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Synthetic Biology in Nigeria: The Level of Awareness amongst Stakeholders

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ABSTRACT: Synthetic biology, an emerging field at the intersection of biotechnology and engineering, has seen a global surge in application and awareness, necessitating a comprehensive understanding of its safe potentials to drive the bio-economy. This study aimed to assess the awareness and perceptions of synthetic biology among Nigerian biosciences stakeholders, including researchers, academicians, policymakers and students. The study employed a purposive online survey targeting diverse bioscience individuals and groups across Nigeria's six geopolitical zones. The study received 107 responses from balanced gender representation with majority within the age group of 31–45 years old. The findings revealed a significant knowledge gap, with only 27.1% of respondents familiar with synthetic biology and 23.4% entirely unaware of it. Most respondents associated synthetic biology with biotechnology or genetic engineering and identified its applications to be in agriculture, medicine, environmental sustainability and research. Despite recognizing its benefits, many expressed concerns about safety, ethics, and regulation; notably, 43.9% of the respondents had concerns about synthetic biology with primary focus on safety and ethical implications. As regards the regulation of synthetic biology, the study showed that 80.4% of the respondents supported the need for synthetic biology regulation with few of the respondents (16.8%) aware of existing agency mandated to regulate synthetic biology. The respondents provided valuable insights into the various ways synthetic biology can be advanced in Nigeria which include increased awareness and capacity building, engagement through social media platforms, integration into education curricula and increased funding and investment in the research. The overall sentiment towards synthetic biology was positive, with 81.3% supporting its practice and 76.6% recognizing its positive global impact. However, a significant portion of respondents remained undecided. This study concludes that there is substantial gap in the knowledge of synthetic biology among bioscience stakeholders in Nigeria and the need for a heightened advocacy including continuous conferences and symposiums for the Nigeria bioscience community on the global potentials, concerns and regulation of synthetic biology. This will foster the acceptance of safe and responsible synthetic biology in Nigeria, thereby contributing to the broader national bio-economy development.

Keywords: Awareness; Bio-economy; Biotechnology; Regulation; Synthetic biology

1. Introduction

Synthetic biology is a multidisciplinary field that combines biotechnology, engineering, and computer science to redesign living organisms or create new biological systems for useful purposes. This includes modifying genetic materials and constructing new biological parts. Globally, it is recognized for its applications in areas such as medicine, agriculture, and environmental management. Synthetic biology can be seen, very simply as the intersection between

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biotechnology and engineering. Very recently the increase in the use of synthetic biology and related techniques has heightened the awareness of the populace particularly in research and the academia on the need for levering synthetic biology for the development of the Bioeconomy. Globally there are different definitions of synthetic biology and none is yet generally accepted. The Ad-hoc Technical Expert Groups (AHTEG) Report to the Convention on Biological Diversity (CBD) on Synthetic Biology provided an operational definition of Synthetic Biology to be "a further development and new dimension of modern biotechnology that combines science, technology and engineering to facilitate and accelerate the understanding, design, redesign, manufacture and/or modification of genetic materials, living organisms and biological systems" [1]. The AHTEG's definition holds significant weight as it stems from a UN-based initiative aimed at guiding international policy on emerging biotechnologies. Synbio Africa in 2023 defined Synthetic Biology as the field of science that involves redesigning organisms for useful purposes by engineering them to have new abilities [2]. There are a diverse range of synthetic biology applications. They include antibody and vaccine production, biofuel production, agricultural bioengineering, microbial engineering, and food production are just a few of the applications that are made possible through the study and practice of synthetic biology [3,4].

In the light of the above, there has been increased use of synthetic biology globally and Nigeria has no other choice but to embrace the ever-dynamic world of biotechnology and by extension synthetic biology [5]. Tour et al. [6] in their article highlighted that three fundamental premises that reinforce the escalation of synthetic biology across the globe within the past decade include (i) that life is information; (ii) that biology can be considered technology; and (iii) that policy responses hinge on the three-way convergence of the life sciences, the information sciences and engineering. More to it is that the divide between our understanding of biology and engineering is collapsing.

Otim et al. [2] in their study identified that there is little information on synthetic biology and its regulatory policies in Africa. Their study which championed an African Centre of Excellence in Synthetic Biology through the SynBio Africa showed that synthetic biology in Africa can significantly contribute to the continental development agenda through development of innovative medicines, reducing environmental degradation, promoting food security through increase in crop production and above all, anchor a sustainable bio-economy.

Nigeria is among the leaders in the African continent with robust biotechnology policy framework in place and more on-going biotechnology related activities. The achievements in safe modern biotechnology activities in Nigeria are highly attributed to the national robust biosafety policy framework aimed at providing effective regulation of modern biotechnology. With considerable scientific infrastructure and clear programs on biotechnology, Nigeria has focused on modern biotechnology areas especially in agriculture and has commercialized some of their products; however synthetic biology has not yet received as much success as biotechnology. One major advantage for Nigeria's potential progress in safe synthetic biology practices is the current legal framework that amended the National Biosafety Management Agency Act in 2019 to carter for the regulation of emerging modern biotechnologies in Nigeria including synthetic biology; gene editing and gene drive [5].

This study as an initiative of SynBio Africa's ambassadors and deputy ambassadors for Nigeria was therefore aimed at assessing the current awareness and impressions of synthetic biology among biosciences stakeholders in Nigeria including researchers, academicians and policy makers. The study was not to draw exhaustive conclusions on the bio-science stakeholders' awareness of synthetic biology but, rather to provide findings of the survey study expected to serve as a compass, steering the course of safe and responsible synthetic biology in the Nigerian bioscience sphere.

2. Methodology

This study employed a purposive online survey to assess the awareness and perceptions of synthetic biology among biosciences stakeholders across Nigeria's six geopolitical zones (North West, North East, North Central, South West, South East, and South South). The process was conducted over a period of four weeks from March 2024. The survey targeted individuals from various fields, including academia, research institutes, government agencies, and industries related to biosciences and biotechnology.

2.1. Participant Selection

Participants were selected through purposive sampling, focusing on stakeholders likely to have an interest or involvement in biosciences and synthetic biology. The selection criteria included researchers, academics, postgraduate students, policymakers, and individuals from bioscience industries. The survey was distributed electronically via email and social media platforms, leveraging professional networks and bioscience group memberships across Nigeria.

Invitations were sent to specific groups identified as key to the study, such as university departments, bioscience organizations, and biotechnology regulatory bodies. A total of 107 participants responded to the survey.

2.2. Survey Design and Distribution

The survey instrument consisted of 19 questions designed by a team of experts, including academicians from leading Nigerian universities, policymakers from the related government agencies and professionals from the bioscience related industry. The questions were crafted to assess the knowledge, perceptions, and concerns regarding synthetic biology. The survey was pilot tested by several individuals to ensure clarity, relevance, and reliability before its full distribution. No major changes were needed after the pilot testing.

