Article

Evaluation of Portuguese Population's Perspectives on Chemical Innovations for Sustainable Development

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ABSTRACT

Background: Chemistry undeniably contributes numerous discoveries and innovations that impact various aspects of societal life and can decisively contribute to more sustainable development. The aim of this study is to evaluate the Portuguese population perspectives on chemical innovations that support sustainable development, focus particularly the topics food industry, health, water technologies, agriculture, energy, and environment.

Methods: The study involved the development and validation of a questionnaire and was conducted using a representative sample of the Portuguese population, with 452 participants of both genders whose ages ranged from 15 to 83 years.

Results: The outcomes from this research highlight that the role chemical innovations for sustainable development are positively perceived in in all topics included in the study, apart from energy. A relative high portion of participants lack knowledge regarding recent chemical developments. A global analysis of the results shows that these perspectives are similar for both genders, independent of residential area, but higher among individuals aged 26 to 65 years and those with higher academic qualifications. Additionally, a model based on Artificial Neural Networks was presented to predict the perspectives of the Portuguese population regarding the chemical innovations for sustainable development. The proposed model performs well, achieving accuracy rates higher than 90%.

Conclusions: The study introduces a new method to evaluate the Portuguese population's overall perspective on chemical innovations for sustainable development and its capacity for improvement. This evaluation is crucial for planning strategies to promote public awareness of the role of chemical innovations in this context.

KEYWORDS: public perspectives evaluation; chemical innovations; sustainable development; artificial neural networks

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ABBREVIATIONS

ANNs, artificial neural networks; mRNA, messenger RiboNucleic Acid; RI, relative importance; SDGs, sustainable development goals

INTRODUCTION

The intersection between chemical innovations and sustainable development has been widely discussed in scientific literature and global policies, particularly within the framework of the United Nations' Sustainable Development Goals (SDGs) [1]. Furthermore, the growing global population poses a significant threat to food security, a crucial factor for sustainable development in this century. Projections by the United Nations [2] suggest that the world's population could reach around 8.5 billion by 2030 and 9.7 billion by 2050, peaking at about 10.4 billion during the 2080s and remaining at that level until 2100. Chemical innovations play a crucial role in promoting sustainability by fostering more efficient agriculture practices [3–5], contributing to energy efficiency [6,7], reducing carbon emissions, managing resources, and minimizing waste [8,9]. Indeed, chemical innovations play a crucial role in advancing sustainable development across a variety of industrial and societal sectors (Figure 1). In the food industry, for instance, new formulations of ingredients and compostable packaging are transforming how we produce, store, and consume food, significantly reducing waste and environmental impact [10–12]. Furthermore, advancements in healthcare include more effective and sustainable medicines developed with lower toxicity and cleaner production methods [13,14]. Innovative water treatment technologies are providing safe and sustainable access to drinking water in previously underserved regions [15], while in agriculture, next-generation fertilizers and pesticides are enhancing agricultural productivity and reducing environmental impact through more efficient and less wasteful methods [3–5]. In the energy sector, chemistry is driving the development of more efficient energy storage batteries and materials for affordable solar cells, thereby advancing towards a cleaner and renewable energy future [6,7]. Regarding the environment, chemistry plays a crucial role in climate change mitigation and adaptation. From carbon capture and storage to waste recycling and the production of biodegradable materials, chemical innovations are helping to preserve fragile ecosystems and reduce pollution. In summary, chemical innovations not only drive the global economy through technological innovation but are also essential to ensuring a sustainable and prosperous future for future generations.

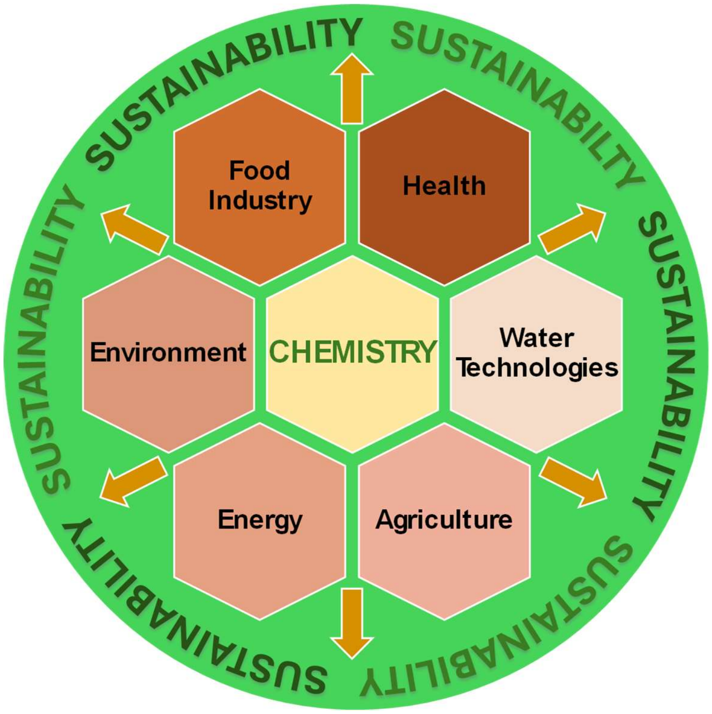


Figure 1. Interrelationship between Chemistry and sustainable development across industrial and societal sectors.

Motivation and Main Contribution

Portugal, like many other countries, faces significant environmental and economic challenges that can benefit from advances in chemical technology. From renewable energy to waste management and sustainable agriculture, chemical innovations have the potential to transform these sectors. However, the success of such innovations depends not only on technological advancements but also on public acceptance and support. As the world increasingly focuses on sustainability, understanding public perception of these innovations becomes crucial. This study aims to evaluate the perspectives of the Portuguese population regarding chemical innovations and their contributions to sustainable development. The main contribution of this paper is the evaluation of these perspectives across several topics using the questionnaire survey technique. This evaluation identifies issues where perspectives are low, although it generally finds higher perspectives on the role of chemical innovations. Moreover, the paper presents an artificial neural network-based model to evaluate the Portuguese population's perspectives on chemical innovations for sustainable development. In addition, this study introduces a new method to evaluate the participants' overall perspective and its capacity for improvement, which play a vital role in grouping individuals with similar attributes and enables customized intervention programs.

STATE OF ART

This section provides a comprehensive literature review on chemical innovations in the context of sustainable development and their integration into educational frameworks. It aims to establish a robust foundation for the analysis presented in the study and to connect the importance of chemical innovations with the education needed for their implementation. Additionally, the section explores the potential of artificial neural networks (ANNs) and their applications across numerous domains. The section is structured into three subsections, each addressing one of these key topics. The Role of Chemical Innovations in Promoting Sustainability and Well-being subsection examines the significant impact that chemical innovations can have on critical sectors such as food industry, healthcare, water technologies, agriculture, energy, and environment. It highlights the solutions these innovations offer to the pressing environmental and economic challenges faced by humanity. The Chemical Innovations in Education subsection emphasizes the role of both formal and informal education in ensuring that society is aware of and prepared to actively participate in the transition to a sustainable future. Finally, the Artificial Neural Networks Approach to Computing subsection introduces the use of ANNs as an advanced data analysis tool. This part of the review illustrates how these computational models can be applied across a wide range of scientific and practical applications.

Role of Chemical Innovations in Promoting Sustainability and Well-Being

Recent literature reveals a wide range of studies exploring chemical innovations across various sectors. Research focuses on seeking sustainable and economically viable solutions applicable to the food industry, healthcare, water technologies, agriculture, energy, and environment. The main goal is to minimize environmental impact, promote resource efficiency, and enhance human health, driving progress toward a more sustainable and healthier future. For example, Stancu et al. [10] investigated the enhancement of polyurethane conveyor belts for the food processing industry through plasma treatment to mitigate bacterial adhesion. The study aimed to modify polyurethane surfaces using corona discharge with air as the treatment medium, exploring parameters like treatment duration and distance between nozzle and substrate. Surface analysis techniques such as X-ray photoelectron spectroscopy revealed changes in surface chemistry, while scanning electron microscopy indicated minimal alterations in surface morphology. The hydrophilicity induced by plasma treatment significantly reduced bacterial adherence, particularly against *Staphylococcus aureus* and *Escherichia coli*, demonstrating up to 99.9% reduction in *E. coli* after 24 hours. The findings highlight plasma technology as a viable method for enhancing polyurethane conveyor belts with antibacterial properties to address contamination concerns in the food industry.

Microalgae are gaining attention in the food industry for their swift proliferation and abundance of proteins, carbohydrates, and colorful compounds. The extraction of these pigments from microalgal matter shows potential for their application as natural colorants and antioxidants. Anagnostopoulou et al. [8] investigated the utilization of microalgae for food applications, focusing on extracting pigments from *Chlorella vulgaris* cultivated in a blend of food industry wastewaters. The study aimed to address economic challenges in microalgae cultivation by optimizing biomass production and pigment extraction efficiency. The authors cultivated *C. vulgaris* in a photobioreactor with brewery wastewater, expired orange juice, and cheese whey, achieving a biomass concentration of 2.2 g/L after 5 days. Bioremediation of the wastewaters ranged from 23% to 77%. Ethanol was identified as the most effective solvent for pigment extraction, surpassing acetone, ethyl acetate, and hexane. The extracted compounds, including lutein and chlorophylls, were encapsulated in alginate beads with high efficiency, demonstrating potential for sustainable valorization of food industry byproducts. According to Anagnostopoulou el al. [8], these findings underscore the viability of microalgae-based solutions for transforming wastewater into high-value food additives, promoting circular bioeconomy principles and sustainable resource management.

Felipe et al. [12] examine the production of aroma compounds through biotechnology, highlighting its advantages over chemical synthesis and natural extraction. The authors demonstrate that producing aromas using microorganisms is not only considered natural but also supports sustainable development. This method aligns with the pillars of sustainability, i.e., environmental, economic, and social aspects, through renewable processes that operate under mild conditions, do not generate toxic waste, and use biodiversity rationally. Additionally, agricultural and industrial residues can be used, and some terpene biotransformation products have shown valuable biological activities, such as antioxidant or anticancer properties. The authors point out that the demand for biotechnological processes is increasing over the next few years, reflecting a trend towards natural flavors in the food industry. The authors suggest that replacing classical processes with bioprocesses is a promising opportunity to meet modern sustainability demands.

Gupta et al. [13] highlight the nutritional value and medicinal properties attributed to apocarotenoids like crocin, crocetin, safranal, and picrocrocin. Enhancing cultivation practices and using genetic engineering are common methods to boost saffron biomolecule production, but optimal purity and output require efficient extraction and identification methods. Understanding the biosynthesis, extraction, and identification of saffron biomolecules is crucial for their potential utilization in the pharmaceutical and food industries.

Nanomedicine presents promising opportunities to enhance patient outcomes and quality of life in cancer care. In their study, Souto et al. [14] explore the advancements in cancer treatment through nanomedicine, particularly in the development of cancer vaccines. The objective was to investigate how nanocarriers, ranging from liposomes to quantum dots, enhance drug delivery and targeting in cancer therapy. The methodology involved reviewing recent clinical studies on nanovaccines and their efficacy in stimulating immune responses against tumor cells. The authors highlighted nanomedicine's potential to revolutionize cancer treatment by improving drug stability, reducing side effects through targeted delivery, and facilitating combination therapies. The study emphasized the need for further research into the safety and long-term effects of nanomaterials, alongside standardized protocols to ensure regulatory approval and clinical adoption. The authors also investigate the primary regulatory challenges associated with nanomedicines and gene vaccines, focusing on their intricate complexities and navigational strategies. The objective is to delineate comprehensive regulatory frameworks that address the safety, efficacy, and ethical considerations unique to these advanced medical technologies. Souto et al. [14] underscore the critical balance required between intellectual property protection and public health promotion to optimize access and innovation in nanomedicine and genetic vaccine development, ultimately enhancing healthcare outcomes worldwide.

Ashraf et al. [4] highlight the rapid growth in global food and agricultural demand due to population increase and emphasize the transformative potential of nanotechnology in these industries. This technology offers innovative solutions for sustainable farming and enhanced food security, quality, and safety. The review covers recent advancements in nanomaterials and their applications throughout the food supply chain, from production to consumption, including improvements in bioavailability, nutritional content, food additives, and packaging. The agricultural sector benefits from nano-products like nano-fertilizers and nano-pesticides, promoting sustainable farming practices. However, concerns about toxicity and safety persist, necessitating updated regulatory measures. Collaboration among government, private research, and academia is crucial for leveraging nanotechnology to address food scarcity. Despite potential risks, nanotechnology's future innovations could revolutionize agro-food systems by enhancing food quality, safety, and traceability, provided that proper management and regulations are in place to ensure consumer acceptance and safety.

Irewale et al. [3] explore the advantages of delivering nutrients to plants at the nanoscale, discussing advancements, obstacles, and opportunities for integrating this emerging technology in African nations. They emphasize prospects and opportunities for global collaboration. While conventional fertilizers have boosted crop productivity, their sustainability is jeopardized by rapid soil degradation and environmental concerns stemming from chemical accumulation in various ecosystems.

Nanotechnology, involving the synthesis and manipulation of materials at the nanometer scale (1 to 100 nm), offers promising solutions to these agricultural sustainability challenges. Moreover, integrating naturally derived biogenic substances like chitosan, cellulose, lignin, and plant extracts into the production of nanofertilizers improves their compatibility with biological systems and enhances their ability to break down naturally. This approach mitigates the environmental hazards linked to chemical fertilizers. Theoretical and experimental research on nanofertilizers has underscored their significant potential for enhancing sustainable agricultural practices.

Kumar et al. [5] highlight nanomaterials and nanocomposites as sustainable alternatives in crop protection and production. They discuss controlled release systems and how nanocomposites like nanopesticides, nanoherbicides, and nanofertilizers interact with soil and the microbiome, noting their limitations in agrochemical applications. The authors emphasize that conventional agriculture relies heavily on synthetic chemicals with adverse effects on human health and the ecosystem. Thus, ensuring sustainable delivery of essential components to crops is crucial for maintaining soil health. Addressing the premature loss and degradation of growth-promoting substances in soil requires innovative techniques. Nanotechnology has the potential to revolutionize agrotechnology, offering advantages over conventional methods and supporting resilient cropping systems for global food security. Exploring plant-nanoparticle interactions further enhances crop yield, disease resistance, and nutrient uptake efficiency. Integrating nanomaterials into smart agrochemical practices and establishing effective frameworks are critical for addressing social acceptance, potential risks, and management challenges in the future.

Screpanti [16] explores the integral role of chemical advancements in bolstering the food production system, aiming to ensure the provision of safe and nutritious food for a growing population. The author highlights the often-overlooked connection between chemical innovations, the food production system, and the 2030 SDGs. Focusing on Switzerland the study emphasizes the critical role of soil in achieving numerous SDGs. It discusses how chemical research and technology can pave new paths for innovation through soil management. The urgency of increasing awareness and valuing responsibly produced, nutritious food is underscored, alongside the need for a systemic approach and collaborative efforts in responsible innovation.

Naeem et al. [15] present a review on the advancement of sustainable membrane technologies for chemical separation processes, targeting a gap in the existing literature by presenting various eco-friendly approaches. The objective is to analyze the use of biopolymers, green solvents, recycled materials, and natural additives in membrane production, emphasizing their potential to replace traditional, environmentally detrimental methods. The study explores the effectiveness of bio-based polymers and the transition to non-toxic solvents like deep eutectic solvents, highlighting the role of recycled plastics and natural additives in enhancing membrane performance and sustainability. The authors underscore the broad applicability of these sustainable membranes in sectors such as wastewater treatment, desalination, and gas separation, while also addressing challenges like mechanical strength, solubility, and cost-effectiveness. Finally, the authors highlight that the integration of green membranes into industrial processes can significantly promote resource efficiency, align with global environmental policies, and support the transition to a circular economy, although pointing out that to achieve large-scale implementation will require continued research, innovation, and collaboration among stakeholders.

Mishra et al. [6] explore photocatalytic hydrogen peroxide generation, emphasizing its ecological benefits and sustainability. The study focuses on the role of photocatalysis in efficiently and environmentally friendly producing hydrogen peroxide. The authors highlight several practical applications of photocatalytic hydrogen peroxide generation. They emphasize its pivotal role in advanced oxidation processes for water treatment, effectively oxidizing organic pollutants in both industrial and municipal wastewater. Additionally, it offers a sustainable pathway to produce high-purity intermediates and pharmaceutical compounds for pharmaceutical and fine chemical synthesis. In energy applications, photocatalytic hydrogen peroxide generation serves as a potential fuel for fuel cells, enabling the storage of solar energy in chemical form and enhancing renewable energy storage capabilities.

