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The Role of Chemistry in Achieving Sustainable Development Goals: Green Chemistry Perspective

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Authors' contributions

This work was carried out in collaboration between both authors. Author UPO wrote the original draft. Author OOA reviewed and edited the final draft, and obtained funding acquisition. Both authors read and approved the final manuscript.

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ABSTRACT

Green chemistry, also referred to as sustainable chemistry, has emerged as a crucial framework for addressing global sustainability challenges and advancing the United Nations 2030 Sustainable Development Goals (UN-SDGs). By focusing on designing chemical products and processes that minimize hazardous substances, green chemistry reduces environmental pollution, conserves resources, and improves public health. It promotes safer, more efficient chemical processes aligned with sustainability principles. The twelve principles of green chemistry offer actionable strategies for achieving key SDGs. For example, green chemistry ensures clean water and sanitation (SDG 6) by minimizing toxic chemical releases into water systems and addresses climate action (SDG 13) through low-carbon technologies and sustainable energy sources. It supports responsible

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production and consumption (SDG 12) by advancing circular economy practices and fostering sustainable industrial processes. In Africa, green chemistry is drawing attention, demonstrating significant contributions to sustainable development. Conferences in Africa have fostered collaboration among researchers, policymakers, and industry leaders while African countries continue to adopt green technologies, including cleaner production techniques and renewable feedstocks in chemical manufacturing. Research laboratories across the continent are implementing techniques like solvent-free synthesis and bio-based catalysts, reducing environmental impacts and enhancing resource efficiency. This article highlights how green chemistry principles drive progress toward the UN-SDGs in Africa. By integrating these principles, green chemistry can help create a sustainable global economy, advancing environmental stewardship, social well-being, and economic growth.

Keywords: Green chemistry; green synthesis; sustainability; sustainable development goals; global impact.

1. INTRODUCTION

Africa is the second largest continent in the world after Asia, having 54 countries and covering around 30.3 million square kilometers (Sayre, 1999). Africa is also distinguished by its rich diversity of cultures, languages, and history. From the ancient civilizations of Egypt and Nubia to the dynamic oral traditions of West African griots, the continent's historical depth informs its scientific and cultural advancements. Linguistic diversity, with over 2,000 languages spoken, reflects the intricate interplay of tradition and modernity shaping the continent's unique approach to sustainability and innovation.

In the 21st century, educational advancements have evolved significantly, prompting African nations to prioritize research addressing environmental and human challenges, thereby involving in research and development to meet the United Nations 2030 Sustainable Development Goals. Of course, the idea for robust research and policy implementation of handling and managing these activities causing danger to health and the environment has become paramount and important in solving the issues associated with pollution from toxic waste, greenhouse gases, and more. For the average people in Africa, their day-to-day activities have and continue to endanger human health, the environment, and equally the air and water with very little awareness about the current and potential negative impacts of their activities. Although these can be characterized by low or poor education, what is more, alarming is that even some educated ones in the various communities of Africa are not exempted from these activities.

The narrative surrounding escalating levels of environmental degradation, water contamination, and air pollution, which have inflicted severe repercussions on African communities encompassing human inhabitants, wildlife, vegetation, aquatic ecosystems, remains incomplete without acknowledging the involvement of foreign entities hailing from well-developed urban centers worldwide where stringent regulations are enforced. These external actors have regrettably failed to uphold similar standards in African settings, engaging in anthropogenic ventures through oil refining and petrochemical enterprises like SHELL, AGIP, among others. The industrial operations of these entities have engendered numerous oil spill incidents with minimal to no efforts directed towards remediation efforts, thus exacerbating the environmental challenges faced by the continent.

The impression and adequate practice of sustainable development are fantastically ideal for Africa as the United Nations SDGs 2030 agenda with different approaches, especially the green chemistry perspective, would aid in controlling and possibly bring to zero some of the activities that are posing a threat to lives and the environment and equally enhance the modern activities for the future.