2.3. Duration

The survey was available for responses over a period of four weeks. Participants were given ample time to respond and were sent reminders periodically to ensure higher participation rates.

2.4. Question Development and Themes

The survey questions were developed in consultation with experts from academia, government, and industry. The themes of the survey were defined based on a literature review of previous synthetic biology awareness studies and reports of discussions arising from the 2023 national conferences relating to biotechnology in Nigeria. Key themes included knowledge of synthetic biology, its applications, ethical concerns, regulation, and future perspectives. The survey was designed to explore these themes in a structured manner, using both multiple-choice questions and open-ended questions to capture qualitative insights.

2.5. Data Analysis

Data were analysed both quantitatively and qualitatively. Quantitative data from closed-ended questions were analysed using descriptive statistics (e.g., frequency distributions, percentages). Qualitative responses from open-ended questions were thematically analysed, with responses coded into recurring themes such as safety, ethics, and regulation. This coding process was done manually and reviewed by two independent researchers to ensure accuracy and consistency.

2.6. Ethical Considerations

Informed consent was obtained from all participants before they began the survey. Participation was voluntary, and respondents were assured of the anonymity and confidentiality of their responses.

3. Respondents

The survey study received a total of one hundred and seven (107) responses, with almost balanced gender groups: 48.6% females and 51.4% males (Figure 1). The age distribution of respondents showed that 55.1% were between 31–45 years old, 23.4% between 18–30 years, 18.7% between 46–60 years, 2.8% between 60–70 years, and 0% between 70-above (Figure 2). Regarding geographical distribution, the responses were from all six geopolitical zones of Nigeria. The South-South zone accounted for 28% of respondents, followed by the North-Central and North-East zones (16.8% each), North-West (15.9%), South-East (12.1%), and South-West (10.31%) (Figure 3).

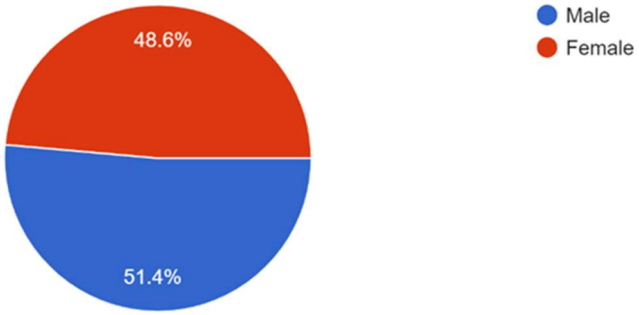

Figure 1. Sex Distribution of Respondents.

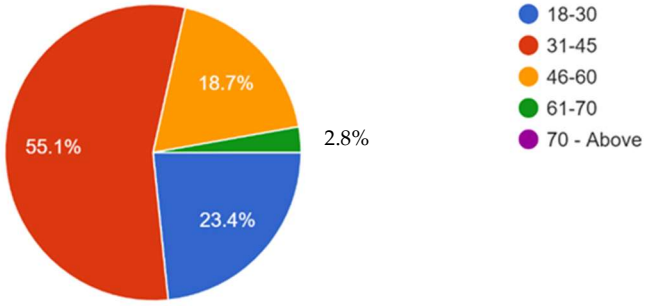

Figure 2. Age Distribution of Respondents.

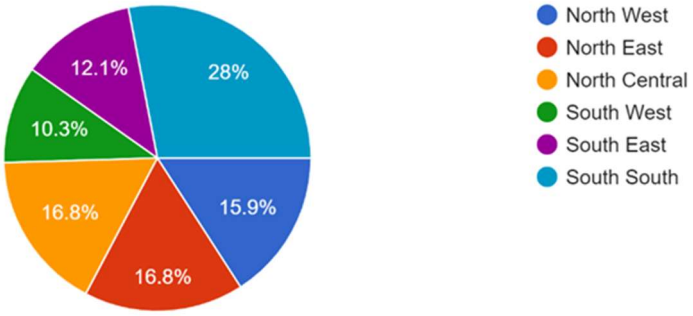

Figure 3. Regional Distribution of the Respondents.

The professional background of respondents was diverse, with 45.8% in academia, 22.4% being students, 19.6% in policy-making/government institutions, and 17.8% from research institutions (Figure 4). Additionally, 3.7% of respondents worked in industry and non-governmental organizations (NGOs), while the remaining participants were health practitioners, entrepreneurs, business people, and others.

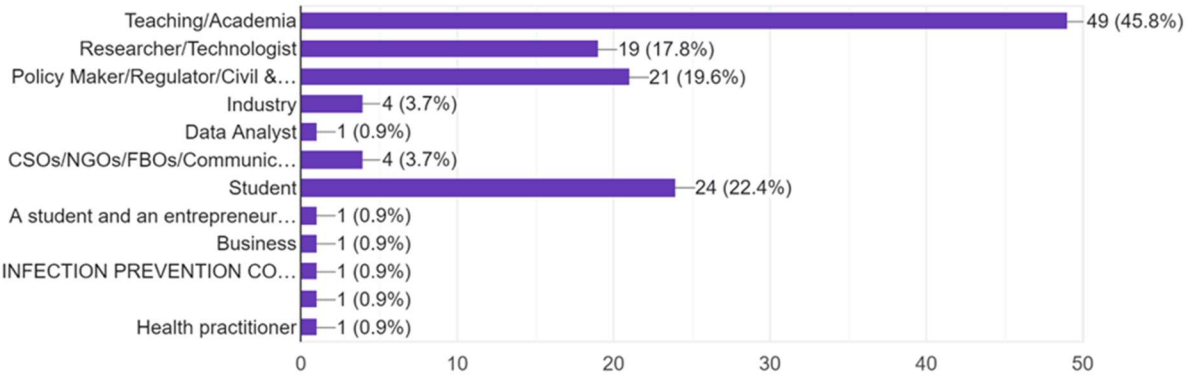

Figure 4. Occupation of the Respondents.

4. Results

4.1. Knowledge of Synthetic Biology

As shown in Figure 5, 27.1% of the respondents were familiar with the term "synthetic biology" while 16.8% had a moderate level of information on the subject. A further 32.7% had heard only a little about it, and 23.4% were entirely unaware of synthetic biology. Despite this range of awareness, a few respondents indicated that they had heard a lot about synthetic biology.

