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Systematic Review of Green Chemistry in Nigeria: Current Status, Challenges and Opportunities

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ABSTRACT

Green chemistry which is an approach to chemical research and development that emphasizes the design of chemical products and processes that are safe, efficient, and environmentally sustainable as illustrated by its 12 principles, has gained significant attention globally. However, its adoption in Nigeria is still very much limited. This research paper methodologically highlights and reviews the current status, challenges, and opportunities for green chemistry in Nigeria. The paper illustrates the potential benefits which adopting green chemistry in Nigeria would present, including enhanced environmental sustainability, improved health and safety, and increased economic competitiveness along with job creation.

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The review also discusses the possible challenges in the process of implementing green chemistry in Nigeria, such as limited awareness, inadequate infrastructure, and insufficient funding. It concludes by identifying opportunities for promoting the adoption of green chemistry in Nigeria, including policy reforms, research and development, and education and training and finally recommendations were made to the governing bodies and policy makers on how the implementations can be done along with the many benefits it poses to the country and world at large.

Keywords: Green, Sustainable, Environment, Chemistry, Nigeria.

1. INTRODUCTION

Over the years, chemistry has evolved to find applications in so many ways, most of which are beneficial to man and nature, while some effects have also been detrimental, especially in terms of pollution. Pollution of air, soil, water, etc. these have come over time via the practice of chemistry, both from by-products of chemical processes which eventually beome pollutants, improper disposal, and management of chemical watse products, etc. This has created a pollution problem (both the significant and the not-so-seemingly significant) which has consequently led to more problems in our environment such as climate change, mutation from exposures to radiation, declining raw material sources, and so on.[1]

With scientists trying to modify and innovate chemistry in such a way that curtails this consistent declinations, the concept of practicing chemistry in a “Green” and “Sustainable” way was concieved. The term 'Green Chemistry' which is also similar to 'Sustainable Chemistry' and 'Circular chemistry'; although they are different,[1] can be described to be the design of chemical processes and products that eliminates or at least reduces the use or generation of hazardous substances.[2] It emerged from a consensus of various already existing ideas during the 1980's leading up to the 1990s when there was increasing attention to the problems of chemical pollution and resource depletion, and the concepts which are now recognized as 'Green Chemistry' were coalesced and the term was more broadly adopted over competing terms such as 'clean' and 'sustainable' chemistry.[3,4]

Figure 1. Green Chemistry Illustration. (Varsha G, 2024).

1.1. Green Chemistry Principles

From its conception, the way of green chemistry has shown to be very important in both the mitigation of waste and environmental pollution, which is evident in the scope of its 12 principles listed and illustrated below.[5]

