
	A22	Biotechnology plays a role in reducing the carbon footprint of industrial processes.
	A23	The integration of biotechnology in industry supports circular economy principles.
Impact on Health	A24	Biotechnological innovations contribute to personalized and targeted healthcare solutions.
	A25	The use of biotechnology supports advancements in preventive healthcare measures.
	A26	Responsible biotechnological practices prioritize patient safety and well-being.
	A27	Biotechnology positively influences the accessibility and affordability of pharmaceuticals.
	A28	The use of biotechnology in medicine contributes to the development of sustainable healthcare solutions.

Table 2. Systematization of the assertions in Part III of the questionnaire.

Impact on Economy	A29	Biotechnological advancements positively impact job creation in various sectors.
	A30	Biotechnological advancements support the development of socially responsible businesses.
	A31	Economic growth can be achieved through responsible biotechnological innovation.
	A32	Social and economic disparities can be reduced through responsible biotechnology use.
	A33	The economic advantages of biotechnology can contribute to poverty reduction.
	A34	Responsible biotechnological practices prioritize long-term economic sustainability.
	A35	Biotechnological practices contribute to sustainable and inclusive economic development.
	A36	Economic benefits from biotechnology should be reinvested in environmental and social initiatives.
	A37	The overall economic impact of biotechnology should be carefully assessed and monitored.

2.3. Participants

The study included an opportunity cohort of 559 participants, spanning ages from 16 to 82, and averaging 40.5 ± 15.9 years old. Table 3 depicts the systematization of participants by age group, gender, and academic qualifications. The analysis within Table 3 reveals that 21.3% of participants were below 25 years old, 29.9% fell within the 26–40 age range, 26.1% were aged 41–50, 14.8% were between 51 and 65, and 7.9% were over 65. Within the overall cohort, 52.2% were female, and 47.8% were male. In terms of academic qualifications, 42.4% attained basic education, 38.1% earned secondary education, 14.3% achieved a degree, and 5.2% possess a post-graduate degree.

Table 3. Systematization of participants according to age group, gender, and academic qualifications.

Variable	Class	Frequency
Age (years old)	≤25	119
	[26, 40]	167
	[41, 50]	146
	[51, 65]	83
	>65	44
Gender	Female	292
	Male	267
Academic Qualifications	Basic Education	237
	Secondary Education	213
	High Education	80
	Post-Graduate Education	29

2.4. Qualitative Data Processing

The information gathered in the second section of the survey comprises non-numeric content and has been evaluated using a Likert scale featuring five levels. Using the methodological guidance provided by Fernandes et al. [44], the non-numerical data underwent a conversion process to become numerical data. In line with this approach, the y responses associated with a particular theme are portrayed within a circle having a radius of $1/\sqrt{\pi}$. The circle is segmented into y sections, with each response option indicated by a mark on the axis, as detailed in Section 3.2, concerning the assessment of the perception of the Portuguese population on the economic impacts of biotechnology-based technologies.

2.5. Artificial Neural Networks

The WEKA 3-8-6 was used to create models based on ANNs, retaining without alteration the default settings for parameters [50,51]. Both the backpropagation algorithm and the logistic activation function were applied in the learning stage [32–34]. Fifteen replicates were carried out in all tests to ensure the statistical significance of the outcomes. Every simulation included the random allocation of data into two distinct partitions, i.e., the training set, which accounted for 67% of the available data and the test set, consisting of the remaining examples. The model development process utilized the former set, with the latter set employed to evaluate its generalization capability.

2.6. Ethical Aspects

The research was executed in adherence to the prevailing legal norms. All participants were briefed on the research aims and voluntarily agreed to participate by completing the questionnaire.

3. Results and Discussion

Within this subdivision, the findings from a study focused on assessing the perception of a cohort of the Portuguese population regarding the economic impacts of the utilization of biotechnological solutions in various fields are disclosed. Out of the 600 questionnaires circulated, 41 (6.8%) were excluded from the analysis due to the lack of responses in the second/third sections. Consequently, the ensuing results rely on the input from 559 participants.

3.1. Frequency of Responses Analysis

The data presented in Figure 1 illustrates the distribution of response frequencies related to the assertions on the theme of the impact of biotechnology on the environment. Its reading indicates that the most common response given to assertions 2, 3, 4, 5, and 6 was *agree*. Concerning assertion 2 (relating to climate change mitigation), the response frequency was 46.3%. In the case of assertion 3 (relating to sustainable research management), the corresponding frequency was 47.8%. Regarding assertion 4 (relating to biodiversity conservation), the *agree* option was chosen by 46.5% of participants, whereas for assertions 5 (relating to environmental sustainability) and 6 (relating to environmental regulations), the same option was chosen by 45.2% and 43.1% of participants, respectively. In assertion 1 (relating to environmental pollution), the option *strongly agree* emerged as the most chosen (70.7%), followed by the option *agree* (19.3%).

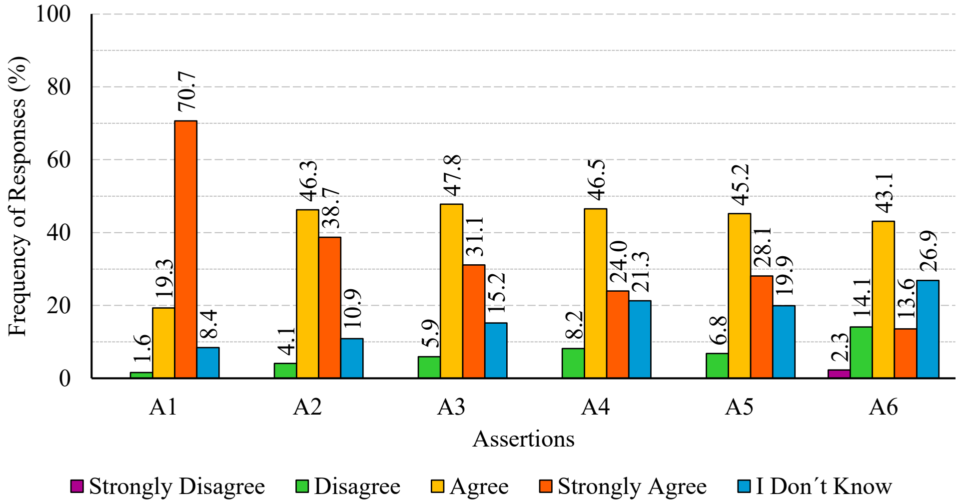

Figure 1. Frequencies of responses (in percentage) associated with the assertions from the A1 to A6 regarding the impact of biotechnology on environment.

Participants chose the *strongly disagree* option solely for assertion 6, though the percentage was low (2.3%). The *disagree* option was ticked by less than 5% of participants for assertions 1 and 2. For assertions 3, 4, and 5, this percentage ranged between 5% and 10%. Only for assertion 6, more than 10% of participants selected this option.

Finally, it is important to emphasize that the *I don't know* option was chosen for all assertions. The largest percentage of *I don't know* responses was recorded for assertion 6 (26.9%), followed by assertion 4 with 21.3%, assertion 5 with 19.9%, and assertion 3 with 15.2%. Relating to assertions 2 and 1, this percentage was less than 15% (i.e., 10.9% and 8.4%, respectively).

The outcomes depicted in Figure 1 reveal that a considerable percentage of participants are unfamiliar with matters concerning legislation, biodiversity, and sustainability. Conversely, there is a prevalence of positive responses (i.e., *strongly agree* and *agree*) for the issues relating to environmental pollution and climate change mitigation. These results align with those documented in Special Eurobarometer 516 [28]. As per the report, across the EU, 89% of respondents express interest (i.e., "*very interested*" or "*moderately interested*") in environmental issues, such as climate change. Additionally, the percentage of respondents expressing being "*very interested*" in environmental concerns varies from 15% in Bulgaria and Lithuania to 71% in Portugal, with an EU average of 42%.

The results presented in Figure 1 align with those reported by Woźniak-Gientka et al. [29], indicating that 69% of Poles expressed support for using microorganisms to treat sewage and other wastes, while 54% believed they could potentially pose a threat to human health and the environment. Concerning the genetic alteration of microorganisms for environmental purification purposes, 55% of Poles found it beneficial, 54% supported such research, and 55% deemed it acceptable.

The data presented in Figure 2 illustrates the distribution of response frequencies related to assertions on the theme of the impact of biotechnology on energy resources. Its reading indicates that the most common response given to assertions 7, 8, 11, and 12 was *agree*. Concerning assertion 7 (relating to sustainable energy sources), the response frequency was 56.2%. In the case of assertion 8 (relating to clean and green energies), the corresponding frequency was 56.7%. Regarding assertion 11 (relating to decentralization of energy production), the *agree* option was chosen by 45.4% of participants, whereas for assertion 12 (relating to energy security) this option was chosen by 44.2% of participants. In assertion 9 (relating to carbon dioxide emissions), the option *strongly agree* emerged as the most chosen (44.2%), followed by the option *agree* (41.7%).