1.1 Green Chemistry as a Pathway to Sustainable Development in Africa

As chemical science has grown in popularity over the past two centuries, it has enabled humans to produce an increasing variety of goods (Manahan, 2005). These include pharmaceuticals, fertilizers, semiconductors, and more. However, in years past and even at present, chemistry has been mishandled in numerous ways such as the release of toxic substances, and pollutants and the production of

nonbiodegradable materials, resulting now as harm to the environment and living things. Considering the current state of chemical science, it is evident there must be a shift from an emphasis on the development of products that ultimately end up as waste to the application of chemistry in ways that support human needs without damaging the earth's ecosystem. Sustainable development is the practice that was designed by the United Nations which is aimed at achieving the best technologies that may reduce or eliminate the application or use of harmful/ hazardous substances. The SDGs programs are basically designed to satisfy the current needs without compromising the intended capacity of upcoming generations to meet their own needs (KTH, n.d.), thereby making the world greener. Consequently, green chemistry, otherwise known as sustainable chemistry, involves maximizing the benefit of chemistry activities while eliminating or greatly reducing its environmental impacts (Manahan, 2005). In principle, green/sustainable chemistry is set to reduce or eliminate the consumption or generation of hazardous substances in the design, manufacture, and application of chemical and biochemical products. In order to achieve these, chemistry is guided by 12 principles when designing materials and processes.

1.2 The Basic Principles of Green Chemistry

The principles of green chemistry were set out to strategically and effectively manage chemical products in a way that fosters clean, less toxic, and environmentally friendly procedures that have a sustainable shelf life. In order to meet these requirements, in 1998 Anastas and Warner, in their work narrated the theory and practice in detail that provides an understanding of the emerging green chemistry movement that describes the 12 principles of green chemistry (Anastas & Warner, 1998). In some parts of the world, and mostly Africa where the culture of good chemical handling practices is very low, the application of these green chemistry rules becomes vital. According to this rule, the best way to treat hazardous waste is to prevent it from being disposed of in the environment. Unfortunately, failure to follow this simple rule has left the world (especially Africa) with most of the difficult hazardous waste locations. According to Anastas and Warmer 1998, the 12 principles are titled and defined as highlighted below.

1) Waste Prevention: The best way to prevent waste is to prevent it from being created in the first place.
2) Atom economy: It is essential to design synthetic methods so that all materials used in the process are incorporated into the final product.
3) Less hazardous chemical syntheses: In order to minimize harm to human health and the environment, synthetic methods should be used and generate substances that possess little or no toxicity.
4) Designing safer chemicals: Product design should include minimizing the toxicity of chemicals while achieving the desired function.
5) Safer solvents and auxiliaries: Auxiliary substances (e.g., solvents, separation agents, etc.) should be used sparingly when possible and be innocuous when employed.
6) Design for energy efficiency: When possible, synthetic methods should be conducted at ambient temperature and pressure to minimize the environmental and economic impacts of chemical processes.
7) Use of renewable feedstocks: The use of renewable raw materials or feedstock wherever technically and economically possible is preferable to depleting materials.
8) Reduce derivatives: If possible, derivatization should be minimized or avoided (blocking functions, protection/deprotection, temporary modifications of physical/chemical processes) because such steps require additional reagents and can generate waste.
9) Catalysis: The incorporation of catalytic reagents is better and superior to stoichiometric reagents.
10) Design for degradation: The design of chemical products should ensure that, after their function is complete, they disappear into harmless degradation products in the environment.
11) Real-time analysis for pollution prevention: Further development of analytical methodologies is required for real-time, in-process monitoring and control earlier to hazardous substance formation.
12) Inherently safer chemistry for accident prevention: The choice of substances used in a chemical process should be carefully

made in order to reduce the probability of a chemical accident.