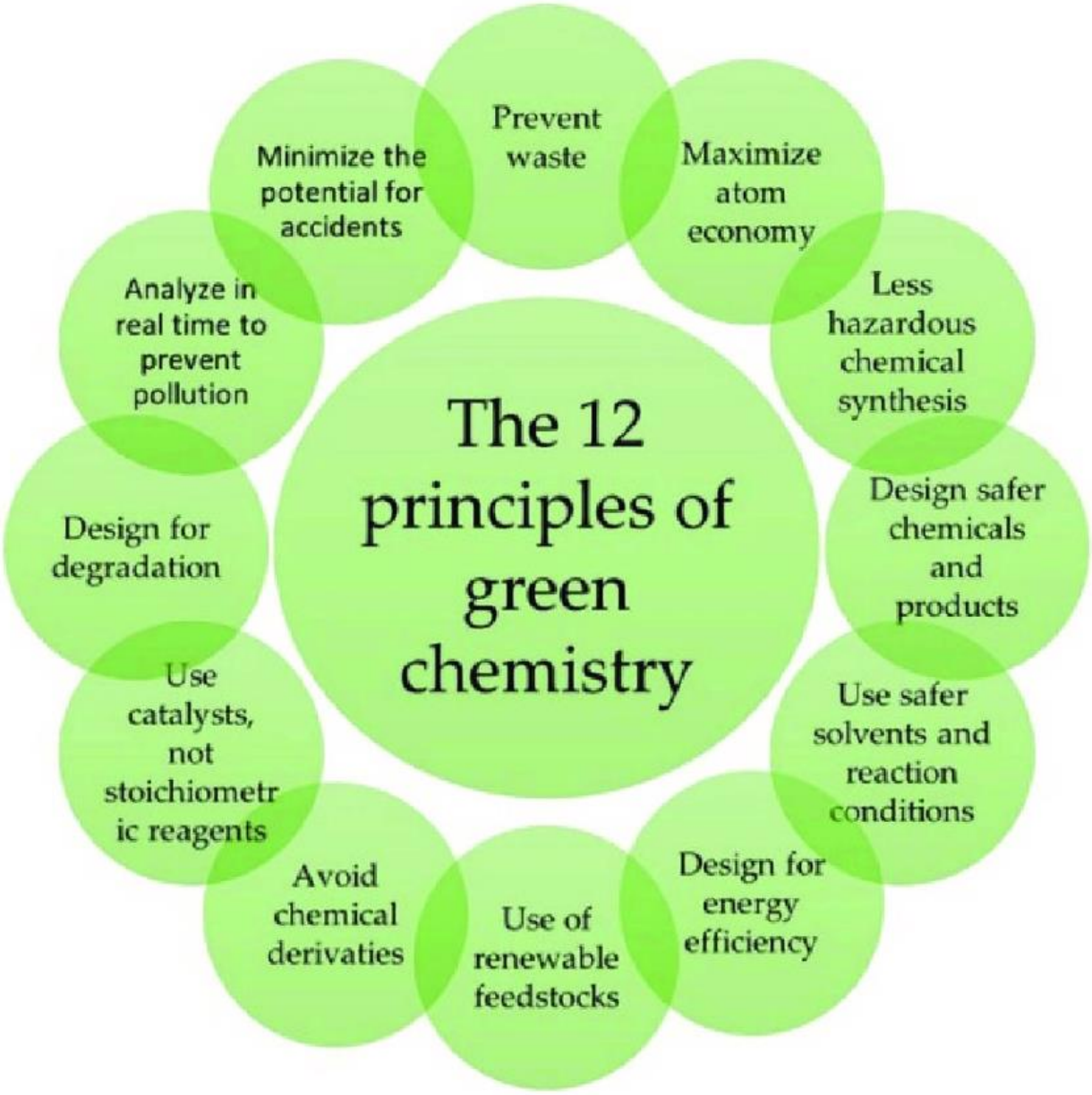

Figure 2. 12 Principles of Green Chemistry. (Humphrey Sam samuel, 2024).

1.1.1. Waste prevention: that is to design chemical synthesis to prevent wastes, i.e leave no waste to treat or cleanup.[6] In contrast to conventional chemistry, which often generates waste that must be managed, Green chemistry focuses on preventing waste rather than treating or cleaning it up after it is formed. Example is Neutralization reaction, which produces no wastes and only useful products.

1.1.2. Maximize atom economy: that is to design synthesis in a way that the final product would contain the maximum proportion of the starting materials, i.e waste few or no atoms.[7]

Example: Combustion of Methane

$CH_4+O_2 \rightarrow CO_2+2H_2O$

This reaction has a high atom economy because all reactant atoms are accounted for in the products.

1.1.3. Design less hazardous chemical synthesis: that is design synthesis that would use and generate substances that have little or no toxicity to or with humans or to the environment.[8]

Example: HCl + NaOH → NaCl + H2O (Neutralization).

This reaction does not produce any toxic byproducts.

1.1.4. Design safer chemicals and products: design chemical products that are fully effective yet have little to no toxicity.[9]
Example: Replacing toxic solvents like benzene with greener alternatives such as ethanol in reactions.

1.1.5. Use safer solvents and reaction conditions:that is ensure to avoid using solvents, auxiliary chemicals, or separation agents. If necessary, use safer ones.[10]
Example: Using water as a solvent instead of organic solvents, such as acetone or dichloromethane, to reduce environmental impact.

1.1.6. Increase energy efficiency: avoid excessive uses or waste of energy during chemical reactions, run them at room temperature and pressure whenever possible.[11]
Example: Using a catalyst in a reaction to lower the required temperature and reduce energy consumption, such as Pt in the hydrogenation of alkenes.

1.1.7. Use renewable feed stocks: the starting materials for feedstock should be renewable rather than resources that deplete. For instance, feedstock from agricultural products and/or wastes should be preferred over depleting sources like fossil fuels.[12]
Example: Using plant-derived biomass, such as sugarcane or corn, to produce bioethanol instead of relying solely on fossil fuels.

1.1.8. Avoid chemical derivatives: derivatives are additional reagents and generate waste, hence using blocking or protecting groups or any temporary modifications should be avoided as much as possible.[13]
Example: Directly converting an alcohol to an alkene without intermediate functional group transformations, reducing the number of steps and waste generation.

1.1.9. Use catalysts, not stoichiometric reagents: catalysts are preferred to stoichiometric reagents as they are effective in small amounts and can carry out a single reaction many times, thereby minimizing waste.[14]
Example: Using enzymes in biocatalysis to selectively convert a substrate into a desired product with higher efficiency and without generating harmful byproducts.

1.1.10. Design chemicals and products to degrade after use: that is design products and chemicals that would be able to break down into innocuous substances after they are used so they do not accumulate as pollutants in the environment.[15]
Example: Using biodegradable polymers, such as polylacticacid (PLA), that break down into CO_2 and H_2O when exposed to micro-organisms.