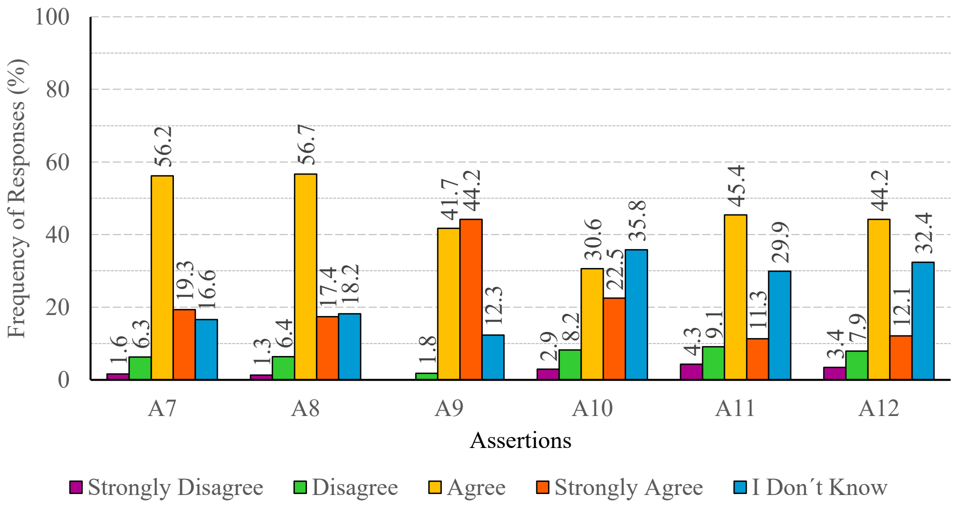

Figure 2. Frequencies of responses (in percentage) associated with the assertions from the A7 to A12 regarding the impact of biotechnology on energy resources.

Apart from assertion 9, participants chose the *strongly disagree* option for all the remaining assertion of this theme, though the percentage was low, ranging between 1.3% and 4.3%. The *disagree* option was ticked in all assertions by a small percentage of participants, varying between 1.8% and 9.1%.

Finally, it is important to emphasize that the *I don't know* option was chosen for all assertions, being the most chosen in assertion 10 (relating to energy storage) with 35.8% of responses. The largest percentage of *I don't know* responses was recorded for assertions 10, 11, and 12, ranging between 29.9% and 35.8%. Relating to assertions 7, 8, and 9, this percentage was less, varying between 12.3% and 18.2%.

The outcomes depicted in Figure 2 reveal that a considerable percentage of participants are unfamiliar with matters concerning energy storage, energy security, and decentralization of energy production. Conversely, there is a prevalence of positive responses (i.e., *strongly agree* and *agree*) for the issues relating to carbon dioxide emissions, sustainable energy sources, and clean and green energies. These results may have been influenced by the progressive increase in energy costs caused by the instability experienced in Europe during the study period. The aforementioned price hike may have positively influenced participants' perception regarding the importance of seeking alternative energy sources independent of geopolitical issues, which is not the case for traditional energy sources.

The results present in Figure 2 align with those reported by Sasa et al. [52] that undertook a study to evaluate the environmental literacy of students enrolled at Applied Science Private University in Jordan. The findings of this study unveiled that the students exhibited a considerable level of environmental knowledge concerning energy, pollution, and recycling. Furthermore, the Special Eurobarometer 516 [28] highlights that Portugal has the highest percentage of respondents (74%) who disagree with the assertion "*Thanks to scientific and technological advances, the Earth's natural resources will be inexhaustible*".

The data presented in Figure 3 illustrates the distribution of response frequencies related to assertions on the theme of the impact of biotechnology on agriculture. Its reading indicates that the most common response given to assertions 13, 14, 15, and 16 was *agree*. Concerning assertion 13 (relating to crop yield and food production), the response frequency was 51.7%. In the case of assertion 14 (relating to pest-resistant and drought-tolerant crop varieties), the corresponding frequency was 51.0%. Regarding assertion 15 (relating to soil health/fertility), the *agree* option was chosen by 56.9% of participants, whereas for assertion 16 (relating to environmentally friendly pesticides) this option was chosen by 69.2% of participants. In this theme, the option *strongly agree* never emerged as the most chosen.

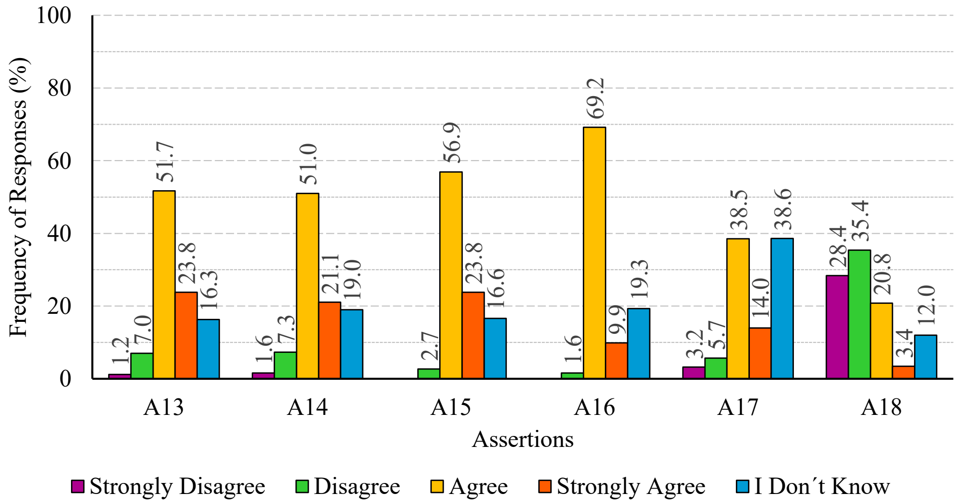

Figure 3. Frequencies of responses (in percentage) associated with the assertions from the A13 to A18 regarding the impact of biotechnology on agriculture.

Apart from assertions 15 and 16, participants chose the *strongly disagree* option for all the remaining assertion of this theme, though the percentage was low, ranging between 1.2% and 3.2% for assertions 13, 14, and 17. Conversely, for assertion 18, 28.4% of participants selected this option. The *disagree* option was ticked in all assertions by a small percentage of participants, varying between 1.6% and 7.3%, except for assertion 18 (relating to genetic modification for enhancing nutritional content in crops), for which this option was ticked by 35.4% of participants.

Finally, it is important to emphasize that the *I don't know* option was chosen for all assertions. The response frequency ranges between 12.0% and 38.6%, being the most chosen option in assertion 17 (relating to precision farming).

The outcomes depicted in Figure 3 reveal that a considerable percentage of participants are unfamiliar with matters concerning precision farming. Conversely, there is a prevalence of positive responses (i.e., *strongly agree* and *agree*) for the issues relating to soil health/fertility, environmentally friendly pesticides, crop yield/food production, and pest-resistant/drought-tolerant crop varieties. Regarding the use of genetic modification for enhancing nutritional content in crops (assertion 18) there is a prevalence of negative responses (i.e., *strongly disagree* and *disagree*). These results align with those reported by Woźniak-Gientka et al. [29], indicating that 60% of Poles would remain unconvinced by various features of transgenic food (e.g., lower price, improved nutritional value, enhanced taste and appearance, and increased durability). Moreover, 45% of Poles assert that the use of biotechnology in food production is harmful, while 46% advocated for its prohibition, and 46% consider it unacceptable. Concerning the utilization of biotechnology to improve drought, pest, and insect resistance, 44% of Poles affirm its utility, while 44% advocate for supporting research in this area, and 45% find it acceptable. Conversely, 26% of respondents are convinced of its harmfulness, 26% seek its prohibition, and 25% consider it unacceptable.

The data presented in Figure 4 illustrates the distribution of response frequencies related to assertions on the theme of the impact of biotechnology on industry. Its reading indicates that the most common response given to assertions 19, 20, 22, and 23 was *agree*. Concerning assertion 19 (relating to sustainable product design), the response frequency was 54.7%. In the case of assertion 20 (relating to the development of eco-friendly materials), the corresponding frequency was 50.6%. Regarding assertion 22 (relating to carbon footprint of industrial processes), the *agree* option was chosen by 40.3% of participants, whereas for assertion 23 (relating to circular economy), this option was chosen by 39.5% of participants. In assertion 21 (relating to industrial waste), the option *strongly agree* emerged as the most chosen (47.2%), followed by the option *agree* (40.6%).

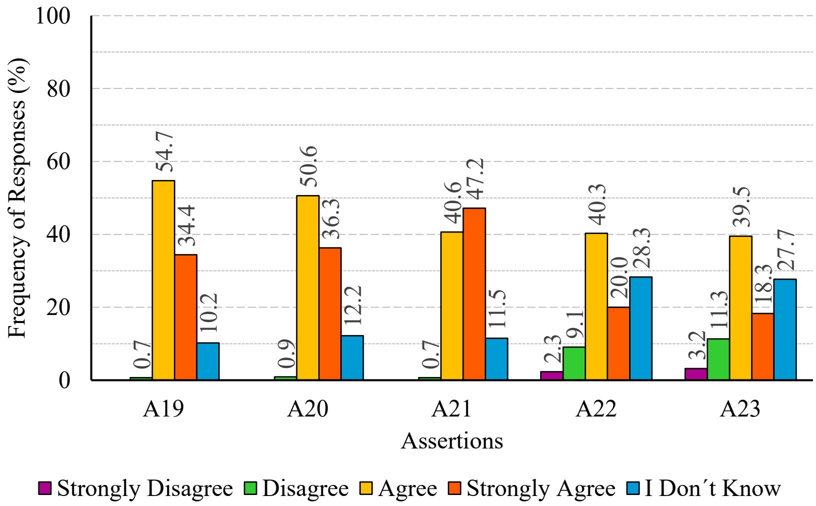

Figure 4. Frequencies of responses (in percentage) associated with the assertions from the A19 to A23 regarding the impact of biotechnology on industry.

Participants chose the *strongly disagree* option solely for assertions 22 and 23, though the percentage was low (2.3% and 3.2%, respectively). The *disagree* option was ticked by less than 1% of participants for assertions 19, 20, and 21. For assertions 22 and 23, this percentage were 9.1% and 11.3%, respectively.