Aiming to assess the transition to sustainable energy storage solutions and their integration into a circular economy within the battery industry, Molaiyan et al. [7] examined the viability and sustainability of novel eco-friendly manufacturing techniques for battery components, emphasizing the crucial role of batteries in reducing greenhouse gas emissions amid rising demand for electric vehicles and portable electronics. The authors highlighted the potential of biomass-derived materials for anodes and bio-based separators, presenting them as promising alternatives to traditional materials like graphite, which has a high environmental and economic cost. By exploring the use of biomass-based carbon and non-toxic electrolytes, the study addressed key challenges in the development of greener lithium-ion batteries and other chemistries. The authors identified the need for a controlled and rational production of biomass-based anodes and the benefits of utilizing abundant elements for cathodes in new battery technologies such as sodium-ion, lithium-sulfur, and potassium-ion batteries. Furthermore, the study underscored the importance of green binders and recycling in minimizing the overall carbon footprint of battery production. This comprehensive assessment offers valuable insights into the transition towards sustainable energy storage solutions and the integration of a circular economy within the battery industry.

Lodhi and Maheria [9] discuss innovative catalytic strategies for converting biomass-derived acids into high-value esters using zeolite-based catalysts. By reviewing recent advancements, the authors highlight the potential of zeolites to produce esters that serve as versatile platform chemicals and biofuels. The commercial potential of biomass-derived esters is also emphasized, showcasing their use as alternatives to conventional fuels like biodiesel and as components in bio-lubricants and cosmetics due to their biodegradability and low toxicity. The authors underscore the contribution of zeolite-based catalysts to sustainable chemistry, promoting both environmental sustainability and economic viability in biomass conversion technologies.

Duarah et al. [17] conducted a study focused on analyzing global bioenergy policies to identify barriers hindering the sustainable development of biofuels as an alternative energy source. The study involved a detailed assessment of policy measures implemented by various national agencies, specifically examining feedstock utilization, blending targets, and government support schemes. The study also highlighted the role of commercial enterprises in the bioenergy sector to provide insights into current market dynamics. The authors also addressed some key issues related to global bioenergy generation, emphasizing the importance of policies that promote domestic feedstock production and advanced biofuel technologies. However, they noted significant challenges in achieving sustainability goals, particularly concerning agricultural land availability and suitable feedstock resources across different geographical regions. The authors advocated for enhanced regional collaboration to improve logistics, management practices, and project outcomes in the bioenergy sector.

A study conducted by Zhong and Kan [18] aimed to explore the interactions among ecological innovations, governmental policies, and natural resources in the context of China, focusing on their combined impact on environmental sustainability and the shift towards renewable energy. The authors used the dynamic autoregressive distributed lag methodology to analyze extensive time-series data from 1981 to 2021. Through this analysis, they investigated the relationships between sustainable energy practices, natural resource management, financial integration, eco-innovation, and environmental quality. The findings underscored the necessity for strategic policies and investments in technology and education to achieve long-term ecological objectives. Additionally, the study highlighted the significant role of preventing the financial exploitation of natural resources in safeguarding China’s environmental integrity.

Chemical Innovations in Education

The inclusion of Sustainable Chemistry Education and Green Chemistry in educational programs is of paramount importance for fostering a generation of scientists and professionals who are equipped to tackle environmental challenges. For example, Zuin et al. [19] highlight the importance of innovation in green and sustainable technologies, which requires highly qualified professionals with critical, interdisciplinary, and systems thinking mindsets. According to the authors, there are some difficulties in understanding the historical roots, differences, and similarities between green chemistry and sustainable chemistry. They argue that efforts are needed to integrate green chemistry education and sustainable chemistry education into chemistry and other educational curricula, including disseminating best practices and forming new partnerships at national, regional, and global levels. Education and capacity building in green chemistry and towards sustainable chemistry are crucial for transforming human resources, institutions, and infrastructure to generate effective knowledge for greener and more sustainable products and processes in a challenging world.

Chen et al. [20] describe the widespread application of green chemistry principles in industrial operations, government regulations, educational practices, and technological innovations worldwide. The authors address critical issues within the framework of green chemistry principles and the circular economy, proposing integrated strategies for their implementation in governance, industry, and education. Practices related to the application of green chemistry principles in the context of the circular economy were analyzed, particularly in countries such as Canada, China, Germany, Japan, South Korea, Sweden, Taiwan, the United Kingdom, and the United States. The analysis covered the implementation of green chemistry principles in governance, industry, and education sectors, suggesting five strategic priorities for integrating Green Chemistry principles into the circular economy: (i) establishing interdepartmental collaboration, (ii) promoting cleaner production and green products, (iii) providing an integrated chemical management system, (iv) implementing green chemistry education programs, and (v) developing a business model. The authors also discuss the incorporation of redesign-reduce-recover-recycle-reuse (5R) practices for waste recovery, the integration of the water-energy-food nexus to improve food security and resource sustainability, and the application of Green Chemistry principles in smart green industrial parks.

Loste et al. [21] investigate the potential of Green Chemistry to enhance sustainability by analyzing the perspectives of students enrolled in the Massive Open Online Course "Environmental Sustainability of Organizations in the Circular Economy". The study's primary aim is to evaluate the awareness and perception of Green Chemistry among individuals outside the traditional chemical sector. The authors conducted two surveys targeting the course participants to gather insights on how Green Chemistry is viewed as a tool for promoting sustainability. Findings indicate that Green Chemistry is relatively unknown compared to other environmental strategies. However, after completing the course, students recognized the value of Green Chemistry and its applicability in their respective fields. The study underscores the importance of education and regulatory support in increasing Green Chemistry awareness and suggests that this course can effectively disseminate Green Chemistry knowledge beyond academic and chemical industry circles, advocating for a multidisciplinary approach and stronger involvement of public authorities to foster broader adoption of Green Chemistry practices.

Barra and González [22] highlight that making current chemistry practices sustainable is a relatively new issue in developing countries, where educational curricula for chemists and engineers rarely emphasize environmental sustainability. This gap hinders the training of professionals who are aware of the environmental implications of synthesizing chemicals and their life cycles. For instance, at the 2016 Latin American Federation of Chemical Associations meeting, not a single paper addressed sustainable chemistry, underscoring the need to incorporate sustainability into educational programs. This issue also relates to the SDGs of sustainable production and consumption. Raising awareness about sustainable chemistry can focus on publicly significant problems like plastic pollution, which involves complex chemical compositions that complicate recycling and disposal. Addressing this requires robust education in chemical synthesis and green chemistry principles to minimize environmental impacts from the outset. Additionally, integrating consumer needs, where chemistry intersects with economics and social sciences, is crucial but often missing in current curricula.

Studying public perception of chemistry’s role is crucial for bridging the gap between scientific communities and the public, fostering trust and appreciation for chemistry’s contributions to society [23]. Several studies have addressed these topics, seeking to contribute to the understanding of how the role of chemistry is perceived by the public. Guerris et al. [24] investigated the public perception of chemistry by analyzing messages on Twitter, a global online social network, which contained the terms “chemistry”, “chemical”, or “chem” in 256,833 tweets from January 1, 2015, to June 30, 2015. They refined the dataset to 50,725 English-language tweets and grouped them using spherical k-means clustering. A panel of 18 chemistry experts classified the resulting clusters into six distinct topics. The study found that predominant topics included the learning environment, encompassing activities in chemistry courses, and human activity, which referred to news and events in the chemical industry. Scientific knowledge, focusing on the dissemination of chemistry-related information, was present in a small percentage of tweets. Analysis based on sentiment values categorized tweets into relevant topics, revealing a predominance of positive perceptions. Examination of unigram and bigram word clouds identified significant usage of chemophobia-related terms within the human activity topic, both positively and negatively categorized. The study also highlighted specific aspects of chemistry courses negatively perceived within the learning environment topic.

Dobbelaar and Richter [25] underscore the pivotal role young chemists will play in reshaping the chemical sector in the years ahead. These emerging professionals will tackle substantial challenges and innovate solutions crucial for a sustainable future. Therefore, understanding their expectations, educational needs, and opportunities for promoting sustainable development across diverse domains is imperative. Thus, the authors conducted a global study inviting young chemists to anonymously share their views on the role and responsibilities of the chemical sector. The findings express optimism that the sector will embrace its leadership role in advancing sustainable development, thereby addressing global warming through collaboration with authorities, sectors, and civil society. Additionally, the authors concluded that young chemists offer specific ideas for effective measures and are eager to contribute to shaping a sustainable future.

Ferreira et al. [26] aim to enhance the understanding of sustainable behavior by investigating the perceptions, knowledge, and opinions of Management and Marketing students at a public Portuguese higher education institution. The study involved an exploratory and longitudinal phase conducted between 2020 and 2022. The findings, derived from both quantitative and qualitative methods, initially indicate low levels of knowledge regarding sustainability, SDGs, and related concepts. Through qualitative analysis, the study highlights terms associated with sustainability and perceived sustainable practices. It also examines perceived changes since the COVID-19 pandemic and identifies potential threats and opportunities in the coming years. The primary conclusion underscores the urgent need for comprehensive education on sustainability and related concepts beyond mere recycling practices. The authors further argue that relying solely on sustainability as a marketing tool is insufficient for creating a sustainable future. They advocate for higher education institutions to develop a new, collective, and sustainable vision for sustainability education.

Waard et al. [27] conducted an exploratory study to explore students' arguments regarding the life cycle of bioplastics and fossil-based plastics. This qualitative research aimed to analyze these arguments using Toulmin's model of argumentation, which includes claim, data, warrant and backing, and qualifier and rebuttals. The study involved 27 students aged 16–17, from grades 10–11, attending various Dutch secondary schools across different regions of the Netherlands. The group comprised 12 girls and 15 boys. Students were introduced to the topics of plastic production, use, and recycling through activities such as watching videos, responding to inquiries, reading articles, and participating in interviews and group discussions. They were then prompted to debate the sustainability of bioplastics versus fossil-based plastics. The findings revealed that students frequently emphasized arguments related to preventing pollution, designing for recycling, and strategies for degradation. However, topics such as waste reduction, the origin of energy and materials, energy efficiency, and costs were rarely discussed or absent. Overall, the students' arguments covered all of Toulmin's categories, with an increase in qualifiers and rebuttals, indicating a deeper understanding of the issue's complexity. This study underscores that students can provide valuable scientific insights when addressing pertinent sustainability issues, and their perspectives benefit from integrating societal considerations. The authors also discuss the implications for designing educational interventions aimed at engaging students in life cycle analysis of plastics.

Artificial Neural Networks Approach to Computing

ANNs take inspiration from biological learning processes, akin to those observed in the human brain. The overarching goal is to emulate the intelligence of the human brain through highly interconnected processing elements called neurons. A key advantage of ANNs is their ability to model complex problems proficiently using only examples, without requiring explicit knowledge of the function or process being modeled [28,29]. The simplest form of ANN is the multilayer perceptron, consisting of one input layer and one output layer, and it may contain one or more hidden layers, with no feedback loops. In contrast, recurrent neural networks may include loops or feedback mechanisms. In a multilayer perceptron, information flows forward through interconnected nodes, with each layer receiving input from the preceding one. The sigmoid function stands out as the most prevalent activation function, altering input features in a nonlinear manner to produce outputs [28,29].

Backpropagation stands as the prevalent training algorithm for multilayer perceptrons [28,29]. It comprises two phases, i.e., the forward and backward propagation. During forward propagation, data flows through interconnected hidden layers, utilizing random weights, to produce output. Subsequently, in backward propagation, the computed error, derived from the difference between observed and desired output values, is transmitted backward through the network, enabling weight adjustments. Two parameters, i.e., the momentum coefficient and the learning rate, govern the backpropagation algorithm, each confined to the interval between 0 and 1. The momentum coefficient guides the direction of weight adjustments, fostering stability, while the learning rate governs the magnitude of these adjustments with each iteration [30].

ANNs are versatile modeling techniques since they can learn and model complex patterns in data, regardless of the domain. They are flexible in handling different types of data (e.g., images, text, or numbers) and can be adapted to solve various problems like classification, prediction, or pattern recognition by adjusting their structure and training process [28,29]. To apply ANNs in different contexts, the data and problem must be from the same domain or share relevant underlying patterns. A neural network trained on one problem, cannot be used directly in a completely different domain, since the network learns patterns specific to the data it was trained on. Each application requires training with relevant data to capture the specific patterns and relationships of that domain, ensuring accurate and useful predictions. This adaptability makes them useful across a wide range of scientific and practical applications. They are employed in finance for stock market prediction [31,32], disease detection and diagnosis [33–35], production optimization [36,37], environmental monitoring and analysis [38–41], and various other fields. ANNs demonstrate remarkable efficacy in processing data characterized by vagueness, uncertainty, incompleteness, and imperfection [29]. Advanced ANN methodologies such as deep learning, regarded as a contemporary and refined view of traditional ANNs alongside hybrid models incorporating diverse computational intelligence techniques exhibit robust adaptability to such datasets, typically with minimal performance variance [42,43].

MATERIALS AND METHODS

This section provides an overview of the study's layout (Figure 2), detailing the experimental setup, data collection strategies, instruments applied, sample profile, and methods of analysis, along with the ethical protocols followed.

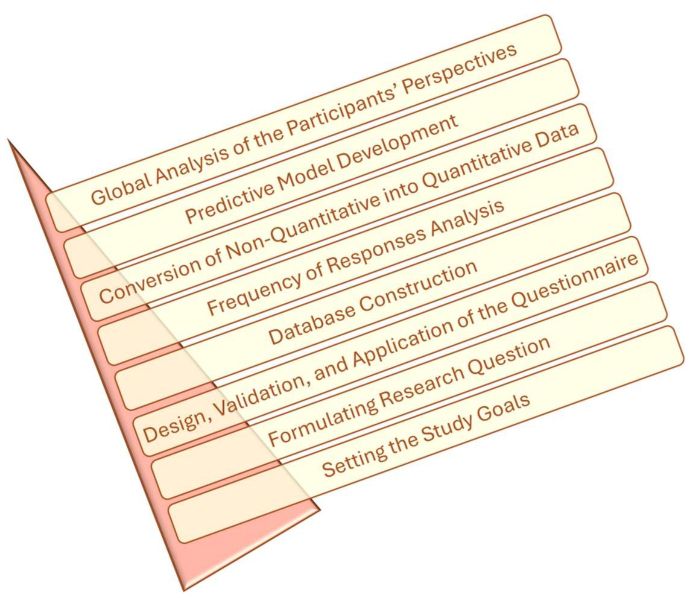


Figure 2. Overview of the study's layout, emphasizing its key steps.

Study Design

The primary aim of this study is to evaluate how the Portuguese population perceives chemical innovations that support sustainable development. Hence, the focus centers on examining the following research question:

What is the Portuguese population's perspectives on chemical innovations for sustainable development?

To implement the methodology proposed by Fernandes et al. [44] for converting qualitative data into quantitative data, a questionnaire was developed that included questions related to six topics (food industry, health, water technologies, agriculture, energy, and environment). Additionally, a question was included to evaluate the overall perspective of each participant regarding the importance of chemical innovations in promoting sustainable development. Details regarding these points are provided in the following subsections.

Data Collection

After a comprehensive review of available methodologies, the questionnaire survey was selected for its straightforward application and flexibility. Furthermore, its structured design aids in the efficient conversion of qualitative data into quantitative form [45–48].

Organized into three sections, the questionnaire developed for this study initiates by collecting sociodemographic details, covering categories like gender, age group, academic qualifications, and residential area. The second section presents a series of questions (Table 1) addressing the study's topics (i.e., food industry, health, water technologies, agriculture, energy, and environment), inviting participants to share their perspectives. Finally, the questionnaire concludes with an inquiry intended to evaluate the overall perspective of each participant regarding the importance of chemical innovations in promoting sustainable development (Figure 3).

Contrasting to the descriptive approach used in the former section, the second section employs a six-point Likert scale (highly relevant, relevant, moderately relevant, slightly relevant, not relevant, and I don't know), whereas the third section uses a three-point Likert scale (high, moderate, and low).

Based on Bell's suggestions [49], a panel of six experts conducted a critical evaluation of the questionnaire, leading to modifications that were included in a revised version. These experts were chosen based on their specialized expertise and professional background in sustainable chemistry, chemical engineering, environmental science, research methodology, healthcare professional, and education and scientific communication. The panel members possessed extensive expertise in green chemistry, development of sustainable materials, innovative chemical technologies, environmental impact assessment and sustainability, questionnaire development and validation, public dissemination of science and sustainability topics, and clinical applications in patient care.

A separate group of participants, distinct from the main sample, was used to evaluate the revised questionnaire's clarity and validity. Cronbach's alpha was used to assess the reliability of the instrument, resulting in a score of 0.86 for the questions in the second and third parts of the questionnaire. A printed copy of the revised questionnaire was personally distributed to each participant of the main sample. Data was collected from September 2023 to March 2024 and all 520 questionnaires were returned and all 520 questionnaires were returned, culminating in a 100% return rate.

Table 1. Topics and their corresponding questions in second section of the questionnaire.