1.1.11. Analyze in real time to prevent pollution: this involves real-time monitoring and control of the synthesis process in order to reduce or totally eliminate formations of undesirable by-product.[16]
Example: Continuously monitoring the pH of waste-water during a reaction to prevent the release of acidic or alkaline effluents.

1.1.12. Minimize the potential for accidents: chemicals and their physical forms (solid, liquid etc) should be designed in such a way that it reduces the risk of chemical accidents such as; fires, explosions, and releases to the environment.[17]
Example: Choosing less reactive reagents, such as using sodium hypochlorite instead of chlorine gas, to minimize the potential hazards during reactions or experiments.

In recent years, there has been a growing interest in green chemistry in Nigeria, with researchers and policymakers recognizing the importance of incorporating sustainable practices into the country's chemical industry. This systematic review of green chemistry in Nigeria aims to provide a comprehensive overview of the current status, challenges, and opportunities in this emerging field. By examining existing research, policies, and initiatives that are related to green chemistry in Nigeria, the paper seeks to identify gaps in knowledge, highlight areas for improvement, and propose recommendations for promoting the adoption of sustainable practices in the country's chemical and technological sector.

2. METHODOLOGY

The method employed for the purpose of this review includes research and data sourcing from different journals and publications both Google Scholar, Springer, etc. and also databases like the Wikipedia and dictionaries, all of which were duly referenced throughout the work. Fom these databases, substantial information concerning the present situation with green chemistry and green technology specifically in the country Nigeria were obtained and systematically reviewd to illustrate the laxities of the country towards embracing the concept. The evidential benefits which other parts of the world which are actively going green are currently enjoying were also sourced, cited, and reviewed to illustrate the potential benefits of the adoption of green concepts to the country Nigeria.

3. GREEN CHEMISTRY INNOVATIONS AND GREEN TECHNOLOGIES

Figure 3. Green Innovations and Technologies. (Samuel Mbah, 2024).

The adoption and implementation of the concept, innovations of green chemistry and green technologies has made significant contributions to major nations around the world and the global community as a whole in many ways.

3.1. Green Innovations And Benefits

Some key ways by which it has benefited the world at large and many countries that have been intentional about going green along with some innovations include;

3.1.1. Environmental Protection

An instance is the European Union's REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) regulation, which has been instrumental in promoting the use of safer chemicals and reducing the environmental impact of hazardous substances. Through REACH, the EU has made significant progress in improving chemical safety and protecting human health and their environment.[18] As green chemistry principles focus on minimizing the use of hazardous substances and general reduction in the generation of pollutants, By promoting cleaner production processes and innovative technologies, countries have been able to significantly decrease their environmental impact. This has led to improvements in air and water quality, preservation of ecosystems, and overall sustainability.

3.1.2. Resource Efficiency

The concept of green chemistry encourages the efficient use of resources by emphasizing waste prevention and the design of processes that maximize the use of raw materials. This has helped many nations reduce their dependence on limited resources, conserve energy, and lower production costs. As a result, countries have been able to drive economic growth while minimizing their ecological footprint simultaneously. The United States Environmental Protection Agency (EPA) as an instance, promotes green chemistry through programs like the Presidential Green Chemistry Challenge Awards, which recognize companies that have made significant contributions to reducing waste and conserving resources through innovative chemical processes.[19]

3.1.3. Health and Safety

By prioritizing the development of safer chemicals and products, green chemistry plays a significantly crucial role in safeguarding public health and enhancing occupational safety. Countries that have embraced green chemistry practices have seen a reduction in chemical-related accidents, improved worker well-being, and better protection for consumers against harmful substances. Canada's Chemicals Management Plan (CMP) for instance, has led to the assessment and management of thousands of chemicals to ensure their safe use and protect human health. By prioritizing the evaluation of high-risk substances and promoting alternatives, Canada has enhanced chemical safety and reduced exposure to harmful chemicals.[20]

3.1.4. Innovation and Competitiveness

Investing in green chemistry research and technology development has the potential to spur innovation and drive competitiveness in various industries. Nations that have adopted green chemistry have seen the emergence of new markets for sustainable products, increased opportunities for green startups, and enhanced global competitiveness through the adoption of environmentally friendly practices. Germany, for one, is known for its strong focus on research and innovation in green chemistry, with initiatives like the German Federal Ministry of Education and Research's (BMBF) funding programs for sustainable chemistry.