Finally, it is important to emphasize that the *I don't know* option was chosen for all assertions. The largest percentage of *I don't know* responses was recorded for assertion 22 (28.3%), followed by assertion 23 with 27.7%, assertion 20 with 12.2%, assertion 21 with 11.5%, and assertion 19 with 10.2%.

The outcomes depicted in Figure 4 reveal that a considerable percentage of participants are unfamiliar with matters concerning the carbon footprint of industrial processes and circular economy. Conversely, there is a prevalence of positive responses (i.e., *strongly agree* and *agree*) for the issues relating to sustainable product design, industrial waste, and development of eco-friendly materials. These findings align with those of Woźniak-Gientka et al. [29], indicating that 59% of respondents consider biotechnology important in the food industry, pointing out the use of microorganisms in the production of food products (e.g., bread, beer, and yogurt). Additionally, 69% of Poles support the use of microorganisms for waste treatment, while 55% believe that genetic modification of microorganisms for environmental purification purposes is beneficial. Furthermore, 64% of Poles view the use of biotechnology and genetic engineering positively in the pharmaceutical industry, especially in the development of new vaccines and drugs.

The data presented in Figure 5 illustrates the distribution of response frequencies related to the assertions on the theme of the impact of biotechnology on health. Its reading indicates that the most common response given to assertions 24, 25, 27, and 28 was *agree*. Concerning assertion 24 (relating to personalized and targeted healthcare solutions), the response frequency was 46.9%. In the case of assertion 26 (relating to preventive healthcare), the corresponding frequency was 43.6%. Regarding assertion 27 (relating to the accessibility and affordability of pharmaceuticals), the *agree* option was chosen by 45.1% of participants, whereas for assertion 28 (relating to sustainable healthcare solutions), those option was chosen by 46.3% of participants. In assertion 26 (relating patients' safety and well-being), the option *strongly agree* emerged as the most chosen (41.3%), followed by the option *agree* (35.8%).

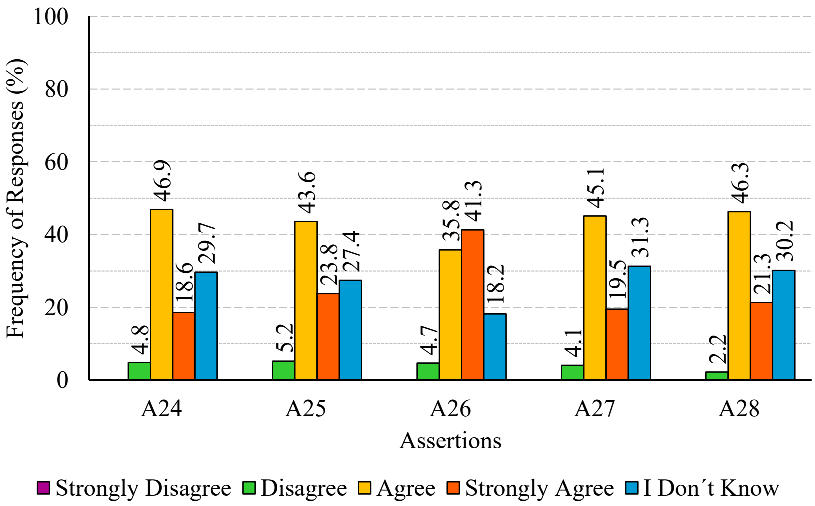

Figure 5. Frequencies of responses (in percentage) associated with the assertions from the A24 to A28 regarding the impact of biotechnology on health.

None of the participants chose the option *strongly disagree*. The *disagree* option was ticked in all assertions by a small percentage of participants, varying between 2.2% and 5.2%.

Finally, it is important to emphasize that the *I don't know* option was ticked in all assertions, varying between 18.2% and 31.3%.

Despite the prevalence of positive responses in all assertions, the outcomes depicted in Figure 5 reveal that a considerable percentage of participants (higher than 18.2%) are unfamiliar with those matters.

The results presented in Figure 5 align with those reported by Woźniak-Gientka et al. [29], indicating that 64% of Poles expressed positivity towards utilizing biotechnology and genetic engineering in the development of new vaccines and drugs, advocating for their continued support and implementation. Conversely, 58% of respondents held concerns that such research could potentially compromise human health and the environment.

The data presented in Figure 6 illustrates the distribution of response frequencies related to the assertions relating to the impact of biotechnology on the economy. Its reading indicates that the most common response given to assertions 30, 31, 32, 34, and 35 was *agree*. Concerning assertion 30 (relating to the development of socially responsible business), the response frequency was 51.0%. In the case of assertion 31 (relating to economic grow), the corresponding frequency was 49.6%. Regarding assertion 32 (relating to reduction of social and economic disparities), the *agree* option was chosen by 48.7% of participants, whereas for assertions 34 (relating to long-term economic sustainability) and 35 (relating to sustainable and inclusive economic development), this option were chosen by 50.6% and 44.7% of participants, respectively. In assertions 29 (relating to job creation), 33 (relating to poverty reduction), 36 (relating to reinvestment of the economic benefits in environmental and social initiatives), and 37 (relating to assessment and monitorization of economic impacts) the option *strongly agree* emerged as the most chosen, ranging between 52.1% and 71.4%, followed by the option *agree*, varying between 28.6% and 34.2%.

None of the participants chose the option *strongly disagree*. The *disagree* option was ticked in assertions 30, 31, 32, 33, 34, and 35 by a small percentage of participants, varying between 2.1% and 8.4%.

Finally, it is important to emphasize that the *I don't know* option was chosen for assertions 30, 31, 32, 33, 34 and 35. The largest percentage of *I don't know* responses was recorded for assertion 30 (28.4%), followed by assertion 35 with 26.3%, assertion 34 with 25.4%, assertion 32 with 14.1%, assertion 33 with 14.0%, and assertion 31 with 13.6%.

Despite the prevalence of positive responses in all assertions, the outcomes depicted in Figure 6 reveal that a considerable percentage of participants are unfamiliar with matters concerning development of socially responsible business, long-term economic sustainability, sustainable/inclusive economic development. Conversely, it is important to highlight there are only positive responses (i.e., *strongly agree* and *agree*) for the issues relating to job creation, reinvestment of the economic benefits in environmental and social initiatives, and assessment and monitorization of economic impacts.

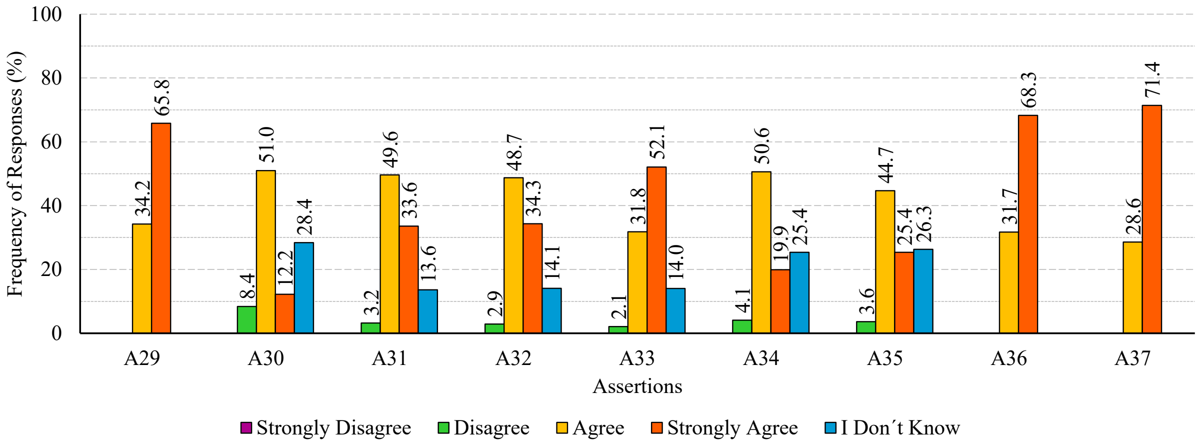

Figure 6. Frequencies of responses (in percentage) associated with the assertions from the A29 to A37 regarding the impact of biotechnology on economy.

The results presented in Figure 6 highlight the positive perception of participants regarding the economic impacts of biotechnology-based technologies. These positive impacts has been emphasized by other authors. Wei et al. [2] assert that the bioeconomy is undergoing both enrichment as an economic activity and evolution as an interdisciplinary concept. The authors highlight the necessity of expediting the diffusion and transfer of biotechnology, integrating the industrial chain of biotechnology–bioindustry–bioeconomy with the innovation chain, and achieving organic connection and simultaneous development from practice to theory. The European Parliament proposed allocating EUR 52.7 billion to address societal challenges from 2021 to 2027, with around 60% designated directly for the bioeconomy [53]. Indeed, the advancements in biotechnology provide solutions to numerous development challenges that society faces today, from the provision of energy for a growing population to the emissions reduction and carbon neutrality, guaranteeing food security and food safety, and addressing the widespread occurrence of chronic diseases worldwide. By fostering public–private partnerships in the delivery of technical cooperation programs, the transformative power of industrial biotechnology can be unlocked to facilitate the inclusive and sustainable industrial development of developing countries. Additionally, the utilization of biotechnology for inclusive and sustainable industrial development can aid in achieving the Sustainable Development Goals, namely Goal 2—Zero hunger, Goal 3—Good health and well-being, Goal 9—Industry, innovation, and infrastructure, and Goal 12—Responsible consumption and production [3].