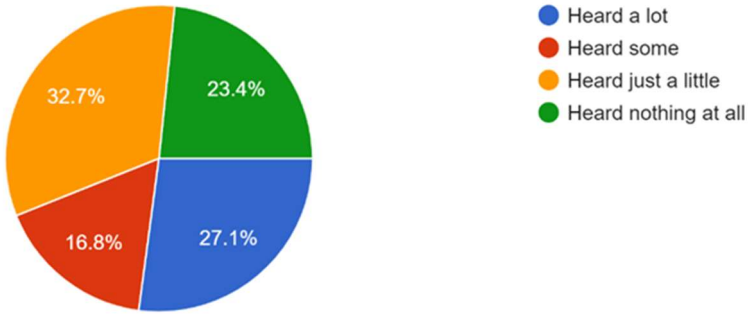

Figure 5. Responses on the Knowledge of Synthetic Biology.

Figure 6 revealed how respondents who had varying levels of familiarity with synthetic biology understood the term. Of those, 23% defined synthetic biology as an aspect of biotechnology, and 21% defined it as a genetic engineering process. Fourteen percent (14%) defined synthetic biology as advanced engineering biology, while 9% associated it with the application of artificial intelligence (AI) or nanotechnology in biology.

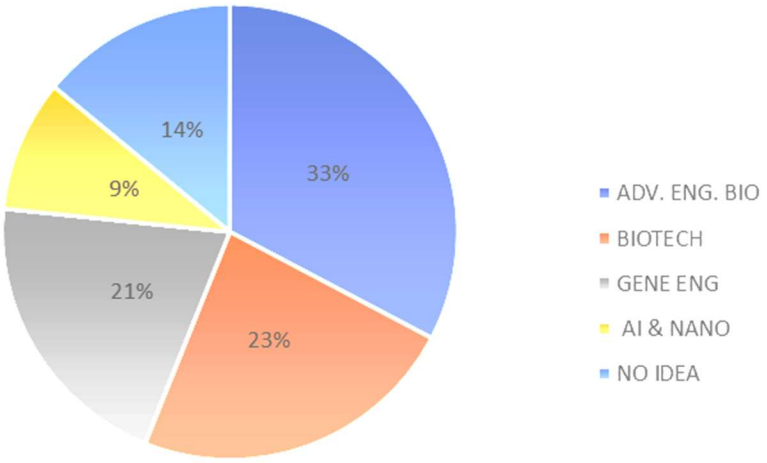

Figure 6. Responses on the Definitions of Synthetic Biology.

4.2. Applications of Synthetic Biology

The survey results, illustrated in Figure 7, show the respondents' perspectives on the applications of synthetic biology. Twenty-one percent (21%) of respondents indicated that synthetic biology could be applied in agriculture, while 14% believed it was primarily useful for research. Twelve percent (12%) saw its most significant application in medicine, and 9% mentioned its potential for environmental sustainability, including bioremediation and biofuels.

Additionally, 8% of respondents linked synthetic biology to genetic studies and DNA characterization, 6% to artificial intelligence, and smaller percentages saw it applicable to vaccine production (5%), drug production (3%), and nanotechnology (1%).

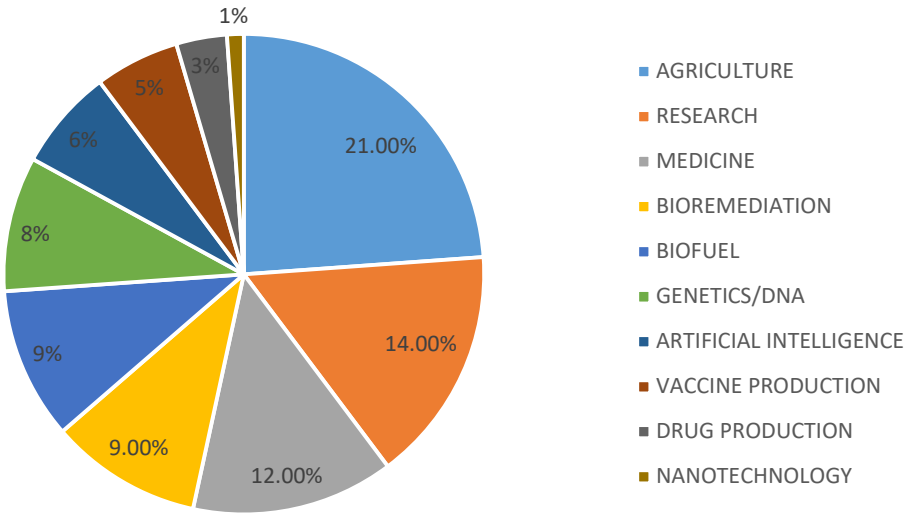

Figure 7. Responses on the Applications of Synthetic Biology.

4.3. Concerns of Synthetic Biology

The responses presented in Figure 8 indicate that 43.9% of the respondents expressed concerns about the applications of synthetic biology, while 25.2% believed that there were no immediate threats or concerns associated with its use. Additionally, 30.8% of respondents were unsure whether any concerns should arise, possibly due to a lack of awareness about synthetic biology processes. Further investigation into the types of concerns revealed that 24% of respondents were worried about safety issues, 16% were concerned about ethics and regulation, respectively, and 13% highlighted concerns regarding dual-use purposes. Moreover, 11% and 9% of respondents expressed fears about the potential use of synthetic biology for bioterrorism and negative training, respectively (Figure 9).

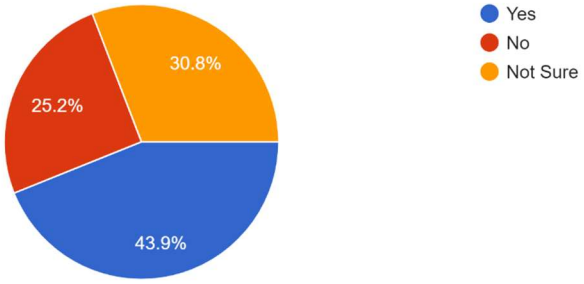

Figure 8. Responses on Concerns about Synthetic Biology.

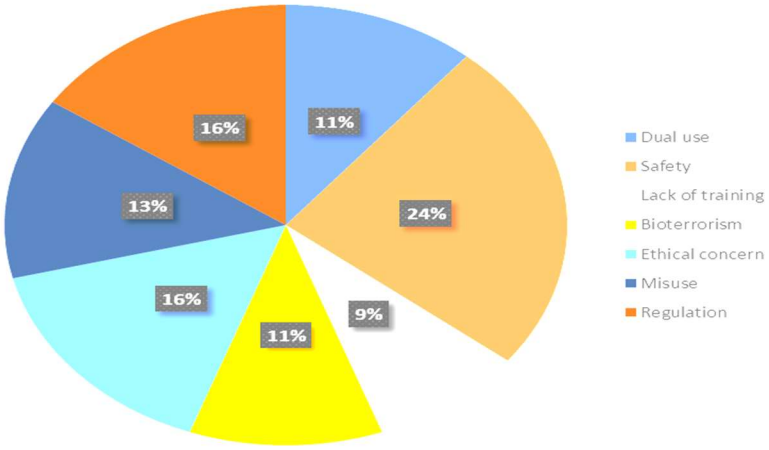

Figure 9. Responses on Kinds of Concerns of Synthetic Biology.