These investments have led to the development of cutting-edge technologies and sustainable products that have boosted Germany's competitiveness in the global market.[21]

3.1.5. Climate Change Mitigation

With the observed negative changes in the Earth's climate, green chemistry offers solutions for mitigating climate change by promoting the use of renewable feedstocks, developing alternative energy sources, and reducing greenhouse gas emissions. Countries that have integrated green chemistry into their climate action strategies have been able to make significant progress towards achieving their emission reduction targets and transitioning to a low-carbon economy. The Kyoto Protocol, which is an international treaty aimed at reducing greenhouse gas emissions, is an instance that has spurred the adoption of cleaner production processes and renewable energy sources in countries around the world. By implementing green chemistry practices, nations have been able to contribute to global efforts to address climate change and transition to a low-carbon economy.[22]

3.1.6. Public Perception and Corporate Responsibility

The ability to embrace green chemistry practices has enhanced the reputation of nations as environmentally responsible entities that prioritize sustainability and are socially responsible. By demonstrating a commitment to green chemistry principles, countries have built trust with citizens, investors, and international partners, leading to positive public perception and support for sustainable initiatives. Companies like Procter & Gamble, for instance, have incorporated green chemistry principles into their product development process, leading to the creation of more sustainable and environmentally friendly consumer goods. By aligning their business practices with sustainability goals, companies can enhance their reputation and demonstrate corporate responsibility to consumers and stakeholders.[23]

3.1.7. Global Collaboration and Knowledge Sharing

By sharing best practices, exchanging knowledge, and working together on international initiatives, green chemistry has facilitated global collaboration among nations, research institutions, and industry stakeholders to address common environmental challenges and promote sustainable development. Countries have been able to leverage collective expertise and resources for the greater good of the planet. The International Sustainable Chemistry Collaborative Centre (ISC3) facilitates collaboration among countries and organizations to promote sustainable chemistry solutions worldwide. Through initiatives like the Global Chemical Leasing Award, ISC3 fosters knowledge sharing and best practices exchange to advance sustainable development goals globally.[24]

Meanwhile, despite the significance and potential benefits of the implementation of green chemistry and its innovations for developing countries like Nigeria,[25] it is still very much lacking.[26] The current practices in these countries, especially based on governmental policies, do not prioritize safety, pollution prevention, and energy efficiency.[27] The prevailing issues of environmental pollution and waste generation stem from policies that focus on end-of-pipe treatment. The dependence on efficient use of resources, particularly energy and water, for incoming generation may result in serious consequences for future generations. Meanwhile, the use of sustainable chemistry has the potential to greatly improve the difficult conditions that many developing countries are facing. Examples of this include the use of solar energy, sustainable farming practices, recycling, and the implementation of life-cycle thinking and analysis for managing chronic issues such as municipal waste. Green chemistry can also greatly benefit water sufficiency issues in areas where water resources are polluted and/or limited.

By utilizing cleaner production and safe, biodegradable chemicals, a significant amount of wastewater can be reused to address the critical need for water in these countries.[28]

3.2. Green Technologies

Figure 4. Recycling and Recycleable Technology. (Telecom Review, 2022).

There is also the concept of Green Technology which refers to the implementation of technology and scientific methods to minimize the negative effects of human activities on nature.[29] This includes techniques such as generating clean energy,[30] employing different forms of fuel, and utilizing technologies that are less damaging to the environment than traditional fossil fuels.[31] Green technology spans a broad spectrum of scientific exploration, comprising fields such as energy, atmospheric science, agriculture, material science, and hydrology.[32] Its primary objective is to diminish the production of carbon dioxide and other greenhouse gases that are the underlying cause of climate change.[33] One of the most fruitful green technologies is solar power[34] and it has in fact become more cost-effective to put into use than fossil fuels in certain and especially developed countries.[35]

Examples of Green Technologies:

Some of the many examples of Green Technologies include:

3.2.1. Emissions treatment

The regulation of the emission of exhaust air produced whilst carrying out industrial production can play a crucial role in decreasing the greenhouse effect. Hazardous materials like methane and carbon dioxide can have a damaging impact on the environment. Industries, including the chemical, petrochemical, and pharmaceutical sectors, are required to eliminate their polluting emissions to prevent severe environmental harm.[36]

3.2.2. Waste-to-Energy

This refers to technology that converts waste into energy. It can be abbreviated as "W2E". There are various methods such as incineration or pyrolysis to achieve energy generation from waste. These waste treatment solutions produce steam, hot water, or electricity, which can be utilized by production plants for their internal processes, offering economic and environmental benefits.[37]

3.2.3. Recycling and Waste Management

This has become crucial due to the disproportionate increase in household and industrial waste. Implementing advanced technologies like smart containers, automated food waste tracking systems, and automated optical scanning can aid in sorting mixed plastics by separating them from other materials.[38]

3.2.4. Bio-fuels

The conversion of plastic waste into biofuel is an economically viable way to add value to the waste. This process, known as pyrolysis, generates two valuable products - fuel oil and char, both in high demand and profitable.[39]