3.2. Non-Numerical Data Conversion

Participant one's selections in the second part of the questionnaire are presented in Figure 7, whereas Figure 8 showcases the quantification of participant one's qualitative data in accordance with the methodology proposed by Fernandes et al. [44]. Thus, participant one's selections for assertions under the theme *impact of biotechnology-based technologies on the environment* are used to elucidate the methodology that followed. In this way, a radius $1/\sqrt{\pi}$ circle was partitioned into six sections, where each response option is mapped onto a mark on the axis (as depicted in Figure 8). This participant indicated the option *agree* in assertions 2, 3, and 5, and the area allotted to each response is computed as $\frac{1}{6}\pi\left(\frac{3}{4\sqrt{\pi}}\right)^2 = 0.09$. With respect to assertion 1, the alternative chosen was *strongly agree*, and the area allotted is $\frac{1}{6}\pi\left(\frac{4}{4\sqrt{\pi}}\right)^2 = 0.17$. For assertion 4, the participant selected the option *disagree*, and the area is $\frac{1}{6}\pi\left(\frac{2}{4\sqrt{\pi}}\right)^2 = 0.05$. Lastly, the alternative choice of *I don't know* for assertion 6 yields an area of zero. The combined quantitative value for the assertions concerning the *impact of biotechnology-based technologies on the environment* selected by participant one is 0.49, which was obtained by adding the individual areas. Similar procedures are applied to other themes, with the corresponding outcomes recorded in Table 4.

PART II

For each assertion tick with × the option that best reflects your opinion.

Impact on the Environment

	Strongly Agree	Agree	Disagree	Strongly Disagree	I Don't Know
A1. The use of biotechnology contributes to the reduction of environmental pollution.	☒	☐	☐	☐	☐
A2. Biotechnological innovations positively contribute to climate change mitigation efforts.	☐	☒	☐	☐	☐
A3. Biotechnological processes must prioritize sustainable resource management.	☐	☒	☐	☐	☐
A4. The responsible application of biotechnology contributes positively to the conservation of biodiversity.	☐	☐	☒	☐	☐
A5. Biotechnology has positive effects on overall environmental sustainability.	☐	☒	☐	☐	☐
A6. Biotechnological advancements should be subject to strict environmental regulations.	☐	☐	☐	☐	☒

Impact on Energy Resources

	Strongly Agree	Agree	Disagree	Strongly Disagree	I Don't Know
A7. Biotechnology plays a significant role in the development of sustainable energy sources.	☐	☒	☐	☐	☐
A8. The use of biotechnology facilitates the development of cleaner and greener energy solutions.	☐	☒	☐	☐	☐
A9. The use of bio-based energy sources contributes to decrease carbon dioxide emissions.	☒	☐	☐	☐	☐
A10. Biotechnology plays a role in improving energy storage technologies.	☐	☐	☐	☐	☒
A11. Biotechnological advancements contribute to the decentralization of energy production.	☐	☐	☒	☐	☐
A12. Biotechnology enhances energy security through diversified and sustainable sources.	☐	☒	☐	☐	☐

Impact on Agriculture

	Strongly Agree	Agree	Disagree	Strongly Disagree	I Don't Know
A13. Biotechnology positively contributes to increased crop yield and food production.	☐	☒	☐	☐	☐
A14. The use of biotechnology promotes pest-resistant and drought-tolerant crop varieties.	☐	☒	☐	☐	☐
A15. The use of biotechnology in agriculture enhances soil health and fertility.	☐	☒	☐	☐	☐
A16. Biotechnological advancements support the development of environmentally friendly pesticides.	☐	☐	☐	☐	☒
A17. Biotechnology supports precision farming, reducing environmental impact.	☐	☐	☐	☐	☒
A18. Genetic modification in agriculture is a viable method for enhancing nutritional content in crops.	☐	☐	☐	☒	☐

Impact on Industry

	Strongly Agree	Agree	Disagree	Strongly Disagree	I Don't Know
A19. Biotechnology positively influences sustainable product design and development.	☐	☒	☐	☐	☐
A20. Biotechnological advancements contribute to the development of eco-friendly materials.	☐	☒	☐	☐	☐
A21. Responsible biotechnological practices contribute to minimizing industrial waste.	☒	☐	☐	☐	☐
A22. Biotechnology plays a role in reducing the carbon footprint of industrial processes.	☐	☐	☐	☐	☒
A23. The integration of biotechnology in industry supports circular economy principles.	☐	☐	☒	☐	☐

Impact on Health

	Strongly Agree	Agree	Disagree	Strongly Disagree	I Don't Know
A24. Biotechnological innovations contribute to personalized and targeted healthcare solutions.	☐	☒	☐	☐	☐
A25. The use of biotechnology supports advancements in preventive healthcare measures.	☐	☐	☒	☐	☐
A26. Responsible biotechnological practices prioritize patient safety and well-being.	☒	☐	☐	☐	☐
A27. Biotechnology positively influences the accessibility and affordability of pharmaceuticals.	☐	☐	☐	☐	☒
A28. The use of biotechnology in medicine contributes to the development of sustainable healthcare solutions.	☐	☐	☐	☐	☒

Figure 7. Responses given by participant one to the assertions A1 to A28, included in the second part of the questionnaire.

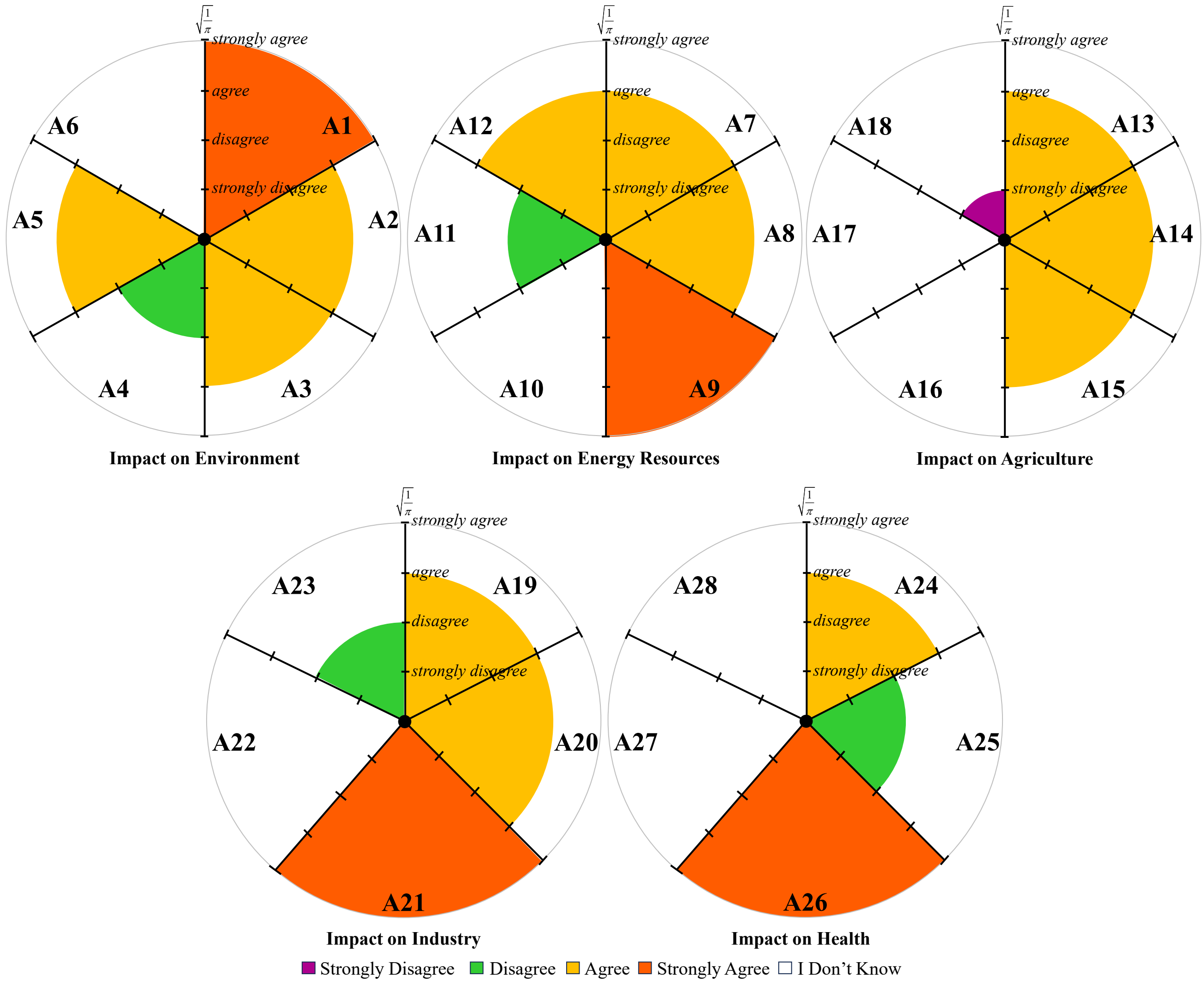

Figure 8. An illustrative overview outlining the methodology used to quantify non-numeric data regarding participant one, regarding the impacts of biotechnology-based technologies on the environment, energy resources, agriculture, industry, and health.

Table 4. Excerpt of the database used to evaluate the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies.

Participant	Environment	Energy Resources	Agriculture	Industry	Health
1	0.49	0.54	0.29	0.48	0.36
2	0.85	0.73	0.78	0.91	0.68
...	...	...	...	...	...
559	0.18	0.22	0.32	0.11	0.23

3.3. Predictive Model of Participants' Perceptions

The values found in Table 4 were employed as input data for training ANNs to perform predictions on the perceptions of the participants on the economic impacts of biotechnology-based technologies. ANNs are computational models that draw inspiration from the human brain. A commonly used network architecture is the unidirectional configuration, featuring layers of artificial neurons or nodes interconnected directly [32–34].