4.4. Impression of Risks and Benefits of Synthetic Biology

The responses shown in Figure 10 indicate that 49.5% of respondents believe the benefits of synthetic biology outweigh the risks, while 15% think there is a balance between risks and benefits. A smaller group, comprising 5.6% of respondents, felt that the risks outweighed the benefits. Additionally, 29.9% of respondents were unsure whether the benefits outweighed the risks, which suggests a significant portion of respondents were unaware or uncertain about the implications of synthetic biology.

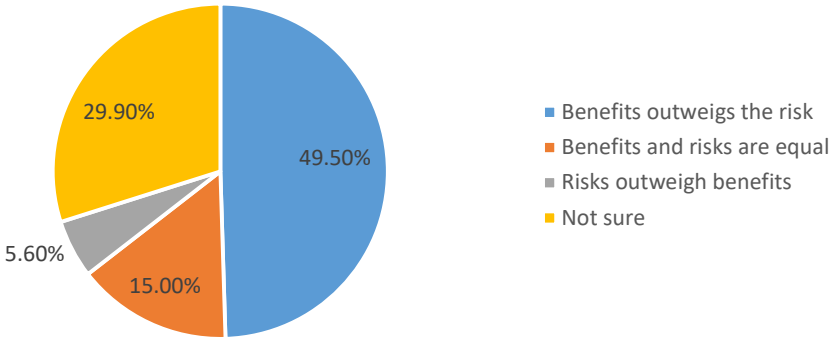

Figure 10. Responses on the Impression of Risks and Benefits of Synthetic Biology.

4.5. Awareness of Institutions That Deal with Synthetic Biology

The survey responses revealed a significant lack of awareness regarding institutions that provide training in synthetic biology. Only 13.1% of respondents indicated knowledge of such institutions, while a substantial 86.9% reported being unaware of any training institutions (See Figure 11). When asked to identify specific institutions, 19% of respondents named research institutes as the main providers of synthetic biology training, 13% pointed to universities

and their departments of molecular biology, and another 13% cited organizations such as the International Institute of Tropical Agriculture (IITA), Ibadan Nigeria, and the Sheda Science and Technology Complex (SHESTCO), Abuja Nigeria. Additionally, 6% of respondents mentioned conferences as venues for synthetic biology training (Figure 12).

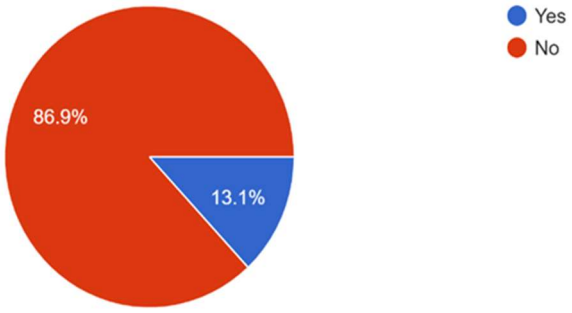

Figure 11. Responses on Synthetic Biology Training Institutions.

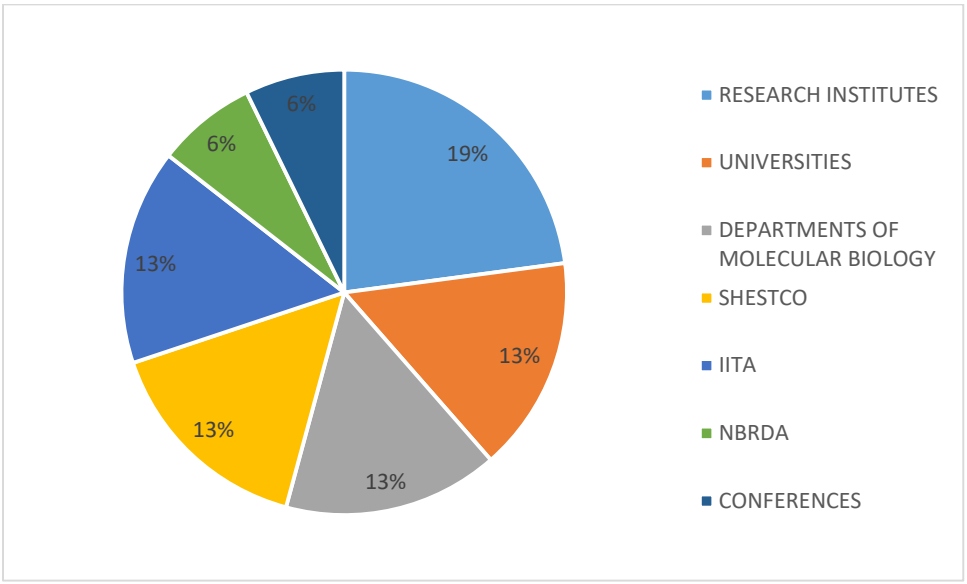

Figure 12. Responses on Institutions that do Synthetic Biology.

4.6. Perceptions on the Improvement of Synthetic Biology

The survey responses revealed various suggestions for advancing synthetic biology in Nigeria. According to the data (See Figure 13), 23% of respondents believe that increasing awareness about synthetic biology is the most critical factor for its improvement. Another 13% of respondents suggested that engagement through social media platforms would enhance visibility and attract a broader audience. Additionally, 11% emphasized the importance of incorporating synthetic biology into educational curricula, while 9% highlighted the need for funding, investment, capacity building, and legislation as key to advancement. Policy improvements were suggested by 7% of respondents, and 5% mentioned the role of traditional media and specialized training programs in advancing synthetic biology in Nigeria.

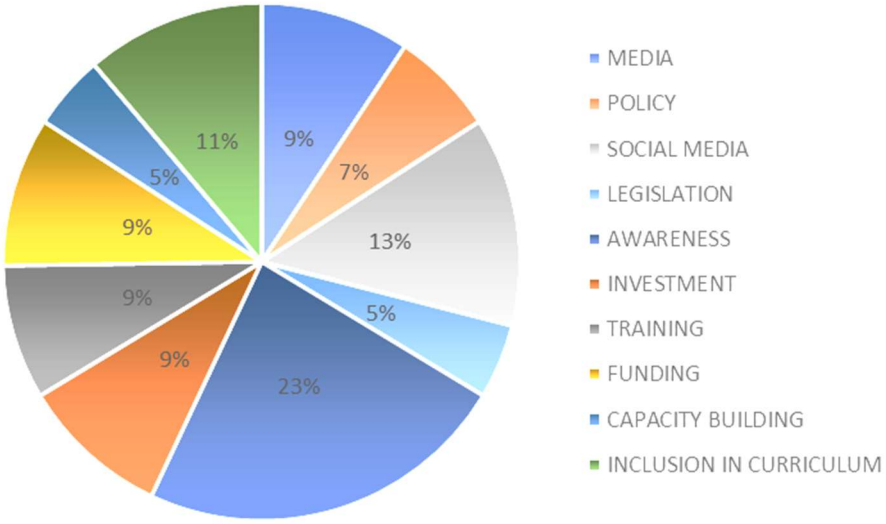

Figure 13. Responses on how Synthetic biology can be Improved in Nigeria.