3.2.5. Wastewater Treatment

This has witnessed significant technological advancements including membrane filtration, microbial fuel cells, nanotechnology, and biological treatments. These processes are used to make water potable or reduce the amount of pollutants discharged into oceans and rivers.[40]

3.2.6. Solar Energy

Energy derived from the sun, aims to reduce dependence on fossil fuels and promote greener solutions. Extensive research and development efforts have been focused on solar energy systems, including technologies like high-vacuum tubes for hot water, polypropylene collectors for hot water, photovoltaic collectors for electricity production, and solar streetlamps.[41]

3.2.7. Wave and Tidal Energy

This harnesses the power of ocean waves and tides. The first wave energy management plant, located in Aguçadoura, Portugal, is capable of supplying electricity to approximately 1500 homes. The plant consists of floating steel tubes called "Pelamis" that convert wave movement into electrical energy.[42]

3.2.8. Eco Vehicles

Also known as ecological vehicles, do not emit pollutants into the atmosphere. They contribute to reducing the presence of harmful gases like carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxide (NOx), unburned hydrocarbons (HC), lead compounds, and sulfur dioxide.[43]

3.2.9. Smart buildings

Also called self-sufficient buildings, generate their own energy without relying on external sources. Incorporating intelligent solar tracking systems in photovoltaic panels allows for optimal utilization of sunlight, increasing energy production without requiring additional surface area.[44]

3.2.10. Vertical gardens and farms

When installed in buildings, these can provide environmental benefits and energy conservation. Vertical gardens require less water and help reduce outside noise pollution. They also contribute to temperature regulation, resulting in energy savings on heating and air conditioning. Extrapolating this technology to farms can save significant amounts of water and preserve fertile soil. There are even vertical farms covering up to 100 hectares in size.[45]

3.3. Current Status of Green Chemistry in Nigeria

Green chemistry is still in its early stages of development in Nigeria.[46] However, there has been a growing recognition of the importance of sustainable practices and environmental stewardship in the country. Efforts are being made by various organizations, institutions, and government agencies to promote the adoption and implementation of green chemistry principles.[47]There has been research and suggestions on how green chemistry concepts can be integrated into the Nigerian academic curriculum, aiming to equip students with knowledge and skills in sustainable chemical practices at an early stage.[48] Additionally, the Nigerian Society of Chemists has been organizing conferences and workshops to raise awareness about green chemistry among scientists and educators.[49][50]

Some research institutions and sectors in Nigeria, such as the Directorate of Research and Innovations Imo State University, are also actively conducting seminars and studies on green chemistry, focusing on areas such as renewable energy, waste management, and environmentally friendly synthesis methods. There are also some university research groups focused on green chemistry and its research, such as:

a) Green Reseach in Analytical Chemistry, Environmental & Climate Change (GRACE & CC). Department of Chemistry, Imo State University.

b) Organic Synthesis & Natural Products Group. Department of Chemistry, Ahmadu Bello University.

c) Analytical/Environmental Chemistry Research Group, Department of Pure and Industrial Chemistry, University of Nigeria, Nsukka. Etc.

These efforts aim to develop sustainable technologies and solutions that minimize the environmental impact of chemical processes.

However, it is important to note that challenges still exist in fully integrating green chemistry practices into industrial processes and policies in Nigeria, even though limited funding, lack of awareness, and traditional practices pose obstacles to the widespread adoption of green chemistry principles. Nonetheless, with increasing global awareness and the commitment of various stakeholders, the future looks promising for the growth and implementation of green chemistry in Nigeria.

3.4. Potential Benefits of Green Chemistry to Nigeria

In a country like Nigeria, with a population of about 202million people, population density of 221 per km^2 and about 51.2% of the population urbanized,[51][52] yet still plagued with diverse and significantly high levels of pollution, both air, water,[53] deforestation,[54] erosion,[55] desertification[56] as well as record levels of wastes both from oil spillage,[57] by-products of industrial processes, etc. and high percentage of these pollutants coming from chemical processes, majority fossil fuel mining, refining, consumption, and other anthropogenic activities.[58] Thorough enlightenment of the masses about and also the implementation of the principles of green chemistry would be of immense benefits such as:

3.4.1. Human Health:

a) **Cleaner air:** reduction of hazardous chemicals being emitted to the atmosphere would lead to less lung damage and diseases.
b) **Cleaner water:** reduction of hazardous chemical wastes to waste, hence leading to cleaner drinking and recreational water.
c) **Increased safety for workers in the chemical industry:** less toxic materials, personal protective equipment required; less potential for accidents (e.g. fire or explosions).
d) **Improved consumer products:** New and safer products will be available for purchase, reducing the risk to consumers. This includes products like drugs, which will be produced with less waste, as well a as replacements for less safe products like pesticides and cleaning agents.
e) **Safer food:** The elimination of persistent toxic chemicals that can enter the food chain will ensure that food is safer for consumption. Additionally, safer pesticides that only harm specific pests and break down quickly after use will be used.
f) **Reduced exposure to toxic chemicals**: Harmful chemicals, such as endocrine disruptors, will be minimized, resulting in lower exposure for individuals. This will benefit both humans and the environment.[59]