Topic	Question	How do you classify the role of the chemical innovations in developing
Food Industry	Q1	• new food additives to improve the safety, flavor, texture, and shelf life of foods?
	Q2	• bioactive ingredients (e.g., antioxidants and dietary fibers) to increase the nutritional value of foods?
	Q3	• healthier substitutes for traditional ingredients, such as fats and sugars?
	Q4	• smart packaging that interacts with food, prolonging its shelf life and indicating its freshness?
	Q5	• more sensitive and faster analytical methods to detect contaminants and ensure food safety?
Health	Q6	• personalized therapies, tailored to the specific genetic and molecular characteristics of each patient?
	Q7	• nanoparticles that deliver drugs directly to diseased cells, minimizing side effects and increasing treatment efficacy?
	Q8	• biocompatible polymers for manufacturing medical devices like stents and prostheses?
	Q9	• mRNA vaccines that instruct the body's cells to produce proteins that trigger an immune response?
	Q10	• more eco-friendly and sustainable synthesis methods for drug production?
Water Technologies	Q11	• catalysts that utilize solar radiation to degrade organic contaminants in water through photocatalytic processes?
	Q12	• technologies like reverse osmosis that utilize semipermeable membranes to remove salt and other impurities from seawater, making it potable?
	Q13	• membranes that allow for the selective removal of contaminants, including viruses, bacteria, and large organic molecules, through nanofiltration and ultrafiltration?
	Q14	• chemical compounds and chelating resins to remove heavy metals such as lead, mercury, and cadmium from water?
	Q15	• chemical sensors for real-time monitoring of water quality, detecting contaminants such as nitrates, phosphates, and heavy metals?
Agriculture	Q16	• superabsorbent materials that aid in water and nutrient retention, ensuring their availability to plants?
	Q17	• genetic modifications in crops to improve traits such as pest resistance, drought tolerance, herbicide tolerance, nutritional quality, and yield?
	Q18	• controlled-release fertilizers, providing nutrients to plants over time in a more efficient and sustainable manner?
	Q19	• chemical products that protect seeds during storage from pests and diseases, ensuring healthy germination when planted?
	Q20	• analytical methods for soil and foliar analysis, allowing monitoring of nutrient levels and adjustment of agricultural practices to ensure adequate plant nutrition?

Table 1. *Cont.*

Topic	Question	How do you classify the role of the chemical innovations in developing
Energy	Q21	• solid electrolytes used in the production of batteries for electric vehicles, portable electronics, and renewable energy storage?
	Q22	• photocatalytic materials for obtaining hydrogen intended to produce fuel cells?
	Q23	• perovskite-based materials as the photovoltaic layer in solar cells used in solar panels and portable electronics?
	Q24	• graphene supercapacitors used in electric vehicles, renewable energy storage, and portable electronics?
	Q25	• chemical processes to capture carbon dioxide from the atmosphere or industrial emissions to produce synthetic fuels, plastics, or other chemical products?
Environment	Q26	• bioplastics produced from renewable raw materials or organic waste for manufacturing packaging and other products?
	Q27	• materials with hydrophobic and oleophilic properties to separate water and oil mixtures in industrial/domestic effluents and oil spills?
	Q28	• chemical methods for soil or water decontamination using microorganisms and plants to degrade or accumulate chemical contaminants?
	Q29	• porous materials such as zeolites, activated carbon, and metal-organic frameworks for water treatment or purification of industrial effluents?
	Q30	• nanomaterials, such as graphene oxide, to capture and decompose atmospheric pollutants to improve air quality?

PART III

On a scale from High to Low, how do you classify your overall perspective regarding the importance of chemical innovations in promoting sustainable development.

Overall Perspective

High (Individuals in this category strongly believe in the importance of chemical innovations for sustainable development. They are highly optimistic about the potential benefits and actively support the adoption and investment in these technologies.) ☐

Moderate (Individuals in this category recognize the potential of chemical innovations but also see possible risks and uncertainties. They support these innovations with some reservations, advocating for a balanced approach that includes strict regulations and thorough evaluation.) ☐

Low (Individuals in this category are skeptical or critical of chemical innovations in the context of sustainable development. They have significant concerns about environmental impacts, safety, and long-term consequences, often favoring traditional methods or alternatives.) ☐

Figure 3. Overview of the third section of the questionnaire.

Participants

From the original distribution of 520 questionnaires, 68 (13.1%) were disqualified from the study due to incomplete responses in the second section. This resulted in a study cohort of 452 participants, whose ages ranged from 15 to 83 years, with a mean age of 40.6 ± 18.7 years.

Participant demographics including gender, age group, academic qualification, and residential area are summarized in Table 2.

Table 2. Distribution of participants by gender, age group, academic qualification, and residential area.

Socio-demographic characteristics	**Categories**	**Occurrence**	
		n	**%**
Gender	Female	246	54.4
	Male	206	45.6
Age Groups	≤25 years old	121	26.8
	26 to 45 years old	148	32.7
	46 to 65 years old	140	31.0
	>65 years old	43	9.5
Academic Qualifications	Basic Education	181	40.0
	Secondary Education	192	42.5
	High Education	59	13.1
	Post-Graduate Education	20	4.4
Residential Area	Northern	155	34.3
	Central	150	33.2
	Southern	147	32.5

Qualitative Data Processing

In the second section, qualitative data was collected and rated on a six-point Likert scale. Following the procedure described by Fernandes et al. [44], this qualitative data was transformed into numerical values by representing the responses to each topic within a unitary circle with a radius of $1/\sqrt{\pi}$. The unit circle is partitioned into r sections, where each section corresponds to a question in the topic being studied. The response options are plotted along the axis, according to the guidelines described in subsection "Conversion of qualitative data into quantitative data".

Artificial Neural Networks

The models based on ANNs were generated using the WEKA software, maintaining the default parameter settings [50,51]. During the learning phase, both the backpropagation algorithm and the logistic activation function were used [28,29]. A total of twenty repetitions were conducted for each test to guarantee the statistical significance of the results. Each simulation involved the random division of data into two separate groups, the training set, comprising 67% of the total data, and the test set, which included the remaining data. The training set was used in model development stage, while the testing set was used to assess its ability to generalize.

Ethical Aspects

Conducted in compliance with current legal standards, the study ensured that all participants were aware of the research aims and willingly agreed to participate by filling out the questionnaire.

RESULTS

This section presents the results of a study evaluating the perspectives of the Portuguese population on chemical innovations for sustainable development, followed by a thorough analysis of responses from a cohort of 452 participants.

Frequency of Responses

Second section of the questionnaire

The percentage distribution of responses to questions Q1 through Q5 (refer to Table 1) concerning the food industry topic is presented in Figure 4. Its analysis reveals a predominance of the most positive responses (highly relevant and relevant) across all questions of this topic, with percentages ranging from 59.7% (in Q4, concerning smart packaging) to 86.5% (in Q5, concerning analytical methods to detect contaminants). Regarding the moderately relevant option, the percentage of responses varied between 9.3% (in Q5) and 14.6% (in Q3, concerning healthier substitutes for fats and sugars). In terms of the negative options (slightly relevant and not relevant), the responses frequencies are low across all questions, ranging from 3.1% (in Q5) to 11.1% (in Q1, concerning new food additives). Finally, it should be noted that the option I don't know was selected by less than 5% of participants in all questions. The only exception was question Q4, where this percentage was 23.9%. Thus, the predominance of highly relevant, relevant, and moderately relevant responses in every question on this topic suggests that participants positively evaluate the role of chemical innovations in the food industry.

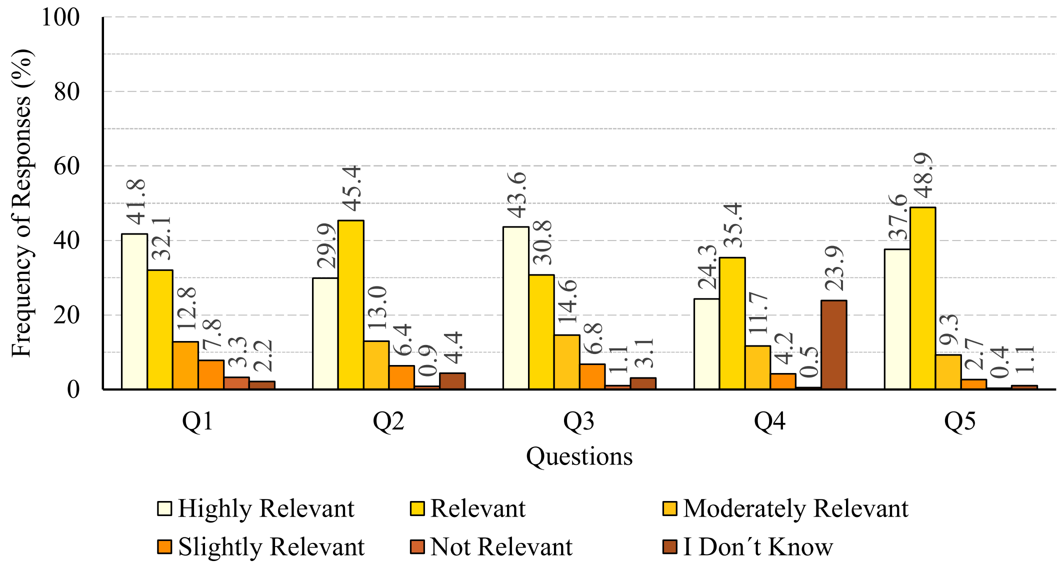


Figure 4. Percentage of responses for each question concerning the topic food industry (Q1 to Q5).

The percentage distribution of responses to questions Q6 through Q10 (refer to Table 1) concerning the health topic is presented in Figure 5. Its analysis reveals a predominance of the most positive responses (highly relevant and relevant) across all questions of this topic, with percentages ranging from 35.6% (in Q7, concerning nanoparticles for targeted delivery of drugs) to 82.5% (in Q10, concerning more eco-friendly/sustainable methods for drug production). Regarding the moderately relevant option, the percentage of responses varied between 12.4% (in Q10) and 28.3% (in Q7). Additionally, it is worth noting that in question Q7, this option was even the most chosen. In terms of the negative options (slightly relevant and not relevant), the responses frequencies are low across all questions, ranging from 4.2% (in Q10) to 11.8% (in Q8, concerning biocompatible polymers). The only exception was question Q9 (concerning mRNA vaccines), where this percentage was 24.8%. Finally, it should be noted that the option I don't know was selected by less than 1% of participants in questions Q9 and Q10. Conversely, in questions Q6 (concerning personalized therapies), Q7, and Q8 this option was selected by 12.4%, 24.8%, and 18.1% of participants, respectively. These results suggest a lack of knowledge or a less positive evaluation of the role of chemical innovations in health topics, particularly in areas such as personalized therapy development, nanoparticles for targeted drug delivery, biocompatible polymers for medical device manufacturing, and mRNA vaccine development.

The percentage distribution of responses to questions Q11 through Q15 (refer to Table 1) concerning the water technologies topic is presented in Figure 6. Its analysis reveals that the frequency of response of the options highly relevant, relevant, and moderately relevant ranges from 8.2% to 30.3%, 18.6% to 49.8%, and 12.4% to 33.0%, respectively. The analysis of Figure 6 also reveals that the predominant response to questions Q14 (concerning remotion of heavy metals) and Q15 (concerning sensors for real-time monitoring) was relevant, selected by 47.8% and 49.8% of participants, respectively, whereas in questions Q11 (concerning photocatalysts to degrade pollutants), Q12 (concerning drink water production by osmose), and Q13 (concerning water purification by nanofiltration), the most common response was moderately relevant, chosen by 30.1%, 33.0%, and 25.4% of participants, respectively. It is worth noting that in this topic, the highly relevant option does not appear as the most chosen, having obtained lower response frequencies than those recorded in the moderately relevant option in all questions apart from question Q15, where it was chosen by 30.3% of participants. In terms of the negative options (slightly relevant and not relevant), the responses frequencies are low across all questions, ranging from 4.9% (in Q15) to 13.3% (in Q11). The only exception was question Q13, where this percentage was 24.1%. Finally, it should be noted that the option I don't know was selected by less than 5% of participants in questions Q14 and Q15. Conversely, in questions Q11, Q12, and Q13 this option was selected by 24.3%, 12.6%, and 22.6% of participants, respectively. These results suggest a lack of knowledge or a less positive evaluation of the role of chemical innovations in water technologies, particularly in areas such as using photocatalysts to degrade pollutants, producing drinking water from seawater by osmosis, and purifying water through nanofiltration/ultrafiltration.

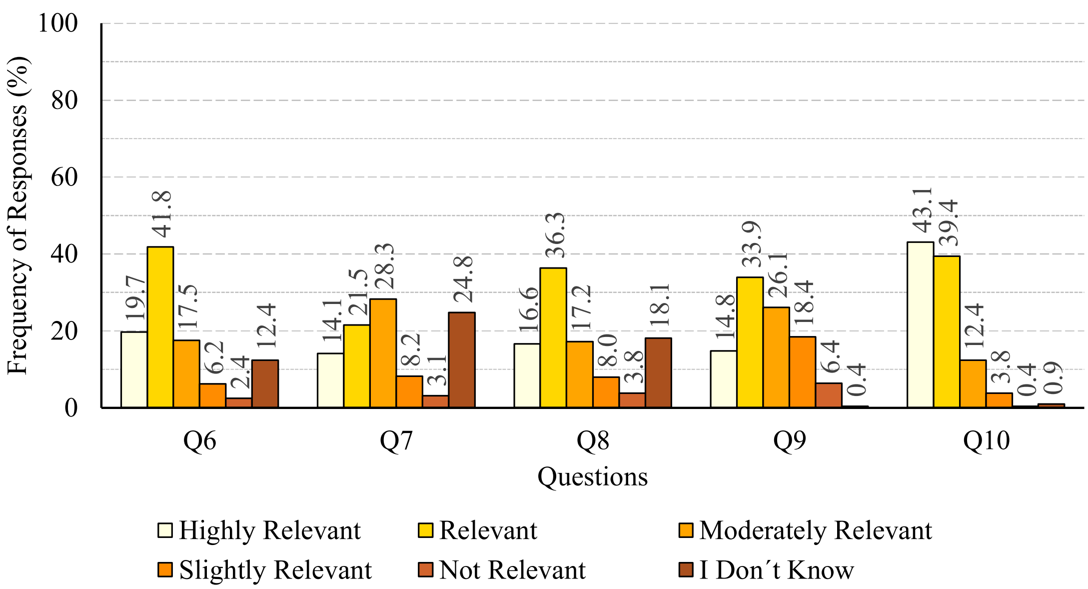


Figure 5. Percentage of responses for each question concerning the topic health (Q6 to Q10).

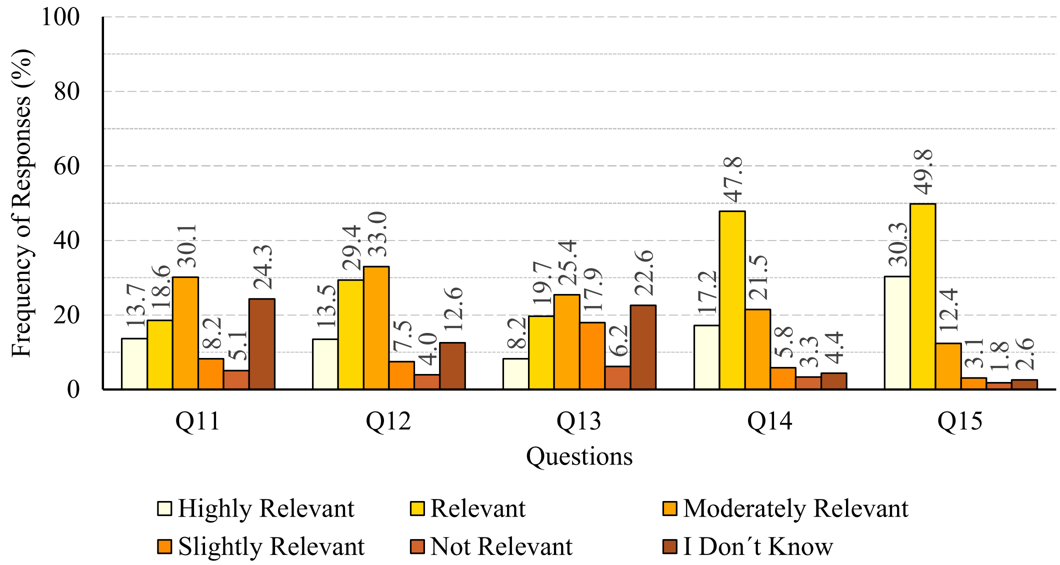


Figure 6. Percentage of responses for each question concerning the topic water technologies (Q11 to 15).