4.7. Impressions on Regulation of Synthetic Biology

The survey results provided a clear view of participants' perspectives on the regulation of synthetic biology in Nigeria. A significant majority, 80.4% of respondents, agreed that synthetic biology should be regulated, reflecting a strong consensus on the importance of oversight and control in the field (See Figure 14). In contrast, 17.8% expressed uncertainty about the need for regulation, indicating some ambivalence or lack of information regarding regulatory measures. Only 1.8% of participants believed there should be no regulation, suggesting minimal support for an unregulated approach to synthetic biology, as noted by [5].

Regarding the awareness of existing regulatory agencies, 16.8% of respondents believed there is an institution mandated to regulate synthetic biology (See Figure 15). Among those who identified such an agency, 57% mentioned the National Biosafety Management Agency (NBMA) as the primary regulatory body (See Figure 16). Other institutions mentioned include Bayero University Kano (10%), Ahmadu Bello University (9%), the National Agency for Food and Drug Administration and Control (NAFDAC) (9%), and smaller percentages for organizations such as the Standards Organization of Nigeria (SON), National Biotechnology Development Agency (NABDA), and the Nigeria Centre for Disease Control (NCDC).

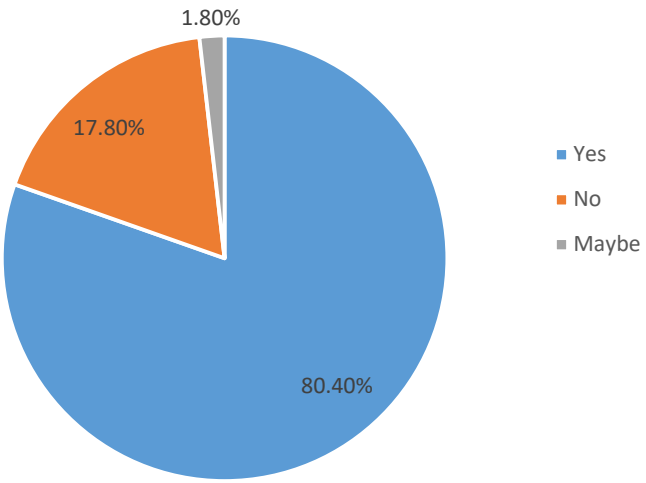

Figure 14. Responses on the Need to Regulate Synthetic Biology.

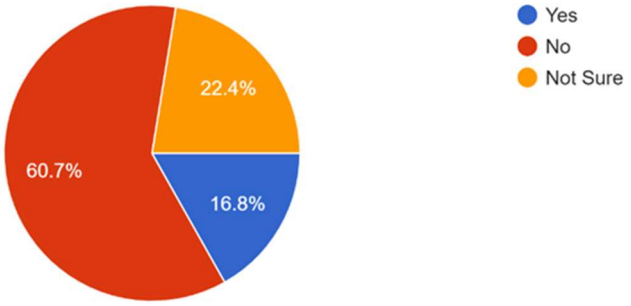

Figure 15. Responses on Institutions Mandated to Regulate Synthetic Biology.

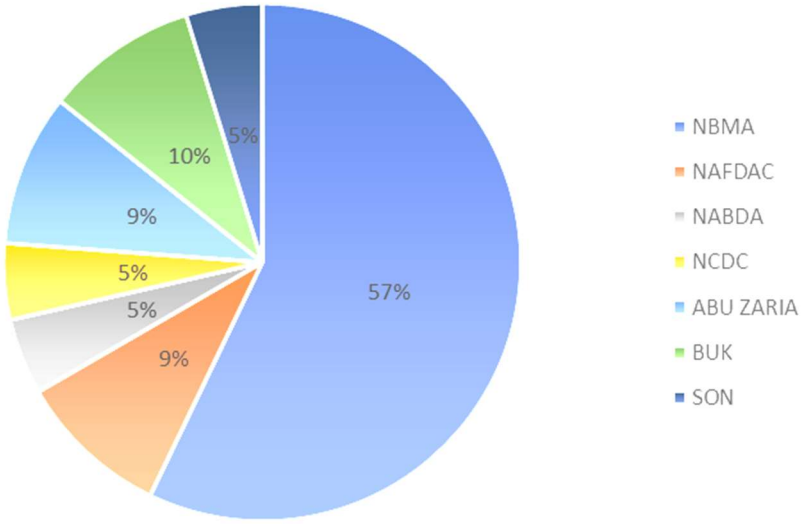

Figure 16. Responses on Agencies that Regulate Synthetic Biology.

When asked who should regulate synthetic biology, 72.9% of respondents believed that the Federal Government, in collaboration with academia and industry, should develop the regulatory framework (See Figure 17). Additionally, 8.4% favored a government-led approach, while 7.5% suggested that industry or academia should take the lead in developing the guidelines, with the government overseeing their implementation. The remaining 11.2% were uncertain about the best regulatory approach.

Figure 17. Responses on how Synthetic Biology should be Regulated.

4.8. Perspectives on the Practice of Synthetic Biology

The responses, as illustrated in Figure 18, provide a comprehensive view of the participants' attitudes towards the practice of synthetic biology. An overwhelming majority, 81.3%, expressed support for the practice of synthetic biology. This strong endorsement reflects a positive attitude and recognition of the potential benefits that safe and responsible

synthetic biology can bring, such as advancements in medical research, environmental sustainability, and biotechnological innovations [4]. Conversely, a very small proportion, just 0.9%, indicated their non-support for the practice of synthetic biology. This minimal opposition could be attributed to concerns about ethical implications, potential risks, or a lack of understanding of the field. The extremely low percentage of opposition highlights that resistance to synthetic biology is not a significant barrier among the public [7]. Additionally, 17.8% of the respondents were undecided about their stance on practicing synthetic biology. This segment represents a considerable proportion of participants who might need more information, education, or engagement to form a clear opinion.