3.4.2. Environmentally-friendly practices

Many chemicals end up in the environment through intentional or unintended releases, as well as improper disposal. Green chemicals will either degrade into harmless substances or be reused. This will protect plants, animals, and ecosystems from harm and contribute to a decrease in global warming, ozone depletion, and smog formation.[60]

3.4.3. Positive impact on the economy and business

Chemical reactions will yield higher amounts of product using smaller feedstock quantities. This will reduce waste, save energy and water, and allow for faster manufacturing and increased production capacity. It will also eliminate the need for costly remediation, hazardous waste disposal, and end-of-the-pipe treatments. Additionally, the use of waste products as replacement for purchased feedstock will be encouraged. This will reduce reliance on petroleum products and their associated dangers and price fluctuations. Chemical manufacturers and their customers will become more competitive in the market by earning and displaying safer-product labels like the Safer Choice label.[61]

3.5. Challenges to Developing Green Technology in Nigeria

Nigeria is confronted with several peculiar challenges which make a green agenda appear unattainable.[62] Some of the challenges to the development of green technologies and practice of Green Chemistry in Nigeria are;[63][64][65]

3.5.1. Economic and Financial Challenges

The development of renewable energy systems in Nigeria faces significant economic and financial challenges. These obstacles stem from several factors, including limited access to funds, insufficient life support, and inadequate information from financial institutions, inadequate investment, oversized energy systems, unsuitable government subsidies, and organizational size.

Most financial institutions may hesitate to invest in renewable energy businesses due to ignorance or inadequacy of information materials about new technologies, which could potentially work against them. Consequently, both the installer and the end-user suffer from inadequate funds, which severely limit the ability to either acquire new renewable energy systems or upgrade existing ones. Moreover, the renewable energy systems' large scale consistently poses a challenge since the initial outlay is relatively higher than most fossil fuel alternatives. As a result, convincing end-users to adopt renewable energy technologies has become increasingly difficult, and investments in new technologies are financially extensive. These factors inevitably lead to high manufacturing costs with low profit margins, making renewable energy systems even more expensive in Africa due to low patronage and high research and development costs.[64][65]

3.5.2. Technical challenges

Developing renewable energy systems in Nigeria has faced a significant challenge due to a lack of technical expertise, which may continue to hinder its progress. The technical failures of these systems are a result of various factors, including the inadequate understanding of local energy needs, insufficient research and development to adapt technology to local conditions, a deficiency of skilled labor to install and maintain the equipment, and a scarcity of replacement parts. These technical barriers have been responsible for the failure of most pilot programs in rural communities where access to maintenance services is difficult and the costs are too high for the beneficiaries. The lack of local consultation and effort to tailor the devices to specific usage requirements lead to outdated designs and equipment that may become obsolete without accessible technical support. Consequently, the energy systems eventually face redundancy and abandonment by users.[63][64]

3.5.3. National Policies and Awareness Program Challenges

The government plays a crucial role in determining the success or failure of national programs aimed at improving living conditions, such as the introduction of renewable energy initiatives. Many African countries have included renewable energy systems in their development plans, but the pace of growth is largely dependent on government interest and involvement. Until 2005, Nigeria had no official policy on renewable energy, which made it difficult to coordinate efforts and progress was mainly driven by individuals, societies, and corporations. This lack of government direction was attributed to political instability and a prioritization of personal interests over national objectives. This situation resulted in slow growth, high system costs, and low awareness among the Nigerian population regarding the benefits of renewable energy. The focus of national policy has been on conventional energy sources for electricity, discouraging investment in alternative options due to subsidies for grid power. This has prevented a fair competition among energy sources, hindering the growth of alternative electricity services.[64][65]

3.5.4. Political, institutional and legislative challenges

If the proper political and legislative framework is established, Nigeria has the potential for significant advancement in renewable energy systems. Due to the foreign nature of the technology, it is necessary to enact appropriate legislation to prevent Nigeria from becoming a dumping ground for technologically advanced nations. This might involve imposing zero taxes on renewable products and providing large subsidies for the poorest communities. Such legislation would also help reduce the importation of sub-standard goods. However, ensuring the security of these installations poses challenges. This issue is not unique to Africa, and globally, security concerns must be considered in deciding how and where to install renewable systems. Security provisions often increase installation costs.