Various ANNs structures were developed and assessed to ascertain the most efficient model for evaluating the perceptions of the participants on the economic impacts of biotechnology-based technologies. The comparison of ANN models' performance was carried out using confusion matrices. The ANN with architecture 5-4-2-1 (Figure 9) emerged with the most favorable response among the diverse network topologies considered for the evaluation of the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies. The ANN model illustrated in Figure 9 is accompanied by its confusion matrix (Table 5), showcasing average values derived from 30 experiments. In each experiment, the dataset was randomly divided into two mutually exclusive partitions. The training set, used for constructing the model, including 372 cases, and the test set, comprising the remaining 187 examples, was used to assess the model performance. From the data displayed in Table 5, one can quantify the model's accuracy for the training set (93.0%, equivalent to 346 successfully identified from 372) and for the test set (90.9%, equivalent to 170 successfully identified from 187). Thus, the 5-4-2-1 ANN model reveals a high effectiveness in the evaluation of the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies, achieving precision levels beyond 90%. The similar values obtained for the model's accuracy for training and test set suggest the absence of overfitting issues. Overfitting occurs when the model learns to memorize the training data too well, capturing noise and random fluctuations in the data rather than the underlying patterns or relationships. This can lead to poor generalization performance, where the model performs well in the training data but fails to accurately predict outcomes in a test set.

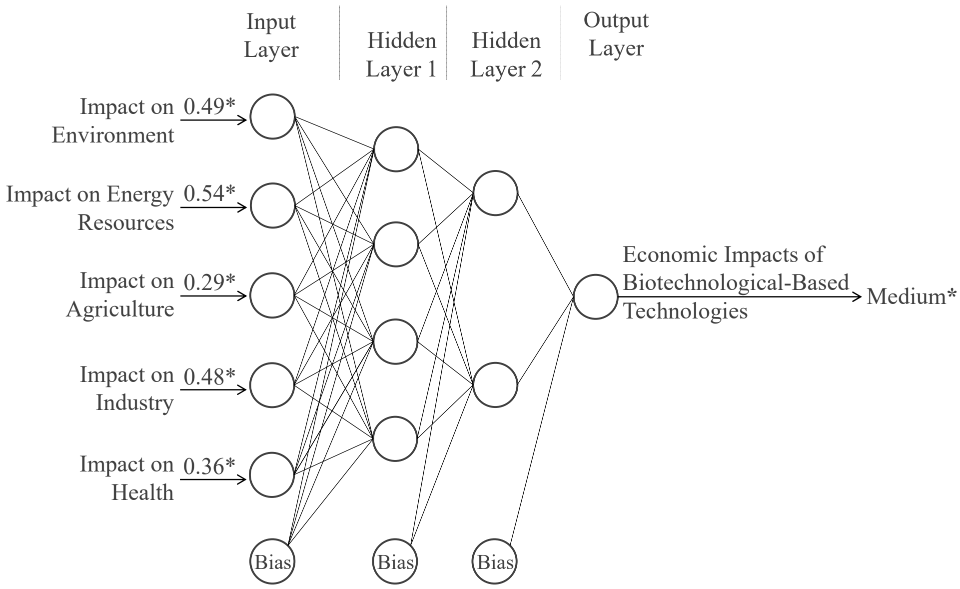

Figure 9. A diagrammatic representation of the ANN model assessing the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies. (* The provided values are for illustrative purposes and are associated with participant 1).

Table 5. Confusion matrix of the ANN model with architecture 5-4-2-1 for the evaluation of the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies.

Predict / Target	Training			Test		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
Low	70	6	0	31	7	0
Medium	8	173	7	4	87	3
High	0	5	103	0	3	52

Through a column-oriented analysis of Table 5, one can gauge how well the model identifies the different strata of participants' perception (i.e., low, medium, or high). A total of 113 participants were identified by the model as appraising the economic impact of biotechnology-based technologies as *low*, corresponding to 20.2% of the cohort. Among these cases, 101 were correctly classified, while the remaining 12 were incorrectly classified as they considered the economic impacts to be *medium*. Considering the 281 participants identified by the model as appraising the economic impact of biotechnology-based technologies as *medium* (50.3% of the cohort), 260 were properly assigned, whereas 21 were incorrectly classified, as 13 of them considered the economic impacts to be *low* and the remaining 8 considered the economic impacts as *high*. Lastly, 165 participants were identified by the model as appraising the economic impact of biotechnology-based technologies as *high*, corresponding to 29.5% of the cohort. Among these cases, 155 were correctly classified, while the remaining 10 were incorrectly classified, as they considered the economic impacts to be *medium*. From these data it is viable to quantify the confidence one can have in the predictions generated by the model. Therefore, the confidence levels stand at 89.4%, 92.5%, and 93.9% for *low*, *medium*, and *high*, respectively.

Moreover, through a row-oriented analysis of Table 5, one can assess the model's ability to identify the number of participants within each distinct stratum. Thus, from the 114 participants that praise the economic impact of biotechnology-based technologies as *low* (20.4% of the cohort), the model successfully identified 101, whereas 13 were incorrectly labeled as *medium*. Considering the 282 participants that praise the economic impact of biotechnology-based technologies as *medium* (50.4% of the cohort), 260 were properly assigned, whereas 22 were incorrectly classified (12 as *low* and 10 as *high*). Lastly, from the 163 participants that praise the economic impact of biotechnology-based technologies as *high* (29.2% of the cohort), the model successfully identified 155, whereas 8 were incorrectly labeled as *medium*.

In order to assess the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the model depicted in Figure 9, a confusion matrix for each output was generated, as outlined in Table 6. Sensitivity indicates the fraction of positive cases (*Low*, *Medium*, or *High*) correctly identified as positive, while specificity indicates the fraction of negative cases (*No-Low*, *No-Medium*, or *No-High*) correctly identified as negative. PPV represents the ratio of correctly classified *Low*, *Medium*, or *High* cases, in contrast with NPV which represents the ratio of correctly classed as *No-Low*, *No-Medium*, or *No-High* [54,55].

Table 6. Confusion matrix concerning each output classes of the ANN model with architecture 5-4-2-1 for the evaluation of the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies.

Target \ Predict	Training Set		Test Set	
	Low	**No-Low**	**Low**	**No-Low**
Low	70	6	31	7
No-Low	8	288	4	145
	Medium	**No-Medium**	**Medium**	**No-Medium**
Medium	173	15	87	7
No-Medium	11	173	10	83
	High	**No-High**	**High**	**No-High**
High	103	5	52	3
No-High	7	257	3	129

Table 7 provides the computed values for the metrics outlined previously. The model demonstrates a strong performance in evaluating the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies, as evidenced by high sensitivity and specificity values varying from 0.82 to 0.98. This fact is reinforced by high PPV and NPV values, varying from 0.89 to 0.98.

Table 7. Sensitivity, Specificity, positive predictive value (PPV) and negative predictive value (NPV) for each output classes of the ANN model with architecture 5-4-2-1.

Class	Training Set				Test Set			
	Sensitivity	**Specificity**	**PPV**	**NPV**	**Sensitivity**	**Specificity**	**PPV**	**NPV**
Low	0.92	0.97	0.90	0.98	0.82	0.97	0.89	0.96
Medium	0.92	0.94	0.94	0.92	0.93	0.89	0.90	0.92
High	0.95	0.97	0.94	0.98	0.94	0.98	0.95	0.98

The variance-based sensitivity analysis [56] was carried out to explore the influence of ANN inputs on the outputs. This relative importance (RI) analysis aids in comprehending the contributions of the inputs in determining the outputs. The findings indicate that the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies is most strongly influenced by the themes *Impact on Health* (RI = 0.26), *Impact on Industry* (RI = 0.24), and *Impact on Energy Resources* (RI = 0.21), whereas the themes *Impact on Agriculture* (RI = 0.16) and *Impact on Environment* (RI = 0.13) have a reduced impact. These outcomes align with those expressed in Section 3.1. Undeniably, the frequency of *I don't know* responses concerning *Impact on Health*, *Impact on Industry*, and *Impact on Energy Resources* themes indicates that even small differences in these responses can lead to great effects on the perception of the economic impacts of biotechnology-based technologies.

3.4. Global Analysis of the Participants' Perceptions

The methodology proposed by Fernandes et al. [44] allowed, for each theme, the conversion of the qualitative information provided by each participant into quantitative information (Figure 8 and Table 4). Aiming to carry out a global analysis of the perceptions of the participants on the economic impacts of biotechnology-based technologies, the values from Table 4 were depicted in a unitary area circle divided into five sections, each representing one of the central themes included in the second part of the questionnaire. Figure 10 illustrates the aforementioned process for participant one. Considering that the values listed in Table 4 were calculated based on a unitary area circle, these values were divided by the number of sections of the new circle (five in this case).

The quantification of participants' perceptions regarding the economic impacts of biotechnology-based technologies on a global way is now feasible. In the case of participant one, the overall perception stands at 0.43, obtained by adding the colored areas in Figure 10. Furthermore, the assessment of each participant's improvement potential is feasible. This potential is represented by the dashed outline area and is calculated as $1 - $ overall perception. For participant one, the improvement potential is given by $1 - 0.43 = 0.57$.

The analysis of Figure 10 also enables the identification of themes in which the participant demonstrates greater difficulties in perceiving the impact of biotechnology-based solutions. In the case of participant one, these are the themes related to the impact of biotechnology-based technologies on agriculture and health.