The percentage distribution of responses to questions Q16 through Q20 (refer to Table 1) concerning the agriculture topic is presented in Figure 7. Its analysis reveals that the frequency of response of the options highly relevant, relevant, and moderately relevant ranges from 12.4% to 41.8%, 19.9% to 37.2%, and 9.9% to 35.6%, respectively. The analysis of Figure 7 also reveals that the predominant response to questions Q19 (concerning chemical products to protect seeds) and Q20 (concerning analytical methods for soil and foliar analysis) was highly relevant, selected by 38.9% and 41.8% of participants, respectively, whereas in questions Q16 (concerning superabsorbent for water and nutrient retention), Q17 (concerning genetic modifications in crops), and Q18 (concerning controlled-release fertilizers), the most common response was moderately relevant, chosen by 33.2%, 35.6%, and 32.3% of participants, respectively. It is worth noting that in this topic, the *relevant* option does not appear as the most chosen, having obtained lower response frequencies than those recorded in the moderately relevant option in all questions apart from questions Q19 and Q20, where it was chosen by 35.2% and 37.2% of participants, respectively. In terms of the negative options (slightly relevant and not relevant), the responses frequencies are low across the majority of questions, ranging from 7.8% (in Q20) to 13.5% (in Q16). The exceptions are the questions Q17 and Q18, where the percentages were 22.6% and 18.6%, respectively. Finally, it should be noted that the option I don't know was selected by less than 5% of participants in questions Q17, Q19, and Q20. Conversely, in questions Q16 and Q18 this option was selected by 8.2% and 16.8% of participants, respectively. These results suggest a lack of knowledge or a less positive evaluation of the role of chemical innovations in agriculture, particularly in areas such as superabsorbent for water and nutrient retention, genetic modifications in crops, and controlled-release fertilizers.

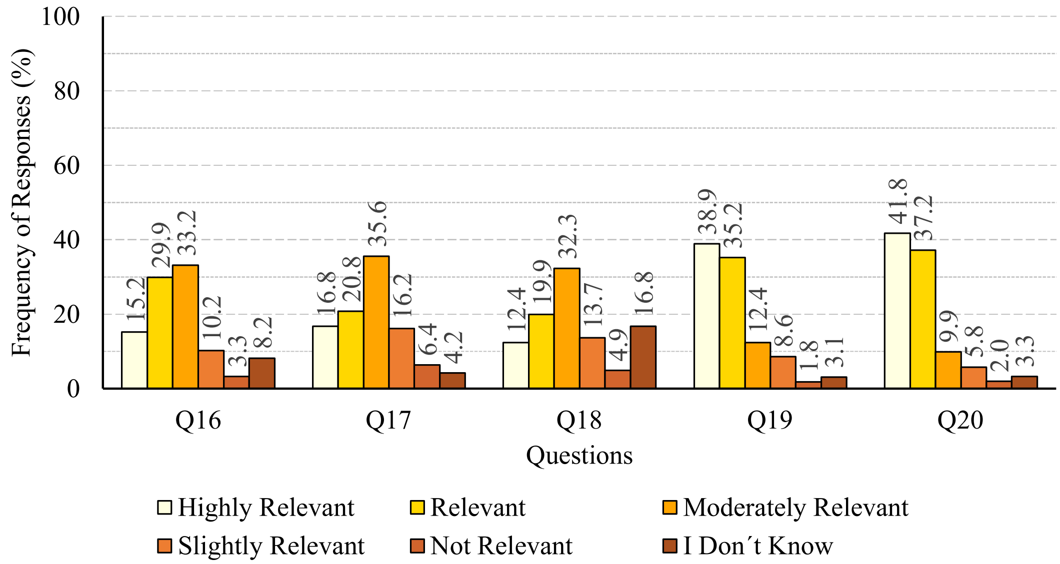


Figure 7. Percentage of responses for each question concerning the topic agriculture (Q16 to Q20).

The percentage distribution of responses to questions Q21 through Q25 (refer to Table 1) concerning the energy topic is presented in Figure 8. Its analysis reveals that the frequency of response of the options highly relevant, relevant, and moderately relevant ranges from 8.2% to 40.3%, 18.4% to 35.8%, and 11.1% to 34.5%, respectively. The analysis of Figure 8 also reveals that the predominant response to question Q25 (concerning chemical products to capture carbon dioxide) was highly relevant, selected by 40.3% of participants. For questions Q22 (concerning photocatalytic materials to produce fuel cells) and Q23 (concerning perovskite-based materials to produce solar cells), the most common response was moderately relevant, chosen by 34.5% and 24.3% of participants, respectively. It is worth noting that for this topic, the predominant response to question Q24 (concerning graphene supercapacitors) was slightly relevant, selected by 25.2% of participants, while for question Q21 (concerning solid electrolytes for batteries), the predominant response was I don't know, selected by 32.5% of participants. In terms of the negative options (slightly relevant and not relevant), the response frequency was low for question Q25, selected by 5.5% of participants, whereas for the remaining questions, these frequencies varied between 14.8% (in Q21) and 33.4% (in Q24). Finally, it should be noted that the option I don't know was selected by less than 7.5% of participants in questions Q22 and Q25. Conversely, for questions Q21, Q23 and Q24, this option was chosen by 32.5%, 23.5%, and 24.6% of participants, respectively. These results suggest a lack of knowledge or a less positive evaluation of the role of chemical innovations in energy, particularly in areas such as solid electrolytes for batteries, photocatalytic materials for fuel cells, perovskite-based materials for solar cells, and graphene supercapacitors.

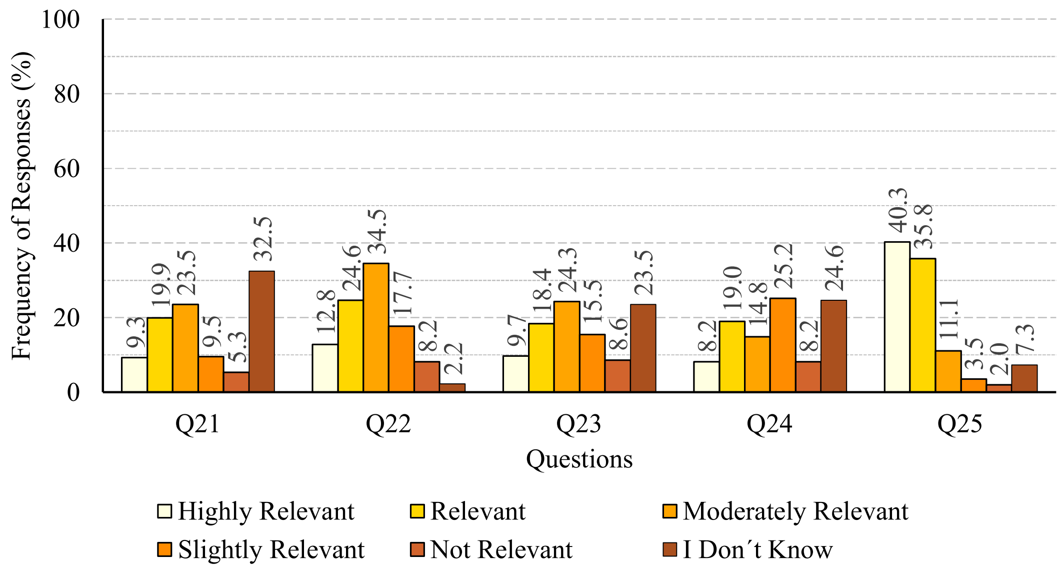


Figure 8. Percentage of responses for each question concerning the topic energy (Q21 to Q25).

The percentage distribution of responses to questions Q26 through Q30 (refer to Table 1) concerning the environment topic is presented in Figure 9. Its analysis reveals a predominance of the most positive responses (highly relevant and relevant) across all questions of this topic, with percentages ranging from 61.3% (in Q27, concerning materials with hydrophobic and oleophilic properties) to 85.0% (in Q28, concerning chemical methods for soil or water decontamination). Regarding the moderately relevant option, the percentage of responses varied between 6.2% (in Q30, concerning nanomaterials to remove atmospheric pollutants) and 9.5% (in Q29, concerning porous materials to treat industrial effluents). In terms of the negative options (slightly relevant and not relevant), the responses frequencies are low across all questions, ranging from 2.9% (in Q26, concerning bioplastics production) to 6.5% (in Q29). Finally, it should be noted that the option I don't know was selected by less than 6% of participants in questions Q26 and Q28. Conversely, in questions Q27, Q29, and Q30 this option was selected by 24.8%, 13.7%, and 14.8% of participants, respectively. These results suggest a lack of knowledge about the role of chemical innovations in environmental topics, particularly in areas such as materials with hydrophobic/oleophilic properties, porous materials for treating water and industrial effluents, and nanomaterials for capturing and decomposing atmospheric pollutants.

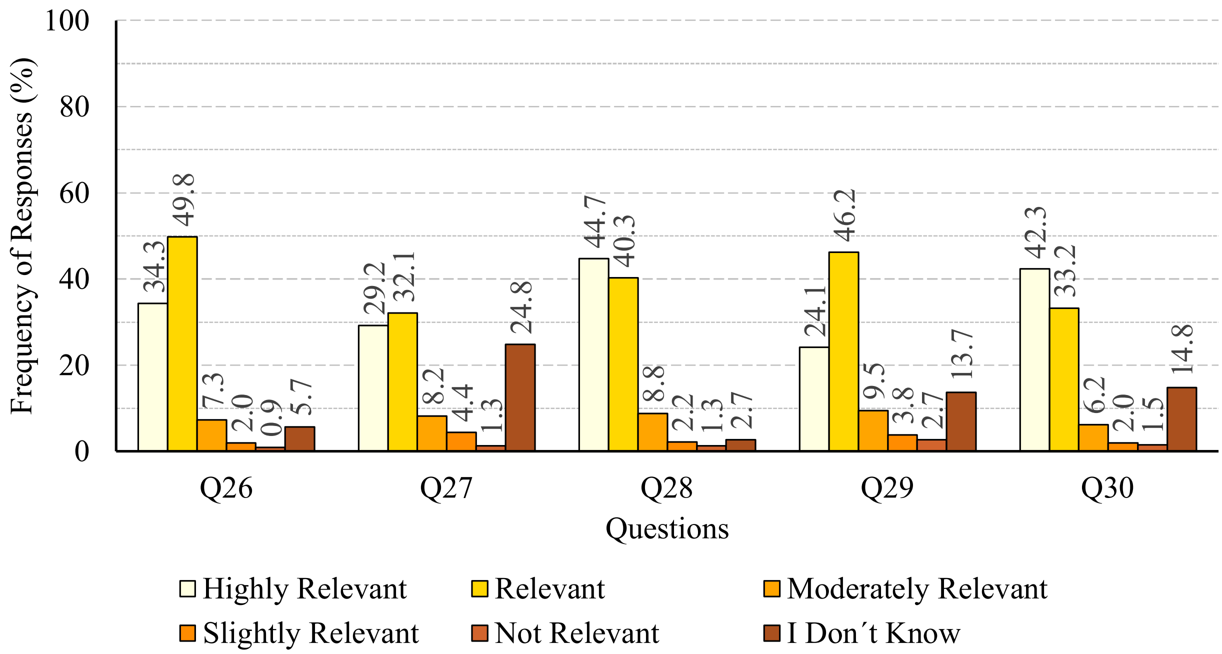


Figure 9. Percentage of responses for each question concerning the topic environment (Q26 to Q30).

A global analysis of these results highlights that the role of chemical innovations for sustainable development is positively perceived in all topics included in the study, apart from energy. Nevertheless, the results also indicate that a relative high portion of participants lack knowledge regarding recent chemical developments, such as smart packaging, nanoparticles for targeted delivery of drugs, biocompatible polymers, photocatalysts to degrade pollutants, water purification by nanofiltration, controlled-release fertilizers, solid electrolytes for batteries, perovskite-based materials to produce solar cells, graphene supercapacitors, and materials with hydrophobic/oleophilic properties. Regarding the energy topic, participants' perspectives are not as positive compared to those of the other topics, particularly concerning perovskite-based materials to produce solar cells and graphene supercapacitors. These findings are consistent with several other studies [20–27], which emphasize a gap in knowledge about some issues including green chemistry and sustainable chemistry.

Third section of the questionnaire

In the third section of the questionnaire, each of the participants was asked to classify their overall perspective regarding the importance of chemical innovations in promoting sustainable development. According to the results obtained, 146 participants (32.3%) rated their overall perspective as low, 173 (38.3%) as moderate, and 133 (29.4%) as high (Figure 10). Its analysis reveals that, when considering the entire sample, there are slight differences in how participants rate their overall perspective on the role of chemical innovations in promoting sustainable development. These results show that 29.4% of participants strongly believe in the importance of chemical innovations for sustainable development, are highly optimistic about their potential benefits, and actively support the adoption and investment in these technologies. Meanwhile 38.3% of participants recognize the potential of chemical innovations but also see possible risks and uncertainties. They support these innovations with some reservations, advocating for a balanced approach that includes strict regulations and thorough evaluation. Finally, 32.3% of participants are skeptical or critical of chemical innovations in the context of sustainable development. They express significant concerns about environmental impacts, safety, and long-term consequences, often favoring traditional methods or alternatives.

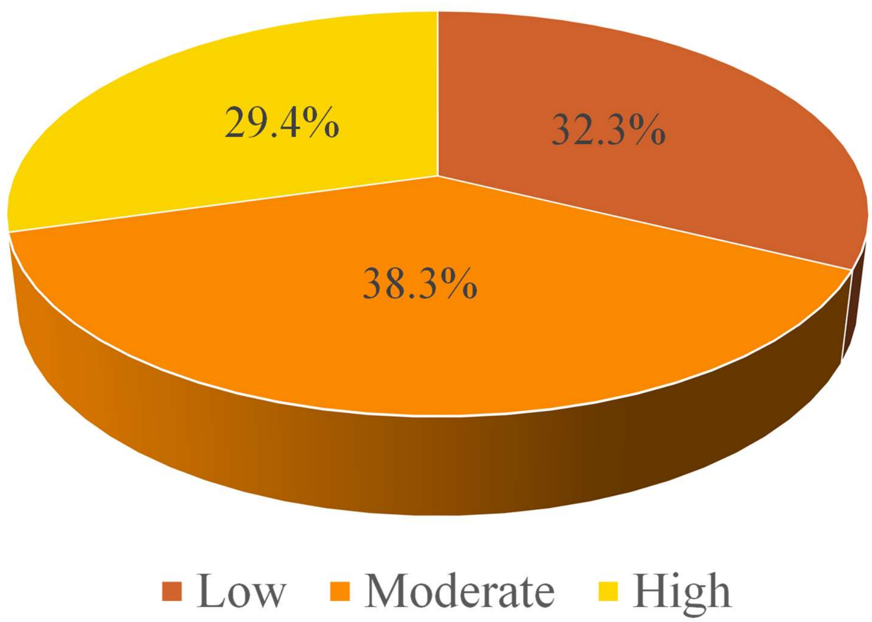


Figure 10. Distribution of response percentages to the question included in third section of the questionnaire.

Effects of Socio-Demographic Variables

Second section of the questionnaire

To explore the effects of socio-demographic variables on participant's perspectives regarding chemical innovations for sustainable development, the responses collected in the second part of the questionnaire were reviewed separately by gender (Table 3), age group (Table 4), academic qualifications (Table 5), and residential area within Portugal (Table 6).

Table 3. Percentage of responses for each question included in the second section of the questionnaire by topics and gender.