Even major projects have suffered from vandalism and theft, and this applies to all types of installations, from personal solar home systems to community mini-solar and street light systems.[63][65]

3.5.5. Social, cultural, and environment constraints

It is crucial for renewable energy technology to be socially accepted, as lack of acceptance can present significant challenges. The technology may not be in demand if local communities do not approve of it. For instance, installing solar cookers in communities that prohibit women from cooking during certain times may not be practical. The reason why many renewable energy projects have failed is that the people who benefit from them were not included in the decision-making process. Engaging end-users can increase interest in the technology because they are more likely to benefit from it when their needs are taken into account or they are convinced of its value.[64][65]

3.5.6. Intermittency of resource availability

This is another major challenge as all renewable electricity resources face this common obstacle, which is the fact that their availability is intermittent. Dealing with the issue of energy storage and management adds to the complexity and cost of these resources. This presents a significant challenge for renewable electricity.[65]

3.6. Advancing Green Chemistry In Nigeria

Being a developing country blessed with rich human and natural resources, Nigeria is endowed with many resources that could be harnessed to green chemistry and green technologies. Some of the opportunities that could be exploited in order to at least set the country on track towards 'going green' are discussed below.

3.6.1. Identification of potential sectors for green chemistry implementation

In Nigeria, there are many of the sectors where green chemistry and need to be implemented, such as:

a) Manufacturing sector: Manufacturing companies should be mandated by policies to ensure that their products are made with Green Chemicals and also their packaging should be have high recycling potential.[66]

b) Agricultural Sector: Some of the chemicals, e.g fertilizers, that that are being used should be assessed to ensure that they are produced with green chemicals that would be of little or no harm to the environment and environment, this an be ensured by replacing these chemicals with more green alternatives such as the bio pesticides, bio fertilizers, and also conversion of agricultural waste into energy or raw materials for production of other necessary materials.[67]

c) Pharmaceuticals: These industries are significant contributors among the many chemical manufacturers that generate significant amount of waste by-products and pollutants such as air pollutants and depleted reagents.[68] Generally, they should try to select materials that have less environmental impact, reduce the use of resources, minimize waste, and run safe processes.

3.6.2. Seek Collaboration Opportunities with International Organizations and Partners

By actively engaging with international organizations, countries can leverage the expertise and resources available to accelerate their green transition. Countries can collaborate with international organizations in several open and proactive ways to go green. Some of such ways include:

a) Join International Environmental Agreements: Countries can become signatories to international agreements such as the Paris Agreement,[69] Kyoto Protocol,[70] or the United Nations Framework Convention on Climate Change. By joining these agreements,[71] countries commit to reducing greenhouse gas emissions and adopt sustainable practices.

b) Seek Technical Assistance: International organizations like the United Nations Environment Programme (UNEP), World Bank, or International Renewable Energy Agency (IRENA) offer technical expertise and advice to countries aiming to adopt sustainable practices. Countries can seek their assistance to develop green policies, implement renewable energy projects, or promote eco-friendly practices.

c) Access Funding Opportunities: Many international organizations provide financial support for green initiatives. Countries can collaborate with these organizations to access funding for renewable energy projects, afforestation programs, or sustainable development initiatives. Examples of such organizations include the Green Climate Fund and Global Environment Facility.

d) Share Best Practices and Knowledge: International organizations facilitate the sharing of best practices and knowledge among countries. Countries can participate in conferences, workshops, or training programs organized by these organizations to learn from successful green initiatives implemented elsewhere. This knowledge exchange helps countries adopt efficient and effective green policies.

e) Participate in Research and Development: Collaboration with international organizations can provide opportunities for joint research and development projects focused on green technologies and sustainable practices. Countries can contribute their resources, expertise, and data to such projects and benefit from the shared knowledge and innovations. Countries should also encourage domestic research right from undergraduate level.

f) Collaborate in Capacity Building: International organizations often provide capacity-building programs to help countries strengthen their institutions and policies related to environmental sustainability. Countries can participate in these programs to enhance their capabilities in areas such as waste management, energy efficiency, or environmental governance.

g) Engage in Policy Dialogues and Advocacy: Countries can actively engage in policy dialogues and advocacy efforts led by international organizations to promote global environmental goals. Through participation in forums and conferences, countries can voice their concerns, share experiences, and influence the development of international policies and guidelines.

3.6.3. Integration of Green Chemistry Practices into Existing Industries

This would definitely allow industry to prevent pollution in innovative ways such as by designing or modifying manufacturing processes to optimize use of resources and reduce the creation of chemical waste.[72]

3.6.4. Development of Capacity Building Programs and Educational Initiatives

Programs could be set up on the educational sectors to help improve knowledge on the field of green chemistry and technologies. It is also paramount to integrate green chemistry into the regular secondary and tertiary education syllabus.

3.7. Opportunity for Job Creation Thorough Green Chemistry in Nigeria

Figure 7. Careers in Green Chemistry and Technology. (Team Leverage Edu, 2023).