Similar procedures are applied to the remaining participants, with the corresponding outcomes depicted in Figure 11 only for the participants listed in Table 4. The analysis of Figure 11 reveals that participant 2 has a good perception of the impact of biotechnology-based solutions, regardless of the theme under consideration, whereas participant 559 reveals greater difficulties in perceiving the impact of biotechnology-based solutions, particularly concerning topics related to the environment and industry. This analysis holds particular importance, highlighting the need for customized intervention approaches. Therefore, it is mandatory to establish a database (Table 8) to sustain a decision support system aimed at analyzing the characteristics of a specific population, facilitating the formation of groups with homogeneous characteristics. Based on these attributes, it is possible to delineate intervention strategies tailored for each group, with the aim of enhancing the population's perception of the economic impacts of biotechnology-based technologies.

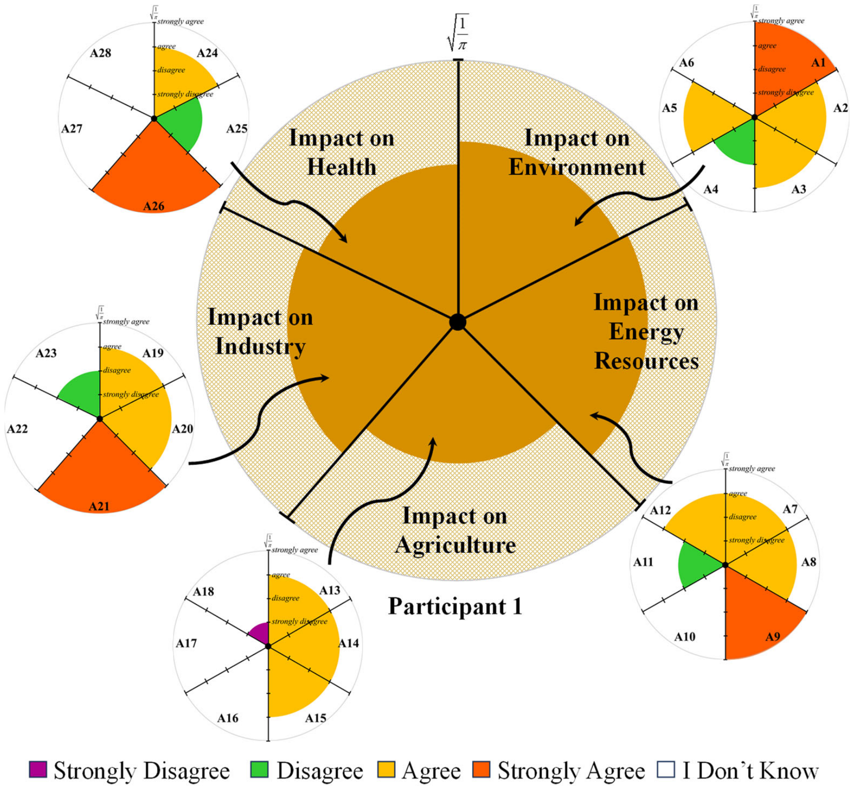

Figure 10. An illustrative overview outlining the methodology used to carry out a global analysis of the perceptions of the participant one on the economic impacts of biotechnology-based technologies.

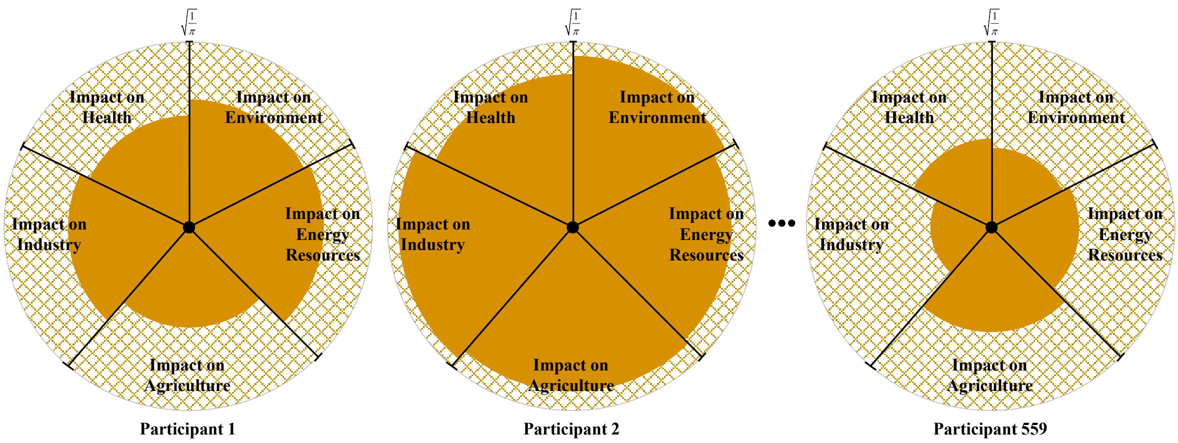

Figure 11. Global analysis of the perceptions of the participants listed on Table 4 on the economic impacts of biotechnology-based technologies.

Table 8. Excerpt of the database used to sustain a decision support system to enhance the perceptions of the Portuguese population on the economic impacts of biotechnology-based technologies.

Participant	Environment	Energy Resources	Agriculture	Industry	Health	Perception	Improvement Potential
1	0.49	0.54	0.29	0.48	0.36	0.43	0.57
2	0.85	0.73	0.78	0.91	0.68	0.79	0.21
...	...	...	...	...	...	...	...
559	0.18	0.22	0.32	0.11	0.23	0.21	0.79

The Prolog program presented in Table 9 interprets the perceptions of the participants on the economic impacts of biotechnology-based technologies using the data provided in Table 8. It defines predicates for each participant entry, sets thresholds for categorization, and includes rules for calculating and categorizing averages based on these thresholds. Thus, in the program presented in Table 9 one may find the following:

- **Facts** (*item_score, 3 arguments*): Each fact in the program represents a score for an item. The first argument is the item code, the second one is the participant code, and the third argument is the score.
- **Retrieving Score** (*get_item_score, 2 arguments*): This predicate retrieves the score for a specific participant based on its code. The first argument is the participant code, and the second argument is the score.
- **Listing Participants Above a Specific Threshold** (*participants_above_threshold, 2 arguments*): This predicate finds all participants with scores above the specified threshold using the *findall* built-in predicate.
- **Average Score** (*average_item_score, 1 argument*): This predicate calculates the average score for all participants using the built-in predicates.
- **Maximum Score** (max_*item_score, 1 argument*): This predicate finds the maximum score among all participants using the built-in predicates.
- **Minimum Score** (min_*item_score, 1 argument*): This predicate finds the minimum score among all participants using the built-in predicates.

Table 9. An excerpt of the program based on the data provided in Table 8 for evaluating the perceptions of the participants on the economic impacts of biotechnology-based technologies.

```
% scores for different items for participant 1
environ_score('ENVIRON', 'Participant 1', 0.49).
energy_score('ENERGY', 'Participant 1', 0.54).
agric_score('AGRIC, 'Participant 1', 0.29).
industry_score('INDUSTRY', 'Participant 1', 0.48).
health_score('HEALTH', 'Participant 1', 0.36).
perception_score('PERCEPTION', 'Participant 1', 0.43).
improvement_score('IMPROVMENT', 'Participant 1', 0.57).
% Retrieving the PERCEPTION score for a specific participant
get_ perception_score(ParticipantCode, Score):-
    perception_score(ParticipantCode, Score).
% Listing all participants with a PERCEPTION score above a specified threshold
participants_above_threshold(Threshold, ParticipantsCodes):-
    findall(ParticipantCode, perception_score(ParticipantCode, Score), Score > Threshold),
                                                                        ParticipantsCodes).
% Calculating the average PERCEPTION score for all participants
average_ perception_score(Average):-
    findall(Score, perception_score(ParticipantCode, Score), Scores),
    sum_list(Scores, Total),
    length(Scores, Count),
    Count > 0, % Prevent division by zero
    Average is Total/Count.
% Finding the maximum PERCEPTION score among all participants
max_ perception_score(MaxScore):-
    findall(Score, perception_score(ParticipantCode, Score), Scores),
    max_list(Scores, MaxScore).
% Finding the minimum PERCEPTION score among all participants
min_ perception_score(MinScore):-
    findall(Score, perception_score(ParticipantCode, Score), Scores),
    min_list(Scores, MinScore).
```

Likewise, the program presented in Table 9 also includes the remaining participants and the remaining topics included in the program database (i.e., improvement potential and the perceptions of the impact of biotechnology on environment, energy resources, agriculture, industry, or health).

Below are some examples of queries aimed at demonstrating how one can interact with the database of the program presented in Table 9 to retrieve specific information or perform calculations based on the scores:

```
% To get the PERCEPTION score for the 'Participant 1'
?- get_perception_score('Participant 1', Score).
% To find all participants with a PERCEPTION score above 0.50
?- participants_above_threshold(0.50, ParticipantsCodes).
% To calculate the average PERCEPTION score for all participants
?- average_perception_score(Average).
% To find the maximum PERCEPTION score among all participants
?- max_perception_score(MaxScore).
% To find the minimum PERCEPTION score among all participants
?- min_perception_score(MinScore).
```

As mentioned earlier, these queries may also focus on participants' improvement potential or the perceptions of the impact of biotechnology on addressed themes (i.e., environment, energy resources, agriculture, industry, or health). Thus, the program presented in Table 9 aims to obtain information about the responses given by the participants, such as:

- Providing the average value of the perception of the economic impacts of biotechnology-based technologies, taking into account all participants;
- Provide the highest/lowest value of improvement potential, taking into account all participants;
- Provide the list of participants whose perception of the economic impacts of biotechnology-based technologies is above/below a certain threshold.
- Provide the list of participants whose improvement potential is above/below a certain threshold;
- Provide the list of participants whose perception of the impacts of biotechnology-based technologies on the environmental is above/below a certain threshold; or
- Provide the list of participants whose perception of the impacts of biotechnology-based technologies on agriculture is above/below a certain threshold, while simultaneously considering the perception of the economic impacts of biotechnology-based technologies above/below another threshold.