Response Options	Gender	Food Industry					Health				
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
I Don't Know	Female	2.0	4.1	2.9	23.2	0.8	11.8	24.0	17.5	0.4	0.8
	Male	2.4	4.8	3.4	24.7	1.5	13.1	25.7	18.9	0.5	1.0
Not Relevant	Female	2.9	0.8	0.8	0.4	0.4	2.0	2.4	3.2	6.1	0.4
	Male	3.9	1.0	1.4	0.5	0.5	2.9	3.9	4.4	6.8	0.5
Slightly Relevant	Female	6.9	5.7	6.1	3.7	2.4	5.7	7.7	7.7	17.9	3.7
	Male	8.7	7.3	7.8	4.9	2.9	6.8	8.7	8.3	18.9	3.9
Moderately Relevant	Female	13.4	13.4	15.0	12.5	9.4	17.9	29.3	17.9	26.4	12.6
	Male	12.1	12.6	14.1	10.7	9.2	17.0	27.2	16.5	25.7	12.1
Relevant	Female	32.9	45.9	31.3	35.8	49.2	42.7	22.0	36.6	34.2	39.4
	Male	31.1	44.7	30.1	35.0	48.5	40.8	20.9	35.9	33.5	39.3
Highly Relevant	Female	41.9	30.1	43.9	24.4	37.8	19.9	14.6	17.1	15.0	43.1
	Male	41.8	29.6	43.2	24.2	37.4	19.4	13.6	16	14.6	43.2
Response Options	**Gender**	**Water Technologies**					**Agriculture**				
		Q11	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	**Q20**
I Don't Know	Female	23.6	11.8	22.0	4.0	2.4	7.7	3.7	16.7	2.9	2.8
	Male	25.2	13.6	23.3	4.8	2.9	8.7	4.8	17.0	3.4	3.9
Not Relevant	Female	4.9	3.7	5.7	2.8	1.6	2.9	5.7	4.5	1.6	1.6
	Male	5.3	4.4	6.8	3.9	1.9	3.9	7.3	5.3	1.9	2.4
Slightly Relevant	Female	7.3	6.5	17.5	5.3	2.9	9.8	15.8	13.0	8.1	5.3
	Male	9.2	8.7	18.4	6.3	3.4	10.7	16.5	14.6	9.2	6.3
Moderately Relevant	Female	30.9	34.1	26.0	22.0	13.0	33.7	36.2	32.9	13.0	10.2
	Male	29.1	31.6	24.8	20.9	11.7	32.5	35.0	31.6	11.7	9.7
Relevant	Female	19.1	30.1	20.3	48.4	50.0	30.5	21.1	20.3	35.4	37.4
	Male	18.0	28.6	18.9	47.1	49.5	29.1	20.4	19.4	35.0	36.9
Highly Relevant	Female	14.2	13.8	8.5	17.5	30.1	15.4	17.5	12.6	39.0	42.7
	Male	13.2	13.1	7.8	17.0	30.6	15.1	16.0	12.1	38.8	40.8
Response Options	**Gender**	**Energy**					**Environment**				
		Q21	**Q22**	**Q23**	**Q24**	**Q25**	**Q26**	**Q27**	**Q28**	**Q29**	**Q30**
I Don't Know	Female	31.7	2.0	22.8	24.0	6.9	5.3	24.4	2.4	13.0	13.9
	Male	33.5	2.4	24.3	25.2	7.8	6.3	25.2	2.9	14.6	16.0
Not Relevant	Female	4.9	7.7	8.1	7.7	1.6	0.8	1.2	1.2	2.4	1.2
	Male	5.8	8.7	9.2	8.7	2.4	1.0	1.5	1.5	2.9	2.0
Slightly Relevant	Female	8.9	17.1	14.6	24.8	3.2	1.6	4.1	2.0	3.7	1.6
	Male	10.2	18.5	16.5	25.7	3.9	2.4	4.8	2.4	3.9	2.4
Moderately Relevant	Female	24.0	35.0	24.8	15.1	11.4	7.3	8.5	9.0	10.2	6.5
	Male	22.8	34.0	23.8	14.6	10.7	7.3	7.8	8.7	8.7	5.8
Relevant	Female	20.3	24.8	19.1	19.5	36.2	50.0	32.5	40.7	46.3	34.1
	Male	19.4	24.3	17.5	18.5	35.4	49.5	31.6	39.8	46.1	32.1
Highly Relevant	Female	10.3	13.4	10.6	8.9	40.7	35.0	29.3	44.7	24.4	42.7
	Male	8.3	12.1	8.7	7.3	39.8	33.5	29.1	44.7	23.8	41.7

Table 4. Percentage of responses for each question included in the second section of the questionnaire by topics and age groups.

Response Options	Age Groups	Food Industry					Health				
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
I Don't Know	≤25 years old	2.5	5.8	4.1	26.5	1.7	13.3	25.6	19.8	0.8	1.7
	26 to 45 years old	2.0	3.4	2.0	22.3	0.7	11.5	23.6	16.9	0.0	0.0
	46 to 65 years old	2.1	4.3	2.9	22.9	0.7	12.1	24.3	17.9	0.0	0.7
	>65 years old	2.3	4.7	4.7	25.4	2.3	14.0	27.9	18.6	2.3	2.3
Not Relevant	≤25 years old	4.1	0.8	1.7	0.8	0.8	3.3	5.0	5.0	8.3	0.8
	26 to 45 years old	2.7	0.7	0.7	0.0	0.0	2.0	2.0	2.7	5.4	0.0
	46 to 65 years old	2.9	0.7	0.7	0.0	0.0	2.1	2.1	3.6	5.7	0.0
	>65 years old	4.7	2.3	2.3	2.3	2.3	2.3	4.7	4.7	7.0	2.3
Slightly Relevant	≤25 years old	9.9	8.3	8.3	5.0	4.1	7.4	9.9	9.1	19.8	5.0
	26 to 45 years old	6.8	5.4	6.1	4.1	1.4	5.4	7.4	7.4	17.0	3.4
	46 to 65 years old	6.4	5.0	6.4	3.6	2.1	5.7	7.1	7.1	17.8	2.9
	>65 years old	9.3	9.3	7.0	4.7	4.7	7.0	9.3	9.3	20.9	4.7
Moderately Relevant	≤25 years old	11.6	11.6	12.4	10.7	8.3	16.5	25.6	14.9	23.1	11.6
	26 to 45 years old	13.5	13.5	15.5	12.8	10.1	18.2	29.7	18.9	27.0	12.8
	46 to 65 years old	13.6	14.3	15.7	12.1	10.0	17.9	30.0	17.9	27.9	12.8
	>65 years old	11.6	11.6	14.0	9.4	7.0	16.3	25.6	16.2	25.6	11.6
Relevant	≤25 years old	31.4	44.6	30.5	34.7	47.9	40.5	20.7	35.5	33.1	38.8
	26 to 45 years old	32.4	45.9	31.1	35.8	49.3	42.6	22.4	37.2	35.1	39.9
	46 to 65 years old	32.9	45.7	30.7	35.7	49.3	42.1	21.5	36.4	33.6	40.0
	>65 years old	30.2	44.2	30.1	34.9	48.8	41.8	20.9	34.9	32.6	37.2
Highly Relevant	≤25 years old	40.5	28.9	43.0	22.3	37.2	19.0	13.2	15.7	14.9	42.1
	26 to 45 years old	42.6	31.1	44.6	25.0	38.5	20.3	14.9	16.9	15.5	43.9
	46 to 65 years old	42.1	30.0	43.6	25.7	37.9	20.1	15.0	17.1	15.0	43.6
	>65 years old	41.9	27.9	41.9	23.3	34.9	18.6	11.6	16.3	11.6	41.9
Response Options	**Age Groups**	**Water Technologies**					**Agriculture**				
		Q11	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	**Q20**
I Don't Know	≤25 years old	26.4	13.2	24.0	5.0	3.3	9.1	5.0	17.4	3.3	4.1
	26 to 45 years old	23.0	12.2	21.6	4.1	2.0	6.8	3.4	16.2	2.7	2.7
	46 to 65 years old	23.6	12.1	22.1	4.3	2.2	8.6	3.6	16.4	2.9	2.9
	>65 years old	25.6	14.0	23.3	4.7	4.7	9.3	7.0	18.6	4.7	4.7
Not Relevant	≤25 years old	5.8	5.0	7.4	4.1	2.5	4.2	7.4	5.8	2.5	2.5
	26 to 45 years old	4.1	3.4	5.4	2.7	0.7	2.7	5.4	4.1	1.4	1.4
	46 to 65 years old	4.9	3.6	5.7	2.9	1.4	2.9	6.4	4.3	1.4	2.1
	>65 years old	7.0	4.7	7.0	4.7	4.7	4.7	7.0	7.0	2.3	2.3
Slightly Relevant	≤25 years old	9.9	9.1	19.8	7.4	4.1	10.7	17.4	14.9	9.9	8.3
	26 to 45 years old	6.8	6.7	16.2	4.6	2.7	9.4	15.5	12.8	8.1	4.7
	46 to 65 years old	7.9	6.4	17.1	5.0	2.1	9.3	15.7	13.6	7.9	4.3
	>65 years old	9.3	9.3	20.8	7.0	4.7	14.0	16.3	14.0	9.3	7.0

Table 4. *Cont.*

Response Options	Age Groups	Water Technologies					Agriculture				
		Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
Moderately Relevant	≤25 years old	28.2	31.4	24.0	19.9	11.6	32.2	34.7	31.3	11.6	9.1
	26 to 45 years old	31.1	33.8	27.0	23.0	12.8	34.5	36.5	33.2	12.8	10.8
	46 to 65 years old	30.7	33.6	25.7	21.4	12.9	33.6	35.8	32.8	12.9	10.0
	>65 years old	30.2	32.5	23.3	20.8	11.5	30.2	34.8	30.2	11.6	9.3
Relevant	≤25 years old	16.5	28.1	17.4	47.1	49.6	28.9	19.8	19.0	33.9	34.7
	26 to 45 years old	20.1	30.4	20.9	48.0	50.7	31.1	21.6	20.9	35.8	37.8
	46 to 65 years old	19.3	30.0	20.7	48.5	50.0	30.0	21.4	20.0	35.6	38.6
	>65 years old	16.3	27.9	18.6	46.5	46.5	27.8	18.6	18.6	34.9	37.2
Highly Relevant	≤25 years old	13.2	13.2	7.4	16.5	28.9	14.9	15.7	11.6	38.8	41.3
	26 to 45 years old	14.9	13.5	8.9	17.6	31.1	15.5	17.6	12.8	39.2	42.6
	46 to 65 years old	13.6	14.3	8.7	17.9	31.4	15.6	17.1	12.9	39.3	42.1
	>65 years old	11.6	11.6	7.0	16.3	27.9	14.0	16.3	11.6	37.2	39.5
Response Options	**Age Groups**	**Energy**					**Environment**				
		Q21	**Q22**	**Q23**	**Q24**	**Q25**	**Q26**	**Q27**	**Q28**	**Q29**	**Q30**
I Don't Know	≤25 years old	34.7	2.5	26.4	26.4	8.3	8.2	27.3	4.1	14.9	17.3
	26 to 45 years old	31.1	2.0	21.6	23.6	6.8	4.7	23.6	2.0	12.8	13.5
	46 to 65 years old	31.4	2.1	22.1	23.6	6.4	4.3	23.5	1.4	13.6	13.6
	>65 years old	34.9	2.3	25.6	25.6	9.3	6.9	25.6	4.7	14.0	16.3
Not Relevant	≤25 years old	5.8	9.9	9.9	9.9	2.5	1.7	1.7	1.7	3.3	1.7
	26 to 45 years old	4.7	7.4	8.1	7.4	1.4	0.0	0.7	0.7	2.0	1.4
	46 to 65 years old	5.0	7.1	7.9	7.1	2.1	0.0	0.7	1.4	2.1	1.4
	>65 years old	7.0	9.3	9.3	9.3	2.3	4.7	4.7	2.3	4.7	2.3
Slightly Relevant	≤25 years old	10.7	19.8	17.4	24.8	5.0	2.5	5.0	2.5	5.0	2.5
	26 to 45 years old	8.8	16.2	14.2	24.3	2.7	1.4	4.1	2.0	2.7	1.4
	46 to 65 years old	8.6	16.4	15.0	25.7	2.9	2.1	4.3	2.1	2.9	2.1
	>65 years old	11.6	20.9	16.4	27.9	4.7	2.3	4.7	2.3	7.0	2.3
Moderately Relevant	≤25 years old	21.5	33.9	22.3	13.3	9.8	5.8	6.6	8.3	8.3	5.8
	26 to 45 years old	24.4	35.2	25.0	15.6	12.1	8.1	9.5	9.5	10.1	6.8
	46 to 65 years old	25.0	35.1	25.7	15.7	11.5	7.9	8.6	9.3	10.0	6.4
	>65 years old	20.9	32.6	23.1	13.9	9.3	7.0	7.0	7.0	9.3	4.7
Relevant	≤25 years old	19.0	22.3	17.4	18.2	34.7	48.7	30.5	39.6	45.5	31.4
	26 to 45 years old	20.9	25.7	19.6	20.3	36.5	50.7	33.1	40.5	46.7	34.4
	46 to 65 years old	20.0	25.7	18.6	19.3	36.4	50.7	32.8	40.7	47.1	33.6
	>65 years old	18.6	23.3	16.3	16.3	34.9	46.5	30.1	39.5	44.1	32.6
Highly Relevant	≤25 years old	8.3	11.6	6.6	7.4	39.7	33.1	28.9	43.8	23.0	41.3
	26 to 45 years old	10.1	13.5	11.5	8.8	40.5	35.1	29.1	45.3	25.7	42.5
	46 to 65 years old	10.0	13.6	10.7	8.6	40.7	35.0	30.0	45.0	24.3	42.9
	>65 years old	7.0	11.6	9.3	7.0	39.5	32.6	27.9	44.2	20.9	41.8

Table 5. Percentage of responses for each question included in the second section of the questionnaire by topics and academic qualifications.

Response Options	Academic Qualifications [1]	Food Industry					Health				
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
I Don't Know	B. Education	3.3	7.2	4.4	27.6	1.7	14.9	32.0	25.4	0.6	1.1
	S. Education	2.1	3.6	3.1	23.4	1.0	12.0	24.5	16.7	0.5	1.0
	H. Education	0.0	0.0	0.0	16.9	0.0	8.5	10.2	5.1	0.0	0.0
	P.-G. Education	0.0	0.0	0.0	15.0	0.0	5.0	5.0	5.0	0.0	0.0
Not Relevant	B. Education	5.0	1.1	1.7	0.6	0.6	3.9	5.0	6.1	8.8	0.6
	S. Education	3.1	1.0	1.0	0.5	0.5	2.1	2.6	3.1	6.3	0.5
	H. Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0
	P.-G. Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slightly Relevant	B. Education	10.5	8.8	9.4	6.1	3.9	8.8	12.2	11.6	26.0	6.1
	S. Education	7.8	6.3	6.8	4.2	2.6	5.7	7.3	7.3	16.1	3.1
	H. Education	1.7	1.7	1.7	0.0	0.0	1.7	1.7	1.7	6.8	0.0
	P.-G. Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0
Moderately Relevant	B. Education	18.8	18.8	21.0	17.7	14.4	25.4	27.6	24.9	25.4	18.2
	S. Education	10.4	10.9	12.5	9.4	7.4	14.6	35.9	14.6	32.8	9.9
	H. Education	5.1	5.1	5.1	5.1	3.4	6.8	13.6	6.8	13.6	5.1
	P.-G. Education	5.0	5.0	5.0	0.0	0.0	5.0	5.0	5.0	5.0	5.0
Relevant	B. Education	29.3	39.2	28.2	29.3	45.2	32.6	17.1	23.2	33.1	39.2
	S. Education	39.6	49.0	38.5	39.1	53.6	47.4	21.4	45.3	34.4	47.9
	H. Education	23.7	54.2	20.3	44.1	49.1	52.5	28.7	44.0	32.1	22.0
	P.-G. Education	10.0	40.0	10.0	30.0	35.0	40.0	40.0	45.0	40.0	10.0
Highly Relevant	B. Education	33.1	24.9	35.3	18.7	34.2	14.4	6.1	8.8	6.1	34.8
	S. Education	37.0	29.2	38.1	23.4	34.9	18.2	8.3	13.0	9.9	37.6
	H. Education	69.5	39.0	72.9	33.9	47.5	30.5	45.8	42.4	45.8	72.9
	P.-G. Education	85.0	55.0	85.0	55.0	65.0	50.0	50.0	45.0	50.0	85.0
Response Options	**Academic Qualifications [1]**	**Water Technologies**					**Agriculture**				
		Q11	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	**Q20**
I Don't Know	B. Education	31.5	15.5	27.1	7.2	3.9	11.0	7.2	21.5	5.0	5.5
	S. Education	24.0	12.0	22.4	3.6	2.6	8.3	3.1	18.2	2.6	2.6
	H. Education	10.2	8.5	13.6	0.0	0.0	1.7	0.0	3.4	0.0	0.0
	P.-G. Education	5.0	5.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Not Relevant	B. Education	7.2	6.1	8.8	5.0	2.8	5.0	8.8	7.2	2.8	2.8
	S. Education	4.7	3.6	5.7	3.1	1.6	3.1	6.3	4.7	1.6	2.1
	H. Education	1.7	0.0	1.7	0.0	0.0	0.0	1.7	0.0	0.0	0.0
	P.-G. Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slightly Relevant	B. Education	12.2	11.6	26.0	8.8	5.0	14.9	23.8	14.9	12.7	8.3
	S. Education	7.3	6.3	16.1	5.2	2.6	9.4	14.6	14.6	7.8	5.7
	H. Education	1.7	1.7	5.1	0.0	0.0	1.7	3.4	11.9	1.7	0.0
	P.-G. Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5. *Cont.*