2. APPLICATION OF GREEN CHEMISTRY

In the 21st century, great success has been recorded in different sectors of chemical industries with the application of green methods in various production processes. For instance, green chemistry has been greatly employed in different laboratories and chemical manufacturing sectors including polymer, fabrics, colour/paint, paper, and pharmaceutical industries. Due to the health and environmental impact of combustion fuel, the idea of green energy from many energy sectors is a game changer as the design of innovative techniques for renewable energy batteries for automobiles, solar cells, and panels for housing and industries. These green technologies offer more advantages such as low cost, energy storage, and environmental friendliness.

2.1 Green Chemistry in the Energy Industry

In African industries, green methods are desirably important virtually in every manufacturing sector to incorporate fewer chemicals and generate less waste and finally end up with a good product. As fossil fuels and coal have provided Africa with most of its energy, they are also the significant polluter of Africa's freshwater supply, and air which is at risk due to climate change. Moreover, one of the major contributors to global warming is the combustion emitted from vehicles or industrial machines. However, great efforts have been made by manufacturers in order to design alternative sources of energy or means of powering machines/vehicles. The green method in this process is the development of clean energy batteries. An example of these clean energy manufacturers is Northvolt AB— A Swedish lithium-ion battery developer and manufacturing company established in 2015 that is committed to creating eco-friendly electric vehicle batteries with a 90% carbon footprint reduction compared to those made using coal.

They are using them to enhance the environment and make it a better place to live in. This type of technological invention is needed in Africa as it is safer, healthy, and best for the replacement of fossil fuel.

2.2 Green Chemistry in Pharmaceutical/Drug Industries

Green chemistry has played a key part in the pharmaceutical industry by revolutionizing the drug design and production process. Ideally, choosing a solvent-free or green solvent (preferably water) and alternative reaction medium, green chemistry (GC) can be comprehensively applied to pharmaceutical synthesis by considering one-pot synthesis, multicomponent reactions (MCRs), continuous processing, and process intensification approaches to reduce atom economy and final waste (Kar *et al*., 2022). Various types of drug synthesis including metal complexation and co-crystallization have been done using the green chemistry method. Ogodo and Abosede in their paper on co-crystallization published in 2022, highlight the advantages of green synthetic approaches such as the use of benign solvent, stirring at room temperature, in an environmentally friendly way, and the method resulted in an excellent yield of 91% (Ogodo & Abosede, 2022). In 1961, ibuprofen was developed by Boots Pure Drug Company in six steps, including a toxic aluminum chloride stage (Acetti *et al*., 2008). However, after the improvement in the synthetic procedure, a three-step process can now be used to distribute ibuprofen globally, but a simpler, more efficient, and stereospecific route is still needed (Ha & Paek, 2021). For years, Zocor (simvastatin), a drug used to treat high cholesterol, was synthesized using a complex method involving large quantities of hazardous reagents resulting in a large amount of toxic waste. A bio-catalysis company, Codexis, developed a method to synthesize a drug using a low-cost feedstock and an engineered enzyme (Hazra, 2021).

2.3 Green Chemistry in Oil Production

Petrochemical industries are where the refining and processing of different chemical raw materials including crude take place. There are thousands of products that are made from petrochemicals, such as plastics, detergents, lubricants, pharmaceuticals, fertilizers, and others. In Africa, particularly Nigeria, oil companies are advancing to an upsurge in petrochemical production. For example, the Dangote refinery, one of the biggest oil refineries in the world was recently built in Nigeria and was inaugurated in May 2023, received the first crude shipment in December 2023, and thereafter, started operation. It is one of the world's largest

single-train refinery capable of processing about 650,000 barrels of crude oil per day (Reuters, 2018). The project estimated cost was more than 19 billion dollars. This newly built industry and other existing ones in Africa were built to bridge the gap between shipping crude oil abroad for refining and hence making locally refined products available. However, the real pollution problems affecting the environment are not yet addressed as more refining facilities, especially unauthorized refiners (an act of sabotage) whose aim is to make a fortune while destroying livelihood and causing more pollution.