3.5. Study Limitations

Despite the interesting results obtained in this study, it is important to mention some limitations that prevented a more detailed assessment of the perceptions of the Portuguese population regarding the economic impacts of biotechnology-based technologies. The main limitation is related to the sample size and the fact that it is an opportunity cohort. With a larger sample, including participants from all regions of the country, it will be possible to obtain results that allow for generalization to the entire Portuguese territory. Additionally, collecting more data on the socio-demographic and socio-economic characteristics of the cohort will enable a deeper analysis of the factors that may influence the perceptions of the Portuguese population regarding the economic impacts of biotechnology-based technologies.

4. Conclusions and Future Work

Understanding the perceptions of the population regarding the economic impacts of biotechnology-based technologies is crucial for several reasons. First and foremost, public opinion plays a significant role in shaping policy decisions, investment strategies, and regulatory frameworks related to biotechnology. As such, policymakers and industry stakeholders need to grasp the public's attitudes, beliefs, and concerns surrounding biotechnological innovations to ensure that policies and practices align with societal values and expectations. This study evaluated how the Portuguese population perceives the economic impacts of these technologies across diverse sectors such as the environment, energy resources, agriculture, industry, and health. The results obtained will facilitate drawing some conclusions. In general, the findings suggest that participants demonstrate a high perception regarding the economic impact of biotechnology-based technologies. However, they reveal difficulties in understanding the impact of these technologies in areas such as health, industry, and energy resources. This statement is supported by the fact that *I don't know* response to the majority of assertions in these areas exhibit percentages ranging from 27.7% to 35.8%. Additionally, a model utilizing artificial neural networks to predict the perception of the Portuguese population regarding the economic impacts of using the mentioned technologies were presented. The proposed model exhibited a robust performance, achieving accuracy rates higher than 90%. This study also presents an innovative approach to quantify the overall perception of the Portuguese population regarding the economic impacts of the biotechnology-based technologies and evaluate their improvement potential. These metrics play a crucial role in shaping communication strategies, educational initiatives, and countering misconceptions or misinformation, aiming to enhance public awareness of the significance of biotechnological advances in fostering sustainable and inclusive economic development. In future work, expanding the cohort to include participants from all regions of Portugal would be beneficial for generalizing the outcomes. Part I of the questionnaire should be expanded to incorporate additional socio-demographic and socio-economic characteristics such as income, occupation, employment status, living arrangement, marital status, language spoken at home, immigration status, as well as hobbies and pastimes. Additionally, the second part of the questionnaire could be broadened to encompass other core themes, thereby enhancing the study's scope. Moreover, since the results have identified specific themes where participants encounter difficulties, various initiatives involving both governmental and non-governmental organizations can be implemented to address these challenges. These initiatives may include outreach and training programs tailored to the target audience's age groups, aimed at raising awareness and providing support on lesser-known themes.

Author Contributions: Conceptualization, H.V. and M.F.; methodology, H.V., J.N. and M.F.; software, H.V. and J.N.; validation, H.V., J.N. and M.F.; formal analysis, H.V. and M.F.; investigation, H.V. and M.F.; writing—original draft preparation, H.V. and M.F.; writing—review and editing, H.V., J.N. and M.F.; visualization, H.V. and M.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by PT national funds (FCT/MCTES, Fundação para a Ciência e Tecnologia and Ministério da Ciência, Tecnologia e Ensino Superior) through the projects UIDB/50006/2020 and UIDP/50006/2020.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Soumia, B.; Rofia, A.; Nadia, Y. Biotechnology: Definitions, types and main applications. *YMER Digit.* **2023**, *22*, 563–575.
2. Wei, X.; Luo, J.; Pu, A.; Liu, Q.; Zhang, L.; Wu, S.; Long, Y.; Leng, Y.; Dong, Z.; Wan, X. From biotechnology to bioeconomy: A review of development dynamics and pathways. *Sustainability* **2022**, *14*, 10413. [CrossRef]
3. Lokko, Y.; Heijde, M.; Schebesta, K.; Scholtès, P.; Van Montagu, M.; Giacca, M. Biotechnology and the bioeconomy—Towards inclusive and sustainable industrial development. *New Biotechnol.* **2018**, *40*, 5–10. [CrossRef]
4. Bala, S.; Garg, D.; Thirumalesh, B.V.; Sharma, M.; Sridhar, K.; Inbaraj, B.S.; Tripathi, M. Recent strategies for bioremediation of emerging pollutants: A review for a green and sustainable environment. *Toxics* **2022**, *10*, 484. [CrossRef] [PubMed]

5. Sharma, I. Bioremediation techniques for polluted environment: Concept, advantages, limitations, and prospects. In *Trace Metals in the Environment: New Approaches and Recent Advances*; Tovar, M.A.M., Saldarriaga-Noreña, H., Saeid, A., Eds.; IntechOpen: London, UK, 2021; pp. 221–236.
6. Ihsanullah, I.; Jamal, A.; Ilyas, M.; Zubair, M.; Khan, G.; Atieh, M.A. Bioremediation of dyes: Current status and prospects. *J. Water Proc. Eng.* **2020**, *38*, 101680. [CrossRef]
7. Ławniczak, Ł.; Woźniak-Karczewska, M.; Loibner, A.P.; Heipieper, H.J.; Chrzanowski, Ł. Microbial degradation of hydrocarbons—Basic principles for bioremediation: A review. *Molecules* **2020**, *25*, 856. [CrossRef] [PubMed]
8. Silva, I.G.S.; Almeida, F.C.G.; Silva, N.M.P.R.; Casazza, A.A.; Converti, A.; Sarubbo, L.A. Soil bioremediation: Overview of technologies and trends. *Energies* **2020**, *13*, 4664. [CrossRef]
9. Kumari, P.; Jasrotia, P.; Kumar, D.; Kashyap, P.L.; Kumar, S.; Mishra, C.N.; Kumar, S.; Singh, G.P. Biotechnological approaches for host plant resistance to insect pests. *Front. Genet.* **2022**, *13*, 914029. [CrossRef]
10. Munaweera, T.I.K.; Jayawardana, N.U.; Rajaratnam, R.; Dissanayake, N. Modern plant biotechnology as a strategy in addressing climate change and attaining food security. *Agric. Food Secur.* **2022**, *11*, 26. [CrossRef]
11. Bigini, V.; Camerlengo, F.; Botticella, E.; Sestili, F.; Savatin, D.V. Biotechnological resources to increase disease-resistance by improving plant immunity: A sustainable approach to save cereal crop production. *Plants* **2021**, *10*, 1146. [CrossRef]
12. Kour, D.; Rana, K.L.; Yadav, A.N.; Yadav, N.; Kumar, M.; Kumar, V.; Vyas, P.; Dhaliwal, H.S.; Saxena, A.K. Microbial biofertilizers: Bioresources and eco-friendly technologies for agricultural and environmental sustainability. *Biocatal. Agric. Biotechnol.* **2020**, *23*, 101487. [CrossRef]
13. Thakur, N.; Kaur, S.; Tomar, P.; Thakur, S.; Yadav, A.N. Microbial biopesticides: Current status and advancement for sustainable agriculture and environment. In *New and Future Developments in Microbial Biotechnology and Bioengineering—Trends of Microbial Biotechnology for Sustainable Agriculture and Biomedicine Systems: Diversity and Functional Perspectives*; Rastegari, A.A., Yadav, A.N., Yadav, N., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 243–282. [CrossRef]
14. Bashir, M.A.; Wu, S.; Zhu, J.; Krosuri, A.; Khan, M.U.; Aka, R.J.N. Recent development of advanced processing technologies for biodiesel production: A critical review. *Fuel Process. Technol.* **2022**, *227*, 107120. [CrossRef]
15. Pryia, P.S.D.; Verma, Y.; Muhal, R.A.; Goswami, C.; Singh, T. Biofuels: An alternative to conventional fuel and energy source. *Mater. Today Proc.* **2022**, *48*, 1178–1184. [CrossRef]
16. Aron, N.S.; Khoo, K.S.; Chew, K.W.; Show, P.L.; Chen, W.H.; Nguyen, T.H. Sustainability of the four generations of biofuels—A review. *Int. J. Energy Res.* **2020**, *44*, 9266–9282. [CrossRef]
17. Koppu, V.; Poloju, D.; Puvvala, B.; Madineni, K.; Balaji, S.; Sheela, C.M.P.; Manchikanti, S.S.C.; Moon, S.M. Current perspectives and future prospects of mRNA vaccines against viral diseases: A brief review. *Int. J. Mol. Cell. Med.* **2022**, *11*, 260–272. [CrossRef] [PubMed]
18. Abinaya, R.V.; Viswanathan, P. Biotechnology-based therapeutics. In *Translational Biotechnology: A Journey from Laboratory to Clinics*; Hasija, Y., Ed.; Academic Press: London, UK, 2021; pp. 27–52. [CrossRef]
19. Haleem, A.; Javaid, M.; Singh, R.P.; Suman, R.; Rab, S. Biosensors applications in medical field: A brief review. *Sens. Int.* **2021**, *2*, 100100. [CrossRef]
20. Ravichandran, S.; Verma, G. Advanced biotechnology-based therapeutics. In *Translational Biotechnology: A Journey from Laboratory to Clinics*; Hasija, Y., Ed.; Academic Press: London, UK, 2021; pp. 53–77. [CrossRef]
21. Jackson, N.A.C.; Kester, K.E.; Casimiro, D.; Gurunathan, S.; DeRosa, F. The promise of mRNA vaccines: A biotech and industrial perspective. *NPJ Vaccines* **2020**, *5*, 11. [CrossRef]
22. Woźniak, E.; Tyczewska, A.; Twardowski, T. A shift towards biotechnology: Social opinion in the EU. *Trends Biotechnol.* **2021**, *39*, 214–218. [CrossRef] [PubMed]
23. Malyska, A.; Bolla, R.; Twardowski, T. The role of public opinion in shaping trajectories of agricultural biotechnology. *Trends Biotechnol.* **2016**, *34*, 530–534. [CrossRef]
24. Jimenez, J.; Gamble-George, J.; Danies, G.; Hamm, R.L.; Porras, A.M. Public engagement with biotechnology inside and outside the classroom: Community-focused approaches. *GEN Biotechnol.* **2022**, *1*, 346–354. [CrossRef]
25. McCluskey, J.J.; Kalaitzandonakes, N.; Swinnen, J. Media coverage, public perceptions, and consumer behavior: Insights from new food technologies. *Annu. Rev. Resour. Econ.* **2016**, *8*, 467–486. [CrossRef]
26. European Commission. Special Eurobarometer Wave EB91.3: Food Safety in the EU. 2019. Available online: https://www.efsa.europa.eu/sites/default/files/corporate_publications/files/Eurobarometer2019_Food-safety-in-the-EU_Full-report.pdf (accessed on 5 March 2024).
27. European Commission. Special Eurobarometer 505: Making Our Food Fit for the Future—Citizens' Expectations. 2020. Available online: https://op.europa.eu/en/publication-detail/-/publication/a37d1acf-7584-11eb-9ac9-01aa75ed71a1 (accessed on 5 March 2024).
28. European Commission. Special Eurobarometer 516: European Citizens' Knowledge and Attitudes towards Science and Technology. 2021. Available online: https://lbg.ac.at/wp-content/uploads/2021/11/ebs_516_science_and_technology_report_EN.pdf (accessed on 5 March 2024).
29. Woźniak-Gientka, E.; Tyczewska, A.; Tomasz Twardowski, T. Public opinion on biotechnology and genetic engineering in the European Union: Polish consumer study. *J. Biotechnol. Comput. Biol. Bionanotechnol.* **2022**, *103*, 185–201. [CrossRef] [PubMed]