Response Options	Academic Qualifications [1]	Water Technologies					Agriculture				
		Q11	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	**Q20**
Moderately Relevant	B. Education	30.4	38.7	19.9	26.0	18.2	39.3	34.8	38.7	18.2	14.9
	S. Education	37.5	35.4	30.2	22.9	9.9	35.5	42.2	34.9	10.4	7.8
	H. Education	13.6	16.9	27.1	8.5	5.1	16.9	25.4	15.2	5.1	5.1
	P.-G. Education	5.0	5.0	25.0	5.0	5.0	5.0	10.0	0.0	0.0	0.0
Relevant	B. Education	13.2	22.6	13.8	44.2	45.9	23.2	16.6	14.4	34.2	34.8
	S. Education	18.2	34.9	19.9	52.6	54.7	35.4	20.8	20.8	35.4	45.3
	H. Education	28.7	28.8	30.5	45.8	50.8	28.9	27.1	27.1	35.6	25.4
	P.-G. Education	40.0	40.0	40.0	40.0	35.0	40.0	40.0	40.0	40.0	15.0
Highly Relevant	B. Education	5.5	5.5	4.4	8.8	24.2	6.6	8.8	3.3	27.1	33.7
	S. Education	8.3	7.8	5.7	12.6	28.6	8.3	13.0	6.8	42.2	36.5
	H. Education	44.1	44.1	22.0	45.7	44.1	50.8	42.4	42.4	57.6	69.5
	P.-G. Education	50.0	50.0	25.0	55.0	60.0	55.0	50.0	60.0	60.0	85.0
Response Options	**Academic Qualifications [1]**	**Energy**					**Environment**				
		Q21	**Q22**	**Q23**	**Q24**	**Q25**	**Q26**	**Q27**	**Q28**	**Q29**	**Q30**
I Don't Know	B. Education	40.3	3.3	28.2	31.5	9.9	8.8	29.8	4.4	17.1	18.8
	S. Education	32.8	2.1	22.9	26.0	7.8	5.2	28.1	2.1	14.1	15.6
	H. Education	15.3	0.0	15.3	6.8	0.0	0.0	6.8	0.0	6.8	5.1
	P.-G. Education	10.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Not Relevant	B. Education	7.7	12.7	13.8	10.5	3.3	1.7	2.2	2.2	4.4	2.8
	S. Education	4.7	6.8	6.8	9.4	1.6	0.5	1.0	1.0	2.1	1.0
	H. Education	1.7	1.7	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	P.-G. Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slightly Relevant	B. Education	14.4	26.0	23.2	30.9	5.5	3.3	7.7	3.9	6.1	3.3
	S. Education	8.9	15.6	14.1	27.6	3.1	1.6	3.1	1.6	3.1	1.6
	H. Education	0.0	5.1	1.7	8.5	0.0	0.0	0.0	0.0	0.0	0.0
	P.-G. Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Moderately Relevant	B. Education	17.1	34.3	17.7	16.0	17.1	11.6	11.1	13.3	14.4	6.1
	S. Education	28.6	41.7	31.2	16.7	9.4	5.7	8.4	7.8	8.3	8.3
	H. Education	32.2	22.0	28.8	8.5	1.7	1.7	1.7	1.7	1.7	1.7
	P.-G. Education	5.0	5.0	5.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0
Relevant	B. Education	15.5	19.3	12.7	10.5	33.8	47.5	29.3	35.9	42.0	34.2
	S. Education	19.8	27.6	16.7	15.6	36.4	54.2	39.6	44.8	47.9	35.9
	H. Education	28.8	25.4	33.9	44.0	42.4	45.8	23.7	42.4	55.9	27.1
	P.-G. Education	35.0	40.0	40.0	55.0	30.0	40.0	10.0	30.0	40.0	15.0
Highly Relevant	B. Education	5.0	4.4	4.4	0.6	30.4	27.1	19.9	40.3	16.0	34.8
	S. Education	5.2	6.2	8.3	4.7	41.7	32.8	19.8	42.7	24.5	37.6
	H. Education	22.0	45.8	18.6	32.2	55.9	52.5	67.8	55.9	35.6	66.1
	P.-G. Education	50.0	55.0	45.0	40.0	70.0	60.0	90.0	70.0	60.0	85.0

[1] B. Education—Basic Education; S. Education—Secondary Education; H. Education—Higher Education; P.-G. Education—Pos-Graduate Education.

Table 6. Percentage of responses for each question included in the second section of the questionnaire by topics and residential area.

Response Options	Residential Area	Food Industry					Health				
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
I Don't Know	Northern	1.9	3.9	3.2	23.9	0.6	12.3	24.5	18.1	0.6	0.6
	Central	2.0	4.7	2.7	24.0	1.3	12.7	25.3	18.0	0.0	0.7
	Southern	2.7	4.8	3.4	23.8	1.4	12.2	24.5	18.4	0.7	1.4
Not Relevant	Northern	3.2	1.3	1.3	0.0	0.6	2.6	3.2	3.9	6.5	0.6
	Central	3.3	0.7	1.3	0.7	0.0	2.7	3.3	4.0	6.7	0.0
	Southern	3.4	0.7	0.7	0.7	0.7	2.0	2.7	3.4	6.1	0.7
Slightly Relevant	Northern	7.7	6.5	7.1	4.5	2.6	6.5	8.4	7.7	18.1	3.9
	Central	8.0	6.6	6.7	4.0	2.7	6.0	8.0	8.0	18.7	4.0
	Southern	7.5	6.1	6.8	4.1	2.7	6.1	8.2	8.2	18.4	3.4
Moderately Relevant	Northern	12.9	13.4	14.2	11.6	9.7	17.4	28.4	17.4	26.5	12.3
	Central	12.7	12.7	14.7	12.0	9.3	17.3	28.0	17.3	26.0	12.7
	Southern	12.9	12.9	15.0	11.6	8.8	17.7	28.6	17.0	25.9	12.2
Relevant	Northern	32.4	45.2	31.0	35.5	49.0	41.8	21.3	36.1	33.5	39.4
	Central	32.0	45.3	30.7	35.3	48.7	41.3	21.3	36.0	33.9	39.3
	Southern	32.0	45.6	30.6	35.4	49.0	42.2	21.8	36.7	34.0	39.4
Highly Relevant	Northern	41.9	29.7	43.2	24.5	37.5	19.4	14.2	16.8	14.8	43.2
	Central	42.0	30.0	43.9	24.0	38.0	20.0	14.1	16.7	14.7	43.3
	Southern	41.5	29.9	43.5	24.4	37.4	19.8	14.2	16.3	14.9	42.9
Response Options	**Residential Area**	**Water Technologies**					**Agriculture**				
		Q11	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	**Q20**
I Don't Know	Northern	24.5	12.3	22.6	4.5	2.6	8.4	4.5	16.8	3.2	3.2
	Central	24.7	12.7	22.7	4.7	2.7	8.0	4.0	16.7	3.3	3.3
	Southern	23.8	12.9	22.4	4.1	2.7	8.2	4.1	17.0	2.7	3.4
Not Relevant	Northern	5.2	3.9	6.5	3.2	1.9	3.2	6.5	5.2	1.9	1.9
	Central	4.7	4.0	6.0	3.3	1.3	3.3	6.7	4.7	1.3	2.0
	Southern	5.4	4.1	6.1	3.4	2.0	3.4	6.1	4.8	2.0	2.0
Slightly Relevant	Northern	8.4	7.7	18.0	5.8	3.2	10.3	16.1	13.5	8.4	5.8
	Central	8.0	7.3	18.0	5.3	3.3	10.0	16.0	13.9	8.7	6.0
	Southern	8.2	7.4	17.7	6.1	2.7	10.2	16.3	13.6	8.8	5.4
Moderately Relevant	Northern	29.7	32.9	25.2	21.4	12.3	32.9	35.5	32.2	12.3	9.8
	Central	30.0	33.3	25.3	21.3	12.7	33.3	36.0	32.0	12.7	10.1
	Southern	30.6	32.7	25.9	21.8	12.3	33.3	35.4	32.7	12.3	10.2
Relevant	Northern	18.7	29.7	19.4	47.7	49.7	29.7	20.6	20.0	34.8	37.4
	Central	18.6	29.4	20.0	48.0	50.0	30.0	20.6	20.0	35.3	37.3
	Southern	18.4	29.3	19.7	47.6	49.7	29.9	21.1	19.7	35.4	36.8
Highly Relevant	Northern	13.5	13.5	8.3	17.4	30.3	15.5	16.8	12.3	39.4	41.9
	Central	14.0	13.3	8.0	17.4	30.0	15.4	16.7	12.7	38.7	41.3
	Southern	13.6	13.6	8.2	17.0	30.6	15.0	17.0	12.2	38.8	42.2

Table 6. *Cont.*

Response Options	Residential Area	Energy					Environment				
		Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30
I Don’t Know	Northern	32.3	2.6	23.9	24.5	7.1	5.2	24.5	2.6	13.5	14.8
	Central	32.7	2.0	23.3	24.7	7.3	6.0	24.7	2.7	14.0	14.7
	Southern	32.7	2.0	23.1	24.5	7.5	6.1	25.2	2.7	13.6	15.0
Not Relevant	Northern	5.2	8.4	8.4	8.4	1.9	1.3	1.3	1.3	2.6	1.9
	Central	5.3	8.0	8.7	8.0	2.0	0.7	1.3	1.3	2.7	1.3
	Southern	5.4	8.2	8.8	8.2	2.0	0.7	1.4	1.4	2.7	1.4
Slightly Relevant	Northern	9.7	17.4	15.5	25.2	3.9	1.9	4.5	2.6	3.9	1.9
	Central	9.3	18.0	15.3	25.3	3.3	2.0	4.7	2.0	4.0	2.0
	Southern	9.5	17.7	15.6	25.2	3.4	2.0	4.1	2.0	3.4	2.0
Moderately Relevant	Northern	23.8	34.2	23.9	14.8	11.0	7.1	8.4	9.0	9.7	6.5
	Central	23.3	34.7	24.7	14.7	11.3	7.3	8.0	8.7	9.3	6.0
	Southern	23.2	34.7	24.5	14.9	10.9	7.5	8.1	8.9	9.5	6.1
Relevant	Northern	20.0	24.5	18.6	18.7	35.5	49.7	32.3	40.0	46.4	33.0
	Central	20.0	24.6	18.0	19.3	36.0	50.0	32.0	40.6	46.0	33.3
	Southern	19.7	24.5	18.4	19.0	36.1	49.7	32.0	40.1	46.3	33.3
Highly Relevant	Northern	9.0	12.9	9.7	8.4	40.6	34.8	29.0	44.5	23.9	41.9
	Central	9.4	12.7	10.0	8.0	40.1	34.0	29.3	44.7	24.0	42.7
	Southern	9.5	12.9	9.6	8.2	40.1	34.0	29.2	44.9	24.5	42.2

DISCUSSION

Concerning the effects of gender on participant’s perspectives regarding chemical innovations for sustainable development, the examination of Table 3 reveals that the difference between male and female response frequencies in the second section of the questionnaire was less than 2.5%. Nevertheless, a consistent trend emerges across all questions, indicating a slightly higher proportion of positive responses (highly relevant, relevant, and moderately relevant) from women, while the converse is true for negative responses (not relevant and slightly relevant) and I don’t know responses.

Regarding the effects of age on participant’s perspectives regarding chemical innovations for sustainable development, the examination of Table 4 reveals that the difference between the response frequencies given by participants from different age groups in the second section of the questionnaire was less than 5%. However, a consistent trend emerges across all questions, indicating a slightly higher proportion of positive responses from participants aged between 26 and 65 years old. In contrast, for negative responses and I don’t know, the response frequency is higher for participants younger than 26 years old and those older than 65 years old.

In terms of how academic qualifications influence participants’ perspectives on chemical innovations for sustainable development, the analysis of Table 5 reveals that the frequency of positive responses is higher for participants with higher academic qualifications (i.e., higher education and post-graduate education), whereas the frequency of negative responses is higher for participants with lower academic qualifications (i.e., basic education and secondary education). The response I don't know is more frequently selected by participants with lower academic qualifications. It is important to highlight that for questions Q4, Q7, Q11, Q21, Q23, Q24, and Q27, this response was marked by more than half of these participants. These questions are related to the role of the chemical innovations in developing smart packaging, nanoparticles for drugs delivery, solar photocatalysts for organic contaminants degradation, solid electrolytes, perovskite-based materials, graphene supercapacitors, and materials with both hydrophobic and oleophilic properties. These findings point, like previous ones, to the importance of including topics related to the contributions of chemistry to sustainability in educational programs, as suggested by several authors [20–23,26,27].

In terms of how residential area influences the participants' perspectives regarding chemical innovations for sustainable development, analysis of Table 6 demonstrates that the variation in response frequencies in the second section of the questionnaire was minimal (less than 1%), regardless of the region in Portugal where participants reside.

Third section of the questionnaire

To conduct a more detailed discussion of the results obtained in the third section of the questionnaire, the influence of socio-demographic variables on the participants' overall perspective was examined. The graph presented in Figure 11 was created for this purpose, showing the responses from the third section of the questionnaire split by gender, age group, academic qualifications, and residential area. Concerning the effects of gender and residential area on participants' overall perspectives regarding chemical innovations for sustainable development, the analysis of Figure 11 reveals that the difference between response frequencies in the third section of the questionnaire was less than 1%. Regarding the comparison of response frequencies across different age groups, the largest differences observed are 23.8% (i.e., 48.8% – 25.0%), 7.4% (i.e., 40.0% – 32.6%), and 17.2% (i.e., 35.8% – 18.6%) for the options low, moderate, and high, respectively. Additionally, it is noteworthy that a trend is observed, indicating a higher proportion of positive responses (moderate and high) for the middle age groups and a higher proportion of low responses for the younger and older age groups. When comparing the response frequencies within the middle age groups, the differences for the options low, moderate, and high were 2.8%, 0.8%, and 3.6%, respectively. Meanwhile, for the younger and older age groups, these differences were 8.3%, 4.6%, and 3.7%, respectively. Finally, regarding academic qualifications, the difference in response frequencies in the third section of the questionnaire was less than 2% when comparing the groups with basic and secondary education, with a slightly higher proportion of positive responses (moderate and high) for the secondary education group. Regarding the groups with high and post-graduate education, 78.0% and 95.0% selected the high option, with no low responses recorded for the post-graduate education group. These results suggest that gender and residential area did not influence the overall perspective regarding chemical innovations for sustainable development. Conversely, age group and academic qualifications do influence the overall perspective, with a higher proportion of positive responses (moderate and high) found among the middle age groups, as well as among participants with a degree or post-graduation. These findings are consistent with several other studies [20–23,26,27], which emphasize the importance of including green chemistry and sustainable chemistry topics in school programs.

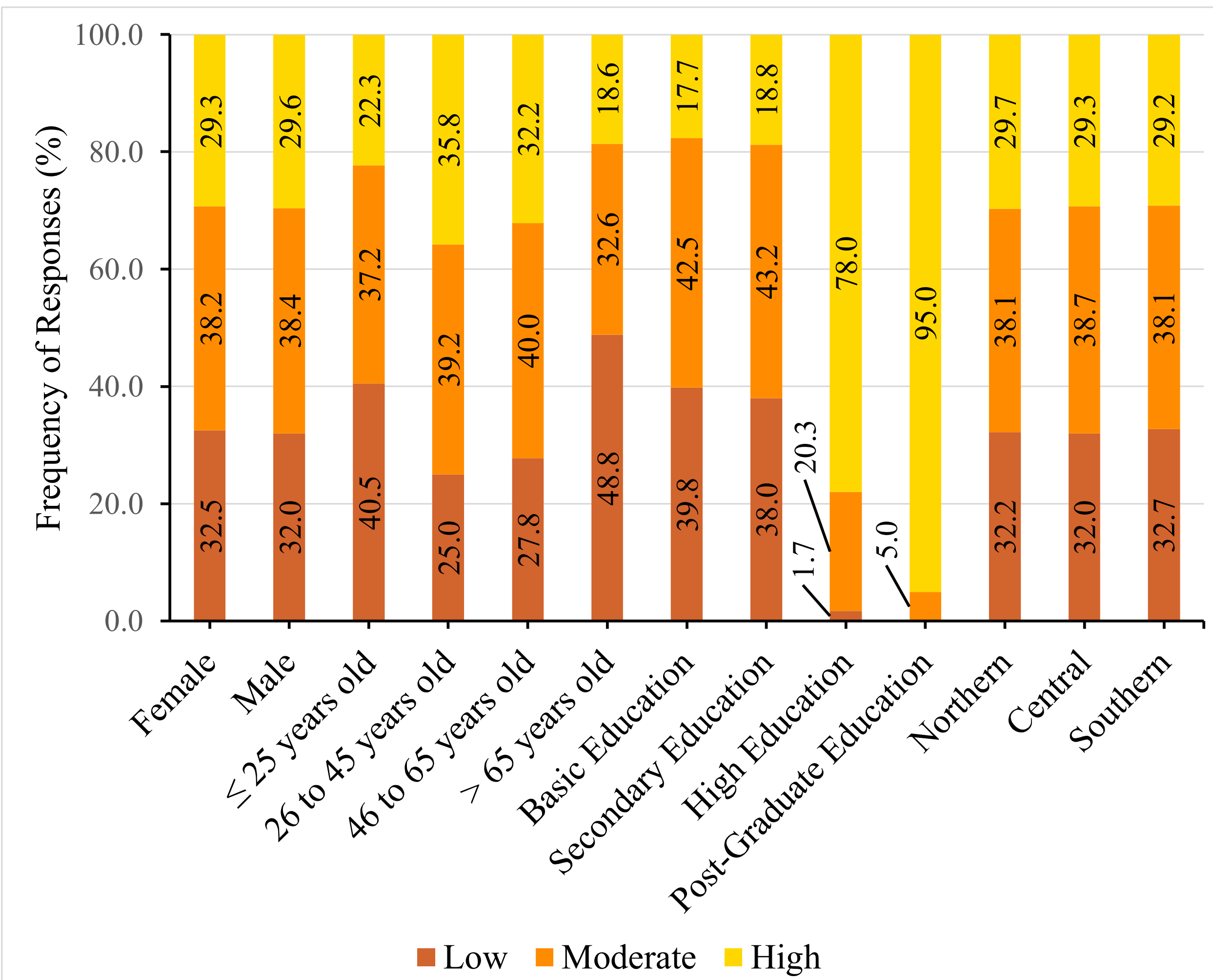


Figure 11. Distribution of response percentages to the question included in third section of the questionnaire by gender, age groups, academic qualifications, and residential area.