In line to meet the set target of reducing carbon emissions by 2050, it's of global environmental interest to ambitiously achieve this goal before then. Therefore, an alternative design would be such that causes fewer hazards to humans and the environment. Thus, green fuel is the best alternative to fossil fuel. Interestingly, carbon-neutral and also carbon-free alternatives to fossil fuels are green fuels made from hydrogen and electricity from renewable sources. They are considered crucial for the future decarbonization of industries such as heavy industry, shipping, and power production.

3. SUSTAINABLE DEVELOPMENT GOALS ASSOCIATED WITH CHEMISTRY

3.1 Zero Hunger

Chemistry can play a key role in achieving SDG 2, by ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture in different societies around the world including Africa. The implementation of green chemistry particularly will not only affect food production but will equally protect the agricultural environment. As a result of breakthroughs in green chemistry, plants will be better protected from pest infestations, food will be produced and distributed more efficiently, packaging will last longer, and food safety and quality will be maintained.

3.2 Good Health and Wellbeing

SDG 3, Good health and Well-being is essential for everyone to have the enablement to work and accomplish their goals and make developments. To achieve the goal of good health and well-being, chemistry is necessary. Advances in chemistry have enabled breakthroughs in medicine and technologies that provide a deeper understanding of the impact of disease and hazardous chemicals on human health. Guégan and colleagues emphasized in their paper that promoting good health and well-being for all, irrespective of age, integrates two key perspectives. Firstly, health is not only a fundamental human right but also a form of capital that supports nation-building and sustainable development. Secondly, well-being is a state of health and happiness influenced by various physical and psychological factors, either individually or in combination (Guégan *et al*., 2018). Therefore, the ability to be in good physical health and satisfy one's basic needs is a key factor in determining physical well-being, whereas psychological well-being depends on one's personal judgment and is often influenced by factors such as social or economic success, pleasure, and harmony with oneself, others, or the environment (Guégan *et al.,* 2018).

3.3 Clean Water and Sanitation

It is often said that "Water is precious to Life!" Hence, water is basic for almost every process of life, but its cleanness is important for every organism and human consumption. Ensuring the availability and sustainable management of water and sanitation for everyone is the prime aim of SDG 6. One of the major challenges African communities are facing today is bad water and poor sanitization, even though water is one of the basic amenities for livelihood but is drastically lacking in this part of the world, Africa. According to the United Nations, several plan indicators have been suggested to target the achievement of SDG 6 (United Nations, 2017). There are six outcome targets in the plan: Safe, affordable drinking water, sanitation, and hygiene access, increased water efficiency, wastewater treatment, safe reuse, integrated water resource management (IWRM) implementation, protection and restoration of water-related ecosystems, and reducing open defecation. As stated by Bartram *et al.,* in order to achieve these implementation targets, water and sanitation support will be expanded to developing countries, and local engagement in water and sanitation management will be supported (Bartram *et al*., 2018).

3.4 Affordable and Clean Energy

The seventh sustainable development goal (SDG 7) aims to provide access to affordable, reliable, sustainable, and modern energy in order to address numerous problems. As part of the goals of the United Nations 2030; the agenda is targeted at economic development, poverty

alleviation, and well-being for all through access to energy (Ritchie *et al*., 2018). There are many activities that require energy, such as jobs and transportation, food security, health, and education (United Nations, 2018). SDG 7 agenda has birthed innovations in various energy sectors such as solar energy for both housing and industry electricity supply, clean cooking solutions, and clean/renewable energy for automobiles, thereby gradually eliminating the use of CO_2 emission fuels which is greatly harmful to both humans and the environment.

3.5 Climate Action

Sustainable development goal thirteen (SDG 13), is focused on solving the issues of climate change which is one of the most endangering issues of the world today. Based on the (2013) Climate Change, fifth assessment Intergovernmental Panel report, the impact of climate change is gradually becoming severe as they are being felt across the globe and might become adverse and irreversible if not well controlled in the coming years (Intergovernmental Panel on Climate Change [IPCC], 2013). In fact, climate change is already impacting agriculture, human health, and water supplies, according to the report, and rising temperatures will affect everyone on the planet eventually. As greenhouse gases in the atmosphere increase, temperatures will probably rise over most land surfaces (Intergovernmental Panel on Climate Change [IPCC], 2013).