When a country, like Nigeria, fully implements green chemistry and its practices, it can create a wide range of job opportunities across various sectors.

Some of these include:

3.7.1. Teaching and Education Sector

As green chemistry becomes more adopted, the education sector would be at the fore front of its implementation as it would be necessary to inculcate it into the curriculums if secondary and tertiary education, thereby creating job opportunities for academics that are knowledgeable in the field to delve into teaching and lecturing.

3.7.2. Chemical Manufacturing Sector

With the adoption of green practices, there will be a need for experts who can create and execute eco-friendly manufacturing methods. Jobs in this area could include chemical engineers, process chemists, and production managers, who will be responsible for ensuring chemical production is both effective and sustainable while having minimal negative impact on the environment.

3.7.3. Renewable Energy Sector

The principles of green chemistry often entail the advancement of alternative energy sources and technologies, which can lead to potential employment options in fields such as renewable energy corporations or scientific organizations. These opportunities could encompass roles such as engineers specialized in solar or wind energy, as well as specialists in the field of bioenergy.

3.7.4. Environmental Consulting and Compliance

The adoption of green chemistry approaches by a country would consequently necessitate companies to adhere to environmental laws and scrutiny of their ecological impact, which would lead to a rise in the need for environmental advisors. Such experts can assist enterprises in meeting regulatory requirements and devising strategies to promote sustainability.

3.7.5. Waste Management and Recycling

The application of green chemistry necessitates reducing the creation of waste and supporting recycling endeavors, which has the potential to produce employment prospects in entities that manage waste, recycle materials, and regain resources. Job opportunities like waste management professionals, recycling coordinators, and circular economy advisors may manifest.

3.7.6. Research and Development

Continuous research and innovation are necessary for the adoption of green chemistry practices. Opportunities for employment in research institutions, universities, and private companies increase for chemists, engineers, and scientists who concentrate on creating sustainable solutions and enhancing current technologies.

3.7.7. Policy and Advocacy

Green chemistry implementation relies on supportive policies and regulations. Governments will require professionals knowledgeable in environmental policy, legislation, and advocacy to shape and enforce green chemistry practices at a national level. Job roles could include policy analysts, environmental lawyers, or sustainability managers within government agencies or non-governmental organizations. [61]

Overall, the implementation of green chemistry can bring about positive economic and job growth by creating opportunities for professionals across academic, scientific, engineering, environmental, and policy fields.

4. CONCLUSIONS

Even though industries and the manufacturing sector need to be taken seriously as they play a vital role in both the process of pollution and mitigation of pollution, emphasis is due to be made on the energy sector because energy is of utmost importance for the economic growth, progress, and development of countries, and it is also essential for addressing poverty and ensuring security. It is critical for all nations to have uninterrupted access to energy. For future economic growth, it is crucial to have long-term access to energy sources that are affordable, accessible, and environmentally sustainable.[73]

Apart from green technologies that were implemented many years ago, such as the hydroelectric energy generation at the Kainjidam, there are barely any recent day instances of green chemistry or green practices in Nigeria, generally due to the lack of awareness of the people as shown by a study in one of the states of the country; AkwaIbom, where 88.69% of the chemistry teachers in the public schools were not aware of Green chemistry and its principles, whereas teachers have a vital role in the integration of greenness into our society.[74] This goes to show the level of the society's ignorance when it comes to green chemistry. Another reason is the lack of consideration the government gives to the environment or need of going green, this is evident in the lack of sensitizations, policies, or implementation of the green chemistry principles of current green innovations or practices like Green energy, tree planting, etc. Instead, the reverse is the case as we see constant deforestation and tree felling, crude oil which is a diminishing resource,[75] and also the cause of a third of the world's carbon emissions,[76] still remains the country's major source of and economic strength and alternate source of energy.[77]

5. RECOMMENDATIONS

Green chemistry has played a transformative role in benefiting major nations and the world at large by driving environmental stewardship, resource efficiency, health and safety improvements, innovation, climate change mitigation, public perception enhancement, and global collaboration. As countries continue to embrace green chemistry principles and integrate them into policy frameworks and industrial practices, the positive impacts on society and the environment are expected to grow, leading to a more sustainable and resilient future for all.

From this study, it is recommended that government and regulatory bodies come up with innovative policies and favorable implementation strategies that generally creates more awareness and engagement of the public with green chemistry principles and practices, and also those that compel these green chemistry practices across all sectors, especially in the cases of waste as many of our wastes can be more useful to us. There should also be provision of funding mechanisms and investments in domestic green chemistry research and development. While on the international level, there is need for the collaboration and exchange of knowledge between academia, industries, and governments as nations can work together towards a more sustainable and resilient future for the planet by implementing green chemistry practices.

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