Conversion of Qualitative Data into Quantitative Data

The options marked by participant 1 in the second section of the questionnaire are displayed in Figure 12. Following the method proposed by Fernandes et al. [44], a unitary area circle (with a radius of $1/\sqrt{\pi}$) was split into as many parts as there are questions for each study's topic (five in this case). The response options were assigned to specific marks on the axis, as shown in Figure 13, and the area (A) associated with each response was computed using equation (1):

$$A = \frac{1}{Q}\left(\frac{n}{N\sqrt{\pi}}\right)^2 \quad (1)$$

where Q is the number of questions in each topic, N is the number of response options, and n is the mark corresponding to each response. In the present case, $Q = 5$ because there are 5 questions per topic, $N = 5$ because there are 5 response options, and $n = 1, 2, 3, 4,$ and 5 for the responses not relevant, slightly relevant, moderately relevant, relevant, and highly relevant, respectively. If the participant selects the response I don't know, then $n = 0$ because no mark is indicated on the axis. Thus, one may have:

$$A_{not\ relevant} = \frac{1}{5}\left(\frac{1}{5\sqrt{\pi}}\right)^2 = 0.008 \quad (2)$$

$$A_{slightly\ relevant} = \frac{1}{5}\left(\frac{2}{5\sqrt{\pi}}\right)^2 = 0.032 \quad (3)$$

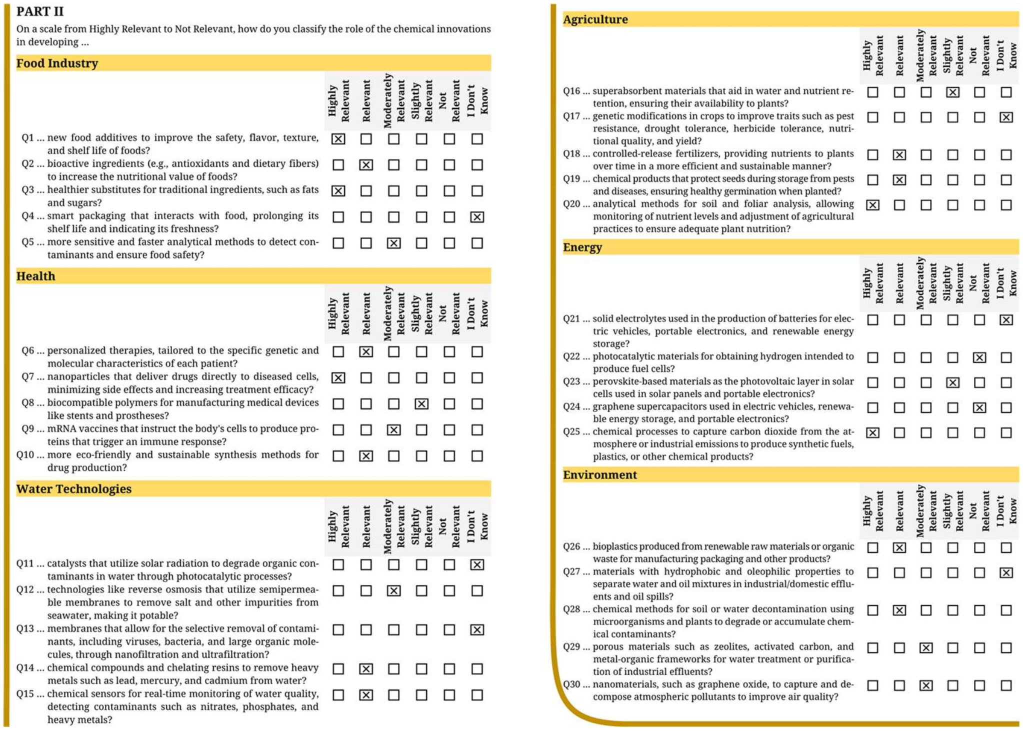
$$A_{moderatly\ relevant} = \frac{1}{5}\left(\frac{3}{5\sqrt{\pi}}\right)^2 = 0.072 \quad (4)$$

$$A_{relevant} = \frac{1}{5}\left(\frac{4}{5\sqrt{\pi}}\right)^2 = 0.128 \quad (5)$$

$$A_{highly\ relevant} = \frac{1}{5}\left(\frac{5}{5\sqrt{\pi}}\right)^2 = 0.200 \quad (6)$$

$$A_{I\ don\acute{}t\ know} = \frac{1}{5}\left(\frac{0}{5\sqrt{\pi}}\right)^2 = 0.000 \quad (7)$$

To illustrate the methodology used to quantify qualitative data, participant 1's choices for questions related to the food industry (Q1 to Q5) were used. In questions 1 and 3, participant 1 chose the highly relevant option, with each response corresponding to an area of 0.200 (equation (6)). In question 2 the choice was relevant, leading to an area of 0.128 (equation (5)), while in question 5 the choice was moderately relevant, leading to an area of 0.072 (equation (4)). Finally, in question 4, the choice was I don't know, leading to an area of zero (equation (7)). The cumulative numerical value for questions related to food industry reached 0.600, determined by adding the individual areas (i.e., 0.200 + 0.128 + 0.200 + 0.000 + 0.072). Similar methodologies were applied to other topics, with outcomes detailed in Table 7.



PART II

On a scale from Highly Relevant to Not Relevant, how do you classify the role of the chemical innovations in developing ...

Food Industry	Highly Relevant	Relevant	Moderately Relevant	Slightly Relevant	Not Relevant	I Don't Know
Q1 ... new food additives to improve the safety, flavor, texture, and shelf life of foods?	☒	☐	☐	☐	☐	☐
Q2 ... bioactive ingredients (e.g., antioxidants and dietary fibers) to increase the nutritional value of foods?	☐	☒	☐	☐	☐	☐
Q3 ... healthier substitutes for traditional ingredients, such as fats and sugars?	☒	☐	☐	☐	☐	☐
Q4 ... smart packaging that interacts with food, prolonging its shelf life and indicating its freshness?	☐	☐	☐	☐	☐	☒
Q5 ... more sensitive and faster analytical methods to detect contaminants and ensure food safety?	☐	☐	☒	☐	☐	☐

Health	Highly Relevant	Relevant	Moderately Relevant	Slightly Relevant	Not Relevant	I Don't Know
Q6 ... personalized therapies, tailored to the specific genetic and molecular characteristics of each patient?	☐	☒	☐	☐	☐	☐
Q7 ... nanoparticles that deliver drugs directly to diseased cells, minimizing side effects and increasing treatment efficacy?	☒	☐	☐	☐	☐	☐
Q8 ... biocompatible polymers for manufacturing medical devices like stents and prostheses?	☐	☐	☐	☒	☐	☐
Q9 ... mRNA vaccines that instruct the body's cells to produce proteins that trigger an immune response?	☐	☐	☒	☐	☐	☐
Q10 ... more eco-friendly and sustainable synthesis methods for drug production?	☐	☒	☐	☐	☐	☐

Water Technologies	Highly Relevant	Relevant	Moderately Relevant	Slightly Relevant	Not Relevant	I Don't Know
Q11 ... catalysts that utilize solar radiation to degrade organic contaminants in water through photocatalytic processes?	☐	☐	☐	☐	☐	☒
Q12 ... technologies like reverse osmosis that utilize semipermeable membranes to remove salt and other impurities from seawater, making it potable?	☐	☐	☒	☐	☐	☐
Q13 ... membranes that allow for the selective removal of contaminants, including viruses, bacteria, and large organic molecules, through nanofiltration and ultrafiltration?	☐	☐	☐	☐	☐	☒
Q14 ... chemical compounds and chelating resins to remove heavy metals such as lead, mercury, and cadmium from water?	☐	☒	☐	☐	☐	☐
Q15 ... chemical sensors for real-time monitoring of water quality, detecting contaminants such as nitrates, phosphates, and heavy metals?	☐	☒	☐	☐	☐	☐

Agriculture	Highly Relevant	Relevant	Moderately Relevant	Slightly Relevant	Not Relevant	I Don't Know
Q16 ... superabsorbent materials that aid in water and nutrient retention, ensuring their availability to plants?	☐	☐	☐	☒	☐	☐
Q17 ... genetic modifications in crops to improve traits such as pest resistance, drought tolerance, herbicide tolerance, nutritional quality, and yield?	☐	☐	☐	☐	☐	☒
Q18 ... controlled-release fertilizers, providing nutrients to plants over time in a more efficient and sustainable manner?	☐	☒	☐	☐	☐	☐
Q19 ... chemical products that protect seeds during storage from pests and diseases, ensuring healthy germination when planted?	☐	☒	☐	☐	☐	☐
Q20 ... analytical methods for soil and foliar analysis, allowing monitoring of nutrient levels and adjustment of agricultural practices to ensure adequate plant nutrition?	☒	☐	☐	☐	☐	☐

Energy	Highly Relevant	Relevant	Moderately Relevant	Slightly Relevant	Not Relevant	I Don't Know
Q21 ... solid electrolytes used in the production of batteries for electric vehicles, portable electronics, and renewable energy storage?	☐	☐	☐	☐	☐	☒
Q22 ... photocatalytic materials for obtaining hydrogen intended to produce fuel cells?	☐	☐	☐	☐	☒	☐
Q23 ... perovskite-based materials as the photovoltaic layer in solar cells used in solar panels and portable electronics?	☐	☐	☐	☒	☐	☐
Q24 ... graphene supercapacitors used in electric vehicles, renewable energy storage, and portable electronics?	☐	☐	☐	☐	☒	☐
Q25 ... chemical processes to capture carbon dioxide from the atmosphere or industrial emissions to produce synthetic fuels, plastics, or other chemical products?	☒	☐	☐	☐	☐	☐

Environment	Highly Relevant	Relevant	Moderately Relevant	Slightly Relevant	Not Relevant	I Don't Know
Q26 ... bioplastics produced from renewable raw materials or organic waste for manufacturing packaging and other products?	☐	☒	☐	☐	☐	☐
Q27 ... materials with hydrophobic and oleophilic properties to separate water and oil mixtures in industrial/domestic effluents and oil spills?	☐	☐	☐	☐	☐	☒
Q28 ... chemical methods for soil or water decontamination using microorganisms and plants to degrade or accumulate chemical contaminants?	☐	☒	☐	☐	☐	☐
Q29 ... porous materials such as zeolites, activated carbon, and metal-organic frameworks for water treatment or purification of industrial effluents?	☐	☐	☒	☐	☐	☐
Q30 ... nanomaterials, such as graphene oxide, to capture and decompose atmospheric pollutants to improve air quality?	☐	☐	☒	☐	☐	☐

Figure 12. Participant 1's responses to questions Q1 to Q30, presented in the second section of the questionnaire.

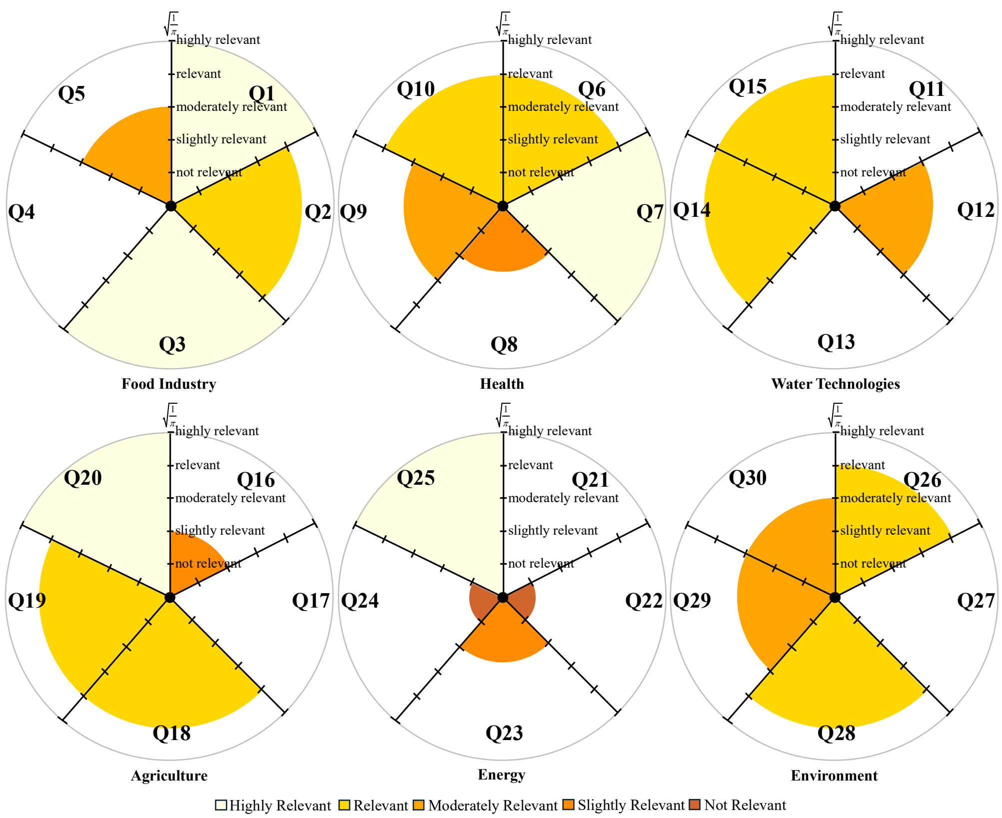


Figure 13. A diagrammatic explanation of the methodology applied to quantify the qualitative responses from participant 1 on topics food industry, health, water technologies, agriculture, energy, and environment.

Table 7. Part of the dataset used to evaluate the Portuguese population's perspectives on chemical innovations for sustainable development.

Participant ID	Food industry	Health	Water technologies	Agriculture	Energy	Environment
1	0.60	0.56	0.33	0.49	0.25	0.40
2	0.86	0.73	0.63	0.66	0.60	0.73
…	…	…	…	…	…	…
452	0.23	0.30	0.15	0.39	0.11	0.20

Predictive Model of Participants' Perspectives

The data provided in Table 7 served as input for training ANNs to evaluate the Portuguese population's perspectives on chemical innovations for sustainable development. The output classifies participants into three categories (i.e., low, moderate, or high) based on their responses to the third section of the questionnaire. Multiple ANN configurations were developed and evaluated to identify the optimal model for evaluating the Portuguese population's perspectives on chemical innovations for sustainable development. Performance comparisons were conducted using confusion matrices. From the various network structures examined, the 6-5-3-1 topology (illustrated in Figure 14) emerged as the most effective choice. This model is accompanied by its corresponding confusion matrix (Table 8), which displays average values obtained from 25 experimental runs. The accuracy of the model can be quantified using the information provided in Table 8 for both the training set (93.1%, indicating 282 cases successfully identified out of 303) and the test set (91.9%, representing 137 cases successfully identified out of 149). Consequently, the 6-5-3-1 ANN model demonstrates notable effectiveness in evaluating the perspectives of the Portuguese population on chemical innovations for sustainable development, with accuracy levels higher than 90%.