In addition to catastrophic effects caused by climate change, scientists predict that extreme weather events such as storms, droughts, hurricanes, and floods will become more common, and that water and food will become inadequate. Small island nations and many coastal cities will be destroyed by rising sea levels and the destruction of numerous plants, fish, and animals (Baehr & Harvey, 2014).

However, as climate change grows and becomes more severe, atmospheric chemistry research has become increasingly important for understanding the causes and predicting the impacts of the change. WHO (2019), reported that there is a close correlation between SDG 13 and SDG 7 on clean energy, but the official mission statement of this SDG 13, is to " Fight the effects of climate change by taking immediate action." (IEA *et al*., 2019)

4. GREEN CHEMISTRY ROLES IN SUSTAINABLE DEVELOPMENT GOALS AND INITIATIVES IN AFRICA

In search of solutions to make the world a better place, the United Nations in collaboration with other scientific bodies such as UNESCO and IUPAC came together to foster an idea to prevent disasters by focusing on different key solution areas including green chemistry (United Nations, 2019). These goals were targeted to spontaneously touch every critical aspect of human life and the inhabiting environments, air, water, and every part of nature that misuse of chemicals can affect. Studies in green chemistry as a cutting-edge effectiveness for sustainable development equally cut across other science and engineering such as biotechnology, biochemistry, pharmacy, and ecology; giving researchers the broad prospect to make great contributions.

Chemistry plays a significant role and has identified several priority Sustainable Development Goals that are integral to the community's work. In addition to technology, economics, and human health, chemistry has a broad impact on global sustainable development, and chemists in various sectors of practice are already taking many steps to do so (European Commission, 2019). Some of the chemistry-associated SDGs programs as highlighted in this article showed clearly that chemistry is the bedrock to achieving UN-SDGs.

In South Africa, numerous initiatives are supporting the growth of green chemistry. The National Cleaner Production Centre (NCPC) in conjunction with Yale University organize workshops dedicated to advancing green chemistry education (Green Chemistry Project - NCPC – SA, 2020). Additionally, the South African Chemical Institute (SACI) emphasizes the importance of green chemistry on its website. Furthermore, the Council for Scientific and Industrial Research (CSIR) in South Africa is engaged in publishing research and conducting green chemistry projects (CSIR, 2024).

Across the continent, several events and workshops further promote green chemistry. A 2-day UK-India-Brazil-Africa programme on ‘green chemistry for sustainable production of biofuels’ was held after the 5th IUPAC international conference on green chemistry, in Durban, South Africa from August 21 to 22, 2014. The 5th IUPAC international conference on green

chemistry was earlier held also in Durban from 17 to 21 August 2014 (Foreign, Commonwealth & Development Office Blogs, 2014). GreenChemAfrica hosted an African Training School on Green Chemistry and Environmental Sustainability in Benguerir, Morocco, in April 2024 (UM6P, 2024). In Southern Africa, a series of Train-the-Facilitators workshops took place, involving participants from various sectors including government, industry, academia, NGOs, and consulting (Yale Center for Green Chemistry & Green Engineering, 2024). Moreover, the American Chemical Society (ACS) organized the Africa Regional Conference on Green and Sustainable Chemistry in Lagos, Nigeria, from May 5-9, 2024, fostering collaboration among researchers, policymakers, and industry leaders (ACS Nigeria, 2024).

5. CONCLUSION

Green chemistry serves as a transformative framework in addressing the pressing challenges of sustainable development. By adhering to its twelve principles, this field promotes the design of chemical products and processes that minimize environmental and health risks while enhancing resource efficiency. Africa, with its unique environmental and socio-economic challenges, stands to benefit significantly from green chemistry innovations. These innovations are integral to achieving the United