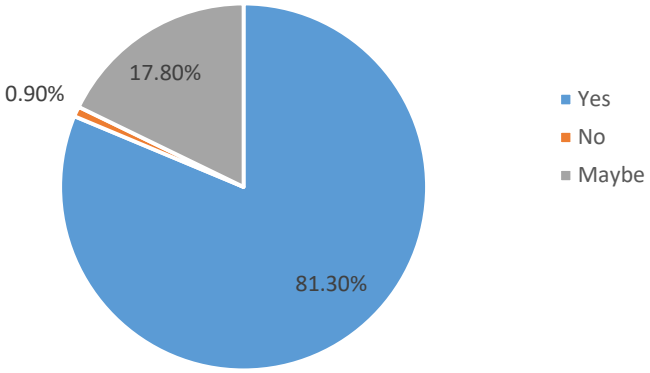

Figure 18. Response on Practice of Synthetic Biology.

4.9. Impact of Synthetic Biology

The responses, as depicted in Figure 19, reveal a strong perception among respondents regarding the global impact of synthetic biology. A significant majority, 76.6%, opined that synthetic biology has a positive impact on a global scale. This optimistic viewpoint likely stems from the numerous advancements and potential benefits that safe and responsible synthetic biology offers. The respondents might have recognized the role of synthetic biology in springing up innovations in healthcare, such as developing new therapies, in agriculture through enhancing food security, in environmental management by creating sustainable biofuels, and in bioengineering through engineered microorganisms that address environmental challenges and enhance industrial production [8].

On the other hand, 23.4% of the respondents were undecided about the global impact of synthetic biology. This considerable fraction of uncertainty suggests that while many see the benefits, there is still a significant portion of the bioscience stakeholders that may lack sufficient information or have reservations about the technology.

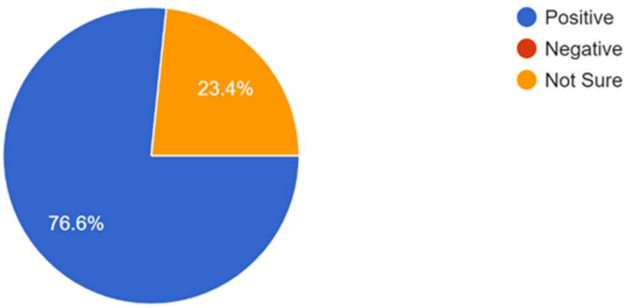

Figure 19. Responses on the Impact of Synthetic biology.

5. Discussion

The respondents' demographics are essential in understanding how synthetic biology is perceived across different age groups and professions. A significant portion of the respondents (78.5%) were aged between 18 and 45, a range where most individuals would not have witnessed the early development stages of synthetic biology, which gained momentum in the mid-2000s. As a result, many respondents in this age group may rely heavily on contemporary

education, media, and current industry applications to form their understanding of the field. This could explain the observed gaps in historical knowledge of synthetic biology, as foundational aspects may not have been emphasized in their education or professional experiences.

In contrast, the fewer older respondents (18.7% between 46–60 years and 2.8% between 60–70 years) may offer a broader perspective, particularly regarding the evolution of biotechnology and its historical challenges. Their responses could be more nuanced, particularly around issues of safety, ethics, and regulation, reflecting concerns that younger respondents may not fully grasp due to their limited exposure to the early challenges of synthetic biology [9].

The geographical distribution of responses shows a fair representation of bioscience stakeholders across Nigeria, highlighting the nationwide interest in synthetic biology. The South-South zone had the highest representation, which could indicate a more robust academic or research presence in that region. The diversity in professional backgrounds academia (45.8%), students (22.4%), and government institutions (19.6%) also suggests that synthetic biology is of interest to various sectors in Nigeria. Notably, the large percentage of academics and students suggests that synthetic biology is being increasingly integrated into educational curricula, while the involvement of policymakers and government workers signals growing institutional interest in regulating and developing the field. However, the relatively low participation of industry stakeholders (3.7%) indicates that the industrial application of synthetic biology might still be in its infancy in Nigeria.

The results indicate that although only 27.1% of respondents were fully familiar with synthetic biology, there is a spectrum of awareness across the population. The fact that some respondents claimed to have heard a lot about synthetic biology emphasizes the growing presence of the field in academic and professional circles. However, the significant proportion of individuals who had little or no knowledge of synthetic biology (56.1%) highlights a gap in awareness and understanding that could hinder the engagement of key stakeholders in the research and application of synthetic biology solutions.

The varying definitions provided by respondents reflect this gap in knowledge. Most respondents defined synthetic biology within the context of biotechnology or genetic engineering (23% and 21%, respectively), which suggests a narrower understanding of the field. This is consistent with global trends, where synthetic biology is often viewed as an extension of biotechnology due to its overlap with genetic engineering. A smaller fraction (14%) recognized synthetic biology as advanced engineering biology, while 9% linked it with artificial intelligence or nanotechnology, highlighting the multidisciplinary nature of the field.

These findings align with Nigeria's National Biosafety Management Agency Act, 2015, which defines synthetic biology as the design and construction of novel artificial biological systems or the redesign of existing natural systems. This overlap in definitions underscores the importance of education and outreach to ensure that stakeholders have a comprehensive understanding of the field's scope and its distinctions from related areas like biotechnology and genetic engineering. The diverse range of responses reflects the broad potential of synthetic biology across multiple sectors. The most common perception that synthetic biology is applicable in agriculture (21%) aligns with its role in genetically modifying crops to increase yields, improve resistance to pests, and enhance nutrient content. This is consistent with global trends, where synthetic biology plays a crucial role in advancing sustainable agricultural practices.

The belief that synthetic biology is useful for research (14%) and medicine (12%) points to its growing influence in academic and clinical environments. Synthetic biology's capacity to design novel biological systems makes it a valuable tool in medical research, particularly for developing therapies and diagnostic tools. Respondents who associated synthetic biology with environmental sustainability (9%) were likely thinking of its applications in bioremediation, where genetically engineered organisms can break down pollutants, or in the production of biofuels, which contribute to a more sustainable energy economy. Smaller percentages linked synthetic biology to genetic studies (8%), artificial intelligence (6%), and emerging fields such as vaccine and drug production (5% and 3%, respectively). This suggests that while respondents recognize synthetic biology's potential in these areas, there may still be limited awareness of its more cutting-edge applications, like bio-inspired nanotechnology (1%).

These findings echo several studies that have connected synthetic biology with all these applications. The field's most significant breakthrough remains its ability to alter metabolism and produce high-value products, from biofuels and plant natural products to polymer precursors and bio-inspired materials [10]. This capability is spearheading an industrial revolution in bio-manufacturing, where microorganisms are transformed into chemical factories that rival traditional organic chemical synthesis methods [11]. The concerns raised by respondents reflect the broader global discourse surrounding the ethical and safety implications of synthetic biology [12,13]. As with any emerging technology, these apprehensions need to be addressed for synthetic biology to gain broader societal acceptance. The primary concerns identified in this study; biosafety, biosecurity, ethics, and regulation mirror the issues discussed in the scientific community.