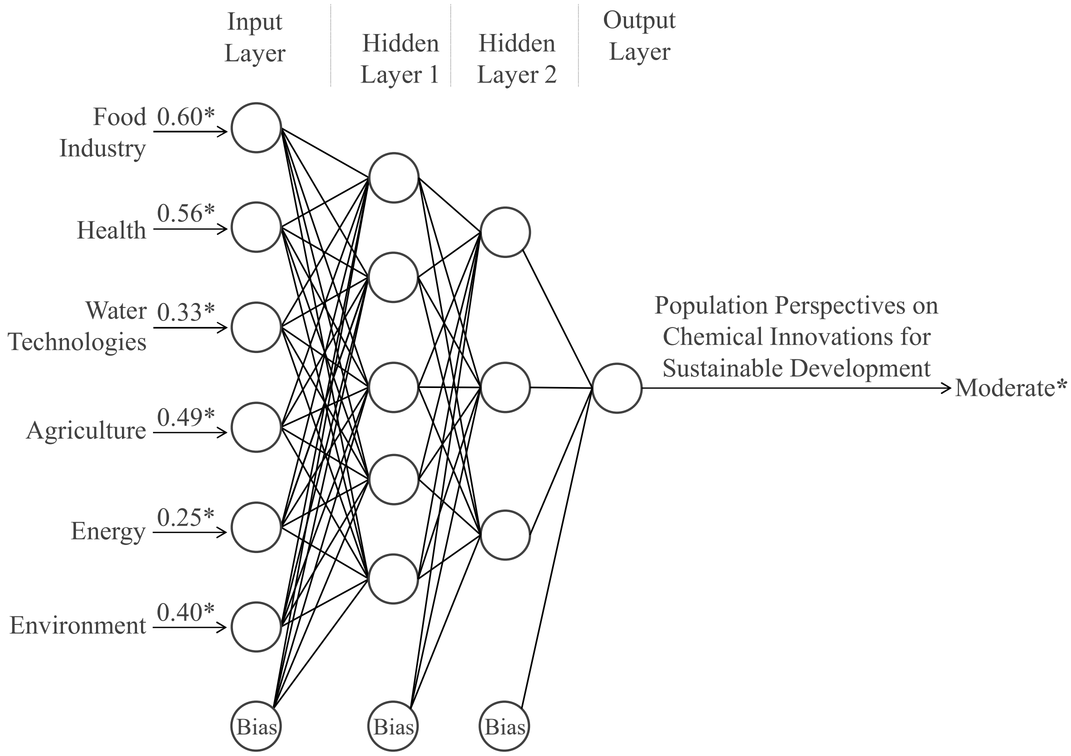


Figure 14. An illustrative diagram presenting the ANN model to evaluate the Portuguese population's perspectives on chemical innovations for sustainable development. (* The values shown are for illustrative purposes and pertain to participant 1).

Table 8. Confusion matrix summarizing the performance of the 6-5-3-1 ANN model to evaluate the Portuguese population's perspectives on chemical innovations for sustainable development.

Predict / **Target**	**Training Set**			**Test Set**		
	Low	Moderate	High	Low	Moderate	High
Low	93	5	0	44	4	0
Moderate	5	107	5	2	51	3
High	0	6	82	0	3	42

By conducting an analysis focused on columns within Table 8, it becomes possible to compute the confidence levels in the model's predictions, i.e., the model's ability to discern the various categories of participants' perspectives (i.e., low, moderate, or high). Within the study's participants, the model identified 144 individuals (31.8% of the sample) as having low perspectives on chemical innovations for sustainable development. Of these, 137 (93 + 44) were correctly classified, while 7 (5 + 2) were misclassified as moderate. The model identified 176 participants (i.e., 38.9% of the sample) as having moderate perspectives on chemical innovations for sustainable development. Of these, 158 (107 + 51) were correctly classified, while 18 (5 + 6 + 4 + 3) were misclassified. Among the misclassified participants, 9 (5 + 4) were classified as having low perspective, and 9 (6 + 3) as having high perspective. Finally, the model identified 132 participants (29.3% of the sample) as having high perspectives on chemical innovations for sustainable development. Of these, 124 (82 + 42) were correctly classified, while 8 (5 + 3) were misclassified as moderate. The confidence levels in the model's predictions can be quantified from the analysis focused on columns within Table 8. These confidence levels for training and testing sets are 94.9% and 95.7% for low, 90.7% and 87.9% for moderate, and 94.3% and 93.3% for high, respectively.

Through an analysis focusing on rows in Table 8, it becomes possible to compute the percentages of low, moderate, and high responses correctly identified by the model. Thus, among the 146 participants with low perspectives on chemical innovations for sustainable development (32.3% of the sample), the model correctly identified 137 (93 + 44), while 9 (5 + 4) were misclassified as moderate. Out of the 173 participants with moderate perspectives on chemical innovations for sustainable development (38.3% of the sample), the model correctly identified 158 (107 + 51), while 15 (5 + 5 + 2 + 3) were misclassified, i.e., 7 (5 + 2) as low and 8 (5 + 3) as high. Finally, from the 133 participants with high perspectives on chemical innovations for sustainable development (29.4% of the sample), the model correctly identified 124 (82 + 42), while 9 (6 + 3) were misclassified as moderate. Thus, the percentages of low, moderate, and high responses correctly identified by the model for training and test sets are 94.9% and 91.7% for low, 91.5% and 91.1% for moderate, and 93.2% and 93.3% for high, respectively.

The examination of variance-based sensitivity [52] was conducted to investigate the relative importance (RI) of the ANN input variables, i.e., how the inputs impact the outputs. The results suggest that the topics energy (RI = 0.25), water technologies (RI = 0.23), and environment (RI = 0.21) have a greater influence in the model output, i.e., the Portuguese population's perspectives on chemical innovations for sustainable development. Conversely, the topics health (RI = 0.12), agriculture (RI = 0.10), and food industry (RI = 0.09) have a lesser impact. These findings match those reported in Frequency of Responses Analysis section. The great number of I don't know responses related to energy, water technologies, and environment topics suggest that even minor differences in these responses can considerably influence the perspectives of the Portuguese population on chemical innovations for sustainable development.

Overall Analysis of the Participants' Perspectives

The approach developed by Fernandes et al. [44] facilitated the conversion of qualitative responses from each participant into numerical data, as illustrated in Figure 13 and detailed in Table 7. Aiming to perform a detailed analysis of participants' perspectives on chemical innovations for sustainable development the data from Table 7 were depicted in a circular diagram with six segments, each addressing one of the topics covered in the second section of the questionnaire. Figure 15 presents an overview of this approach for participant one. Taking into account that the data presented in Table 7 were derived from a unitary area circular diagram, each value was divided by the number of sections present in the new chart (i.e., six sections) to adjust them.

The overall perspective on chemical innovations for sustainable development, as perceived by participants, can now be quantified. Regarding participant 1, the overall perspective score is 0.44, corresponding to the sum of the highlighted areas in Figure 15. Additionally, it is possible to assess the participant's capacity for improvement. Calculated as one minus the overall perspective score, this capacity is depicted by the dashed outline area. For participant 1, the improvement capacity is 0.56 (i.e., 1 − 0.44).

Figure 15 helps identify the topics where participants find it most difficult to recognize the role of chemical innovations in sustainable development. For example, participant 1 demonstrates poor awareness of the importance of chemical innovations in topics related to energy and water technologies. This procedure is replicated for the remaining participants, with Figure 16 displaying the findings for those outlined in Table 7. Analysis of Figure 16 concerning the remaining participants in Table 7 indicates that participant 2 has a strong awareness of the importance of chemical innovations across the topics studied, whereas participant 452 faces greater challenges in perceiving these impacts across the different topics. The importance of this analysis lies in establishment of a database (Table 9) to understand a specific population, enabling exploration of participants' improvement capacity and their perspectives on chemical innovations for sustainable development. This database allows gathering insights from participants' responses and acquiring relevant information, such as:

- The mean value of individuals' perspectives on chemical innovations for sustainable development;
- The lowest/highest value of improvement capacity considering all individuals;
- All individuals whose perspectives on chemical innovations for sustainable development is higher/lower than a specific value;
- All individuals whose improvement capacity is higher/lower than a specific value;
- All individuals whose perspectives on chemical innovations for sustainable development is higher/lower than a specific value; or
- All individuals whose perspective on food industry topic is higher/lower than a specific value and the perspectives on chemical innovations for sustainable development is higher/lower than another value.
- All individuals whose self-rating equal to high and the improvement capacity is higher/lower than a specific value.

This information facilitates grouping individuals with similar attributes and enables customized intervention programs for enhancing the population's perspectives on chemical innovations for sustainable development.

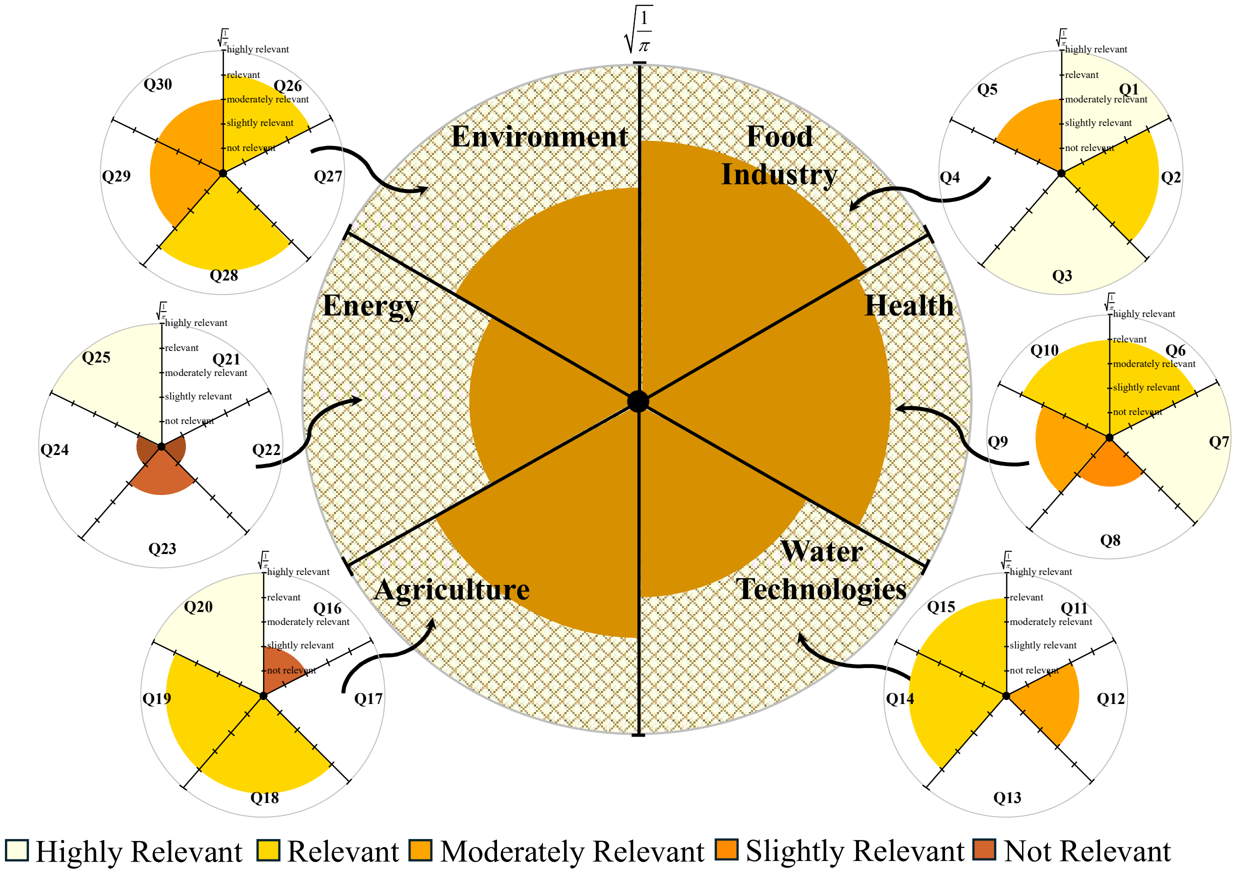


Figure 15. A diagrammatic representation of the process used to evaluate participant 1's overall perspectives on chemical innovations for sustainable development.

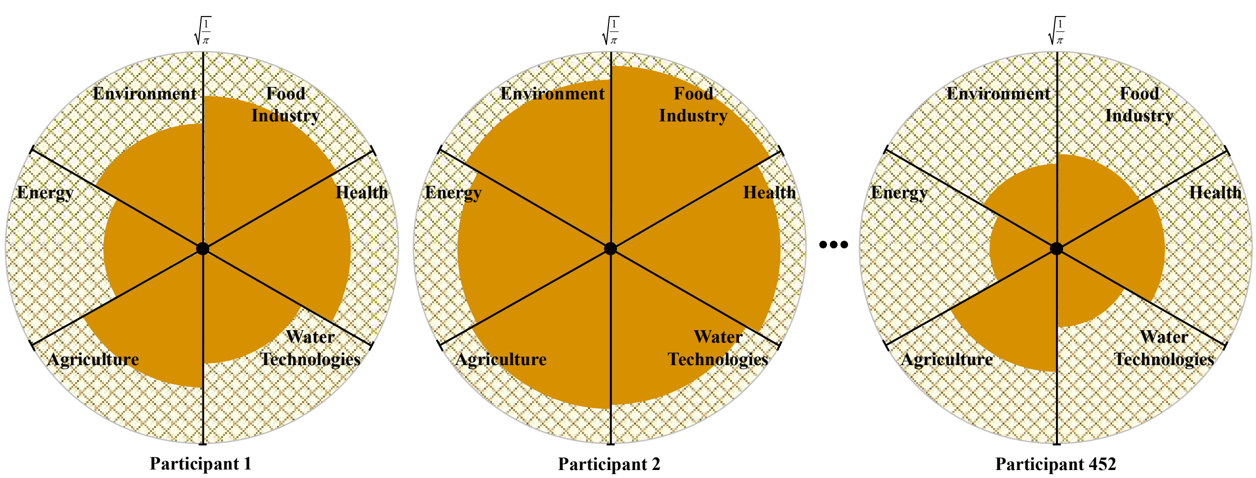


Figure 16. Visual depiction of the overall perspectives on chemical innovations for sustainable development for participants listed in Table 7.

Table 9. Part of the dataset used to improve the Portuguese population’s perspectives on chemical innovations for sustainable development.

Participant ID	Food industry	Health	Water technologies	Agriculture	Energy	Environment	Global Perspective	Improvement Capacity	Participants’ Self-Rating of their Overall Perspectives
1	0.10	0.09	0.06	0.08	0.04	0.07	0.44	0.56	moderate
2	0.14	0.12	0.11	0.11	0.10	0.12	0.70	0.30	high
…	…	…	…	…	…	…	…	…	…
452	0.04	0.05	0.03	0.07	0.02	0.03	0.24	0.76	low

CONCLUSIONS

The focus of this study was to evaluate the Portuguese population's perspectives on chemical innovations for sustainable development addressing topics such as food industry, health, water technologies, agriculture, energy and environment. The outcomes shows that chemical innovations for sustainable development are positively perceived in all topics except energy. Many participants lack knowledge of recent advancements like smart packaging, nanoparticles, biocompatible polymers, photocatalysts, nanofiltration, controlled-release fertilizers, solid electrolytes, perovskite solar cells, graphene supercapacitors, and hydrophobic/oleophilic materials. Regarding the effects of socio-demographic characteristics, the study found that gender and residential location did not impact participants' perspectives on chemical innovations for sustainable development. Regarding the influence of age, despite small differences in response frequencies among different age groups, participants aged between 26 and 65 years showed a slightly higher proportion of positive responses. The same trend is observed when analyzing the influence of academic qualifications. In this case, participants with high academic qualifications exhibit a higher frequency of positive responses. The trends mentioned earlier also applied when analyzing the influence of socio-demographic variables on participants' self-rating of their overall perspectives on chemical innovations for sustainable development. Gender and residential area showed no influence, while age group and academic qualifications did, with a higher proportion of positive responses (moderate and high) observed among middle-aged participants and those with a degree or post-graduation. Moreover, an artificial neural network-based model was introduced to evaluate the Portuguese population's perspectives on chemical innovations for sustainable development. The model exhibited strong performance, achieving accuracy rates higher than 90%. In addition, this study introduces a new method to evaluate the Portuguese population's overall perspective on chemical innovations for sustainable development and its capacity for improvement. These evaluations play a vital role in developing communication strategies, enhancing educational efforts, and clarifying misunderstandings, ultimately to raise public awareness of the role of chemical innovations for sustainable development. Although this study yielded interesting findings, some limitations must be considered for a more thorough analysis of how the Portuguese population perceives the role of chemical innovations in sustainable development. The primary limitation is the sample size. Future research would benefit from a larger cohort to ensure more generalizable results. Moreover, the first section of the questionnaire may be extended to gather more socio-demographic and socio-economic information, such as income, occupation, employment status, among others. In addition, incorporating more key topics into the second part of the questionnaire could widen the study's reach. Furthermore, with the identification of specific issues where participants encounter difficulties, joint actions by governmental and non-governmental organizations can be initiated to overcome these obstacles. Such efforts might involve specific educational and training programs, designed for different age groups, focusing on raising the perspectives of the role of chemical innovations for sustainable development and offering support on less familiar issues.

DATA AVAILABILITY

The dataset of the study is available from the authors upon reasonable request.

AUTHOR CONTRIBUTIONS

MF and HV designed the study. MF and HV performed the data collection. MF and HV made the model. MF and HV analyzed the data. MF and HV wrote and revise the paper.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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