30. Kooffreh, M.E.; Ikpeme, E.V.; Mgbado, T.I. Knowledge, perception, and interest regarding biotechnology among secondary school students in Calabar, Cross River State, Nigeria. *Biochem. Mol. Biol. Educ.* **2021**, *49*, 664–668. [CrossRef]
31. Klop, T.; Severiens, S. An exploration of attitudes towards modern biotechnology: A study among Dutch secondary school students. *Int. J. Sci. Educ.* **2007**, *29*, 663–679. [CrossRef]
32. Aggarwal, C. *Neural Networks and Deep Learning: A Textbook*; Springer: Cham, Switzerland, 2018.
33. Witten, I.H.; Frank, E.; Hall, M.A.; Pal, C.J. *Data Mining—Practical Machine Learning Tools and Techniques*, 4th ed.; Morgan Kaufmann: Cambridge, MA, USA, 2017.
34. Haykin, S. *Neural Networks and Learning Machines*, 3rd ed.; Prentice Hall: New York, NY, USA, 2009.
35. Li, C.; Zhang, C.; Yu, T.; Liu, X.; Yang, Y.; Hou, Q.; Yang, Z.; Ma, X.; Wang, L. Use of artificial neural network to evaluate cadmium contamination in farmland soils in a karst area with naturally high background values. *Environ. Pollut.* **2022**, *304*, 119234. [CrossRef] [PubMed]
36. Dawood, T.; Elwakil, E.; Hector, H.; Delgado, J. Toward urban sustainability and clean potable water: Prediction of water quality via artificial neural networks. *J. Clean. Prod.* **2021**, *291*, 125266. [CrossRef]
37. Goudarzi, G.; Hopke, P.; Yazdani, M. Forecasting $PM_{2.5}$ concentration using artificial neural network and its health effects in Ahvaz, Iran. *Chemosphere* **2021**, *283*, 131285. [CrossRef] [PubMed]
38. Fernandes, A.; Chaves, H.; Lima, R.; Neves, J.; Vicente, H. Draw on artificial neural networks to assess and predict water quality. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *612*, 012028. [CrossRef]
39. Alshayeji, M.; Ellethy, H.; Abed, S.; Gupta, R. Computer-aided detection of breast cancer on the Wisconsin dataset: An artificial neural networks approach. *Biomed. Signal Process. Control* **2022**, *71*, 103141. [CrossRef]
40. Li, A.; Qi, M.; Li, W.; Yu, X.; Yang, L.; Wang, J.; Li, D. Prediction and verification of the effect of psoriasis on coronary heart disease based on artificial neural network. *Heliyon* **2022**, *8*, e10677. [CrossRef]
41. Tumpa, P.; Kabir, M.A. An artificial neural network based detection and classification of melanoma skin cancer using hybrid texture features. *Sens. Int.* **2021**, *2*, 100128. [CrossRef]
42. Zhang, W.; Li, Z.; Li, G.; Zhuang, P.; Hou, G.; Zhang, Q.; Li, C. GACNet: Generate Adversarial-Driven Cross-Aware Network for Hyperspectral Wheat Variety Identification. *IEEE Trans. Geosci. Remote Sens.* **2024**, *62*, 5503314. [CrossRef]
43. Zhang, W.; Zhao, W.; Li, J.; Zhuang, P.; Sun, H.; Xu, Y.; Li, C. CVANet: Cascaded visual attention network for single image super-resolution. *Neural Netw.* **2024**, *170*, 622–634. [CrossRef] [PubMed]
44. Fernandes, A.; Vicente, H.; Figueiredo, M.; Neves, M.; Neves, J. An evaluative model to assess the organizational efficiency in training corporations. In *Future Data and Security Engineering*; Lecture Notes in Computer Science; Dang, T., Wagner, R., Küng, J., Thoai, N., Takizawa, M., Neuhold, E., Eds.; Springer: Cham, Switzerland, 2016; Volume 10018, pp. 415–428. [CrossRef]
45. Cohen, L.; Manion, L.; Morrison, K. *Research Methods in Education*, 8th ed.; Routledge: New York, NY, USA, 2017.
46. DeKetele, J.-M.; Roegiers, X. *Méthodologie du Recueil d'Informations: Fondements des Méthodes d'Observation, de Questionnaire, d'Interview et d'Études de Documents*, 5th ed.; DeBoeck Universite: Paris, France, 2016.
47. Patton, M.Q. *Qualitative Research and Evaluation Methods: Integrating Theory and Practice*, 4th ed.; SAGE Publications Inc: Thousand Oaks, CA, USA, 2015.
48. McMillan, J.; Schumacher, S. *Research in Education: Evidence-Based Inquiry*, 7th ed.; Prentice Hall: New York, NY, USA, 2009.
49. Bell, J. *Doing Your Research Project: A Guide for First-Time Researchers in Education, Health and Social Science*, 5th ed.; Open University Press: Maidenhead, UK, 2010.
50. Frank, E.; Hall, M.; Witten, I.H. The WEKA Workbench. Online Appendix for "Data Mining: Practical Machine Learning Tools and Techniques" Morgan Kaufmann, Fourth Edition. 2016. Available online: https://www.cs.waikato.ac.nz/ml/weka/Witten_et_al_2016_appendix.pdf (accessed on 5 March 2024).
51. Hall, M.; Frank, E.; Holmes, G.; Pfahringer, B.; Reutemann, P.; Witten, I.H. The WEKA data mining software: An update. *SIGKDD Explor.* **2009**, *11*, 10–18. [CrossRef]
52. Sasa, T.; Ahmad, W.A.; Bahtiti, N.H.; Abujaber, M.; Adeyleh, A.; Miri, O. Assessment level of environmental literacy among applied science private university (ASU) students. *WSEAS Trans. Environ. Dev.* **2022**, *18*, 1012–1020. [CrossRef]
53. European Parliament. Horizon Europe—Framework Programme for Research and Innovation (2021–2027). 2021. Available online: https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/628254/EPRS_BRI(2018)628254_EN.pdf (accessed on 5 March 2024).
54. Vilhena, J.; Vicente, H.; Martins, M.R.; Grañeda, J.M.; Caldeira, F.; Gusmão, R.; Neves, J.; Neves, J. A case-based reasoning view of thrombophilia risk. *J. Biomed. Inform.* **2016**, *62*, 265–275. [CrossRef] [PubMed]
55. Florkowski, C. Sensitivity, specificity, receiver-operating characteristic (ROC) curves and likelihood ratios: Communicating the performance of diagnostic tests. *Clin. Biochem. Rev.* **2008**, *29* (Suppl. S1), S83–S87.
56. Kewley, R.; Embrechts, M.; Breneman, C. Data strip mining for the virtual design of pharmaceuticals with neural networks. *IEEE Trans. Neural Netw.* **2000**, *11*, 668–679. [CrossRef]