Biosafety concerns, such as the risk of exposure to harmful pathogens and toxic chemicals, are consistent with those already present in biotechnology fields like agricultural biotechnology [14]. However, synthetic biology's potential to create novel organisms introduces unique risks that must be carefully managed [15]. As more sophisticated organisms are engineered, new biosafety protocols may need to be developed to protect both workers and the public. Biosecurity is another significant issue, particularly with the potential for synthetic biology to be misused for harmful purposes, such as recreating known pathogens, enhancing existing ones to be more dangerous, or engineering microbes to produce harmful biochemicals [16]. The fear of bioterrorism and dual-use purposes, as reflected by 13% of respondents, underscores the importance of stringent regulations to prevent the misuse of synthetic biology technologies.

The environmental concerns raised particularly regarding biodiversity and ecosystem disruptions are also noteworthy [17]. Synthetic organisms used in agriculture, for instance, may have unintended consequences on land use and ecosystem services. These potential impacts reinforce the necessity for robust regulatory frameworks that ensure thorough risk and safety assessments before synthetic organisms are deployed in real-world applications [18]. Addressing these concerns through comprehensive regulatory measures, ethical debates, and transparent public engagement will be crucial to mitigating risks and promoting the responsible use of synthetic biology. The results demonstrate a generally positive attitude towards synthetic biology, with nearly half of the respondents recognizing the significant benefits of its applications in fields like medicine, agriculture, and environmental management. This favorable view is likely influenced by the transformative possibilities synthetic biology presents, such as the development of more effective drugs, drought-resistant crops, and biofuels that contribute to societal well-being and economic growth [19].

A noteworthy group of respondents perceives a balance between the risks and benefits, indicating awareness of both the potential advancements and the challenges posed by synthetic biology. This group seems to recognize the innovative solutions that synthetic biology offers while remaining conscious of ethical, environmental, and safety concerns that accompany these advancements. The smaller segment of respondents (5.6%) who believe that the risks outweigh the benefits might be primarily concerned with the unintended consequences of synthetic biology. Issues such as ecological disruption, biosecurity threats, and ethical dilemmas could drive this cautious perspective. These concerns align with broader discussions on the potential hazards of synthetic biology, including the disruption of natural ecosystems and the potential misuse of the technology for harmful purposes [20]. The substantial proportion of unsure respondents (29.9%) underscores the need for increased education and awareness campaigns. This uncertainty reflects a gap in knowledge about synthetic biology, not only within the broader public but even among bioscience stakeholders. Informing stakeholders and the public about synthetic biology's potential applications, associated risks, and regulation is crucial to fostering a more informed discourse on the benefits and challenges of this emerging field [8].

The results highlight a critical need for increased awareness and information dissemination about available synthetic biology training institutions in Nigeria. With only 13.1% of respondents aware of such institutions, it is evident that there is either a lack of visibility or a limited number of institutions providing training in this emerging field. The identification of research institutes as the primary hubs for synthetic biology training by 19% of the respondents aligns with findings in the study by [21], which recognizes the importance of research centers in fostering advanced training and development. However, the limited recognition of universities as key players in synthetic biology education, with only 13% of respondents pointing to these institutions, is concerning. This is consistent with [22], which suggests that higher education institutions are under-utilized in training the next generation of synthetic biologists, despite having the potential to play a more prominent role. The mention of organizations such as IITA and SHESTCO by another 13% of respondents underscores the significance of these institutions in promoting scientific research and innovation in Nigeria. These organizations are well-established within the research community and are expected to be influential in driving synthetic biology education and training forward. Interestingly, 6% of respondents noted that synthetic biology training occurs during conferences, highlighting the role of professional gatherings as important venues for skill development and networking. Conferences provide opportunities for hands-on training and staying current with advancements in the field, making them valuable for both knowledge dissemination and professional growth.

Overall, the survey results reveal a fragmented landscape of synthetic biology training in Nigeria, with research institutes, universities, and specialized organizations playing varying roles. However, the low level of awareness about these institutions points to the need for a more coordinated approach to increasing visibility and accessibility to synthetic biology education. Enhancing awareness of existing programs and improving access to training opportunities can help bridge the gap and foster greater development in this important field [2]. The survey responses suggest a multifaceted strategy for improving synthetic biology in Nigeria, with a strong emphasis on awareness creation. The fact that 23% of respondents called for increased awareness underscores the need for more educational and informational outreach

programs. Synthetic biology remains a relatively new field for many, and improving understanding through public campaigns, workshops, and conferences could significantly boost interest and participation in this domain [23].

Engagement through social media platforms, suggested by 13% of the respondents, is another modern approach that could play a pivotal role in advancing the field. Social media has the power to reach a wide audience, including the general public, students, and professionals. By leveraging platforms such as Twitter, LinkedIn, and Facebook, stakeholders can foster discussions, share updates on breakthroughs, and engage with a global audience on synthetic biology topics. This approach could help demystify synthetic biology and increase its appeal to a diverse demographic [11].

Education also plays a crucial role in this endeavor, as emphasized by 11% of respondents who suggested the inclusion of synthetic biology in the educational curricula. As mentioned in various studies, integrating synthetic biology into the curricula of higher institutions can give students early exposure to the field, providing them with the necessary knowledge and skills to contribute to its future development [14]. This step would ensure a steady pipeline of trained professionals capable of advancing synthetic biology research and innovation in Nigeria.

Funding, investment, and capacity building were also deemed important, with 9% of respondents highlighting the need for financial support, training programs, and legislative backing. As noted in [16], sufficient funding is essential for establishing research labs, supporting experimental projects, and running training programs. Moreover, capacity building ensures the continuous development of skills and expertise within the field. Legislation, such as the National Biosafety Management Agency Act of 2015, already provides a regulatory framework for synthetic biology in Nigeria. However, more targeted regulations and support could further promote safe and ethical advancements in the field.

Policy improvements were identified by 7% of respondents as another important factor. Developing policies that incentivize research and development, foster public-private partnerships, and streamline the commercialization of synthetic biology innovations can create an enabling environment for growth. Effective policies can remove barriers to innovation while maintaining the necessary safety and ethical standards required in such a highly specialized field. Finally, 5% of respondents pointed to the role of traditional media and specialized training programs. Traditional media campaigns can further publicize synthetic biology, making it more accessible and understandable to a wider audience. Meanwhile, specialized training programs can offer in-depth, hands-on experience for individuals looking to pursue careers in this field [24]. This dual approach would ensure both public awareness and professional competence, driving the advancement of synthetic biology in Nigeria. In summary, the responses reveal that a comprehensive approach encompassing awareness creation, social media engagement, educational integration, funding, capacity building, legislative support, policy improvements, and media outreach is essential for advancing synthetic biology in Nigeria (See Figure 13).

The survey responses indicate a strong preference for the regulation of synthetic biology, with 80.4% of participants supporting the need for regulatory oversight. This overwhelming majority highlights a broad consensus that synthetic biology, as a rapidly evolving field, requires robust frameworks to ensure safety and ethical standards. The small percentage of respondents (1.8%) who opposed regulation reflects a minimal inclination toward a laissez-faire approach, in line with previous studies, such as [5], that point to the risks of an unregulated synthetic biology landscape.

However, the responses also reveal a gap in awareness regarding which institution currently oversees synthetic biology regulation. Only 16.8% of respondents identified an existing regulatory body, suggesting a need for better communication and advocacy about Nigeria's regulatory framework. The National Biosafety Management Agency (NBMA) was the most commonly cited institution, recognized by 57% of respondents. This aligns with NBMA's mandate to regulate modern biotechnologies, including synthetic biology, as per the National Biosafety Management Agency Act of 2015 (as amended in 2019). NBMA's authority over gene editing, gene drives, and synthetic biology demonstrates its central role in ensuring the safe development and application of these technologies in Nigeria. In line with the NBMA Act 2015 (as amended), the agency also collaborates with other institutions and subject-matter experts in performing risk assessments.

Interestingly, academic institutions such as Bayero University Kano (10%) and Ahmadu Bello University (9%) were also viewed as potential regulatory entities, reflecting the perception that universities may play a role in the governance of synthetic biology. However, this may stem from the involvement of these institutions in research and training, rather than direct regulatory authority. Similarly, organizations such as NAFDAC, SON, NABDA, and NCDC were mentioned by respondents, suggesting a perception that synthetic biology regulation could require collaboration across various sectors, given the wide range of potential applications, from food and drug safety to disease prevention and biotechnology standards.

The survey also highlights differing views on the optimal regulatory structure for synthetic biology in Nigeria. The majority (72.9%) favored a collaborative approach, with the Federal Government working alongside academia and

industry to create comprehensive guidelines. This reflects international best practices, which advocate for multi-stakeholder engagement in developing regulatory frameworks. Such an approach ensures that regulatory standards are informed by scientific research and practical industry considerations. Meanwhile, 8.4% preferred a centralized government-led framework, with the government solely responsible for guideline development, and 7.5% supported a system in which academia or industry develops the guidelines, with government enforcement. This split in opinions suggests ongoing debates about the most effective regulatory model for synthetic biology.

The study findings further align with recommendations from studies like [5,7], which call for dedicated regulatory frameworks tailored to the specific challenges and opportunities of synthetic biology. The Convention on Biological Diversity (CBD) has similarly emphasized the importance of proactive regulation to manage the risks and benefits associated with synthetic biology. In Nigeria, adopting a separate set of standards and guidelines for synthetic biology, in line with global discussions under the CBD, could help address these regulatory challenges and ensure that the country remains at the forefront of biosafety and biotechnology governance.

Overall, the survey results underscore the importance of regulation in synthetic biology, with a strong preference for a collaborative, multi-stakeholder approach involving government, academia, and industry. However, gaps in awareness about existing regulatory bodies and responsibilities highlight the need for improved communication and clarity about synthetic biology oversight in Nigeria. This will ensure that the field can develop safely, ethically, and in line with global best practices (See Figure 17).

The survey responses indicate that while there is substantial backing for the practice of synthetic biology, it is important to put in place measures to address the concerns and informational gaps that lead to uncertainty or opposition. This could involve more comprehensive educational initiatives, transparent discussions on ethical issues, and showcasing successful applications and safe practices in synthetic biology to garner broader acceptance and informed support [15].

The undecided respondents highlight the necessity for continuous education and transparent communication about the successes, challenges, regulation, and future potentials of synthetic biology. This could involve public engagement initiatives, educational campaigns, and open forums to build a well-rounded understanding of the ethical, societal, and environmental implications of synthetic biology [21,25].

6. Conclusions

The findings of this study have provided a view of the awareness of the synthetic biology among bioscience stakeholders in Nigeria and also illuminated critical issues for future consideration in view of the significant gap in the knowledge of synthetic biology among these stakeholders. Synthetic biology is an emerging biotechnology and as expected may witness the “crisis of trust” especially in developing countries like Nigeria contributing to high level of unawareness of it’s potentials, concerns and regulation among the public even within the bioscience stakeholders. The benefits of safe and responsible application of synthetic biology cannot be overemphasized and it is therefore recommended that articulated policy initiatives on synthetic biology that will heighten advocacy including conferences and symposiums, capacity building and stakeholder participation be champpioned with the aim of working on the collective vision for the future safe bio-economic growth. It is also recommended that in promoting awareness and stakeholders participation on issues of synthetic biology in Nigeria, a need to consider and hold upon the already policy pre-requisites such as the biosafety law (which mandates the regulation of synthetic biology) and biotechnology policy, the national value system, and the communicative channels that will enable efficient participation in synthetic biology. This will together foster the acceptance of safe and responsible synthetic biology in Nigeria, thereby contributing to the broader national bio-economy development.

To promote the safe and responsible development of synthetic biology in Nigeria, there is an urgent need for a comprehensive policy framework that addresses both the potential benefits and risks of the technology. Policymakers should focus on strengthening existing biosafety regulations, such as the NBMA Act, and ensuring that these regulations are implemented to reflect the latest advancements in synthetic biology. Additionally, promoting public engagement through conferences, symposiums, and stakeholder consultations will be essential for building trust in the technology. Nigeria can also benefit from aligning its synthetic biology policies with international best practices, particularly those developed under the Convention on Biological Diversity (CBD). Looking to the future, Nigeria has the opportunity to position itself as a hub for safe and responsible synthetic biology innovation in Africa. By fostering a supportive ecosystem that encourages research, development, and commercialization of synthetic biology applications, Nigeria can unlock new economic opportunities in areas such as biotechnology, agriculture, healthcare, and environmental

management. This will require sustained investment in education, research infrastructure, and public-private partnerships to drive the growth of safe and responsible synthetic biology and ensure its contributions to national bio-economic development.

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Author Contributions

All the authors provided significant contribution to this study. Conceptualization, J.C.I., O.K.N., A.M. and E.A.; Methodology, O.K.N. and J.C.I.; Validation, G.O. and E.A.; Investigation, J.C.I., O.K.N. and A.M.; Data Curation, O.K.N.; Writing—Original Draft Preparation, J.C.I. and O.K.N.; Writing—Review & Editing, J.C.I., O.K.N., A.M. and G.O.; Visualization, J.C.I., O.K.N.; Supervision, J.C.I. and O.K.N.; Project Administration, J.C.I., O.K.N. and A.M.

Ethics Statement

Not applicable.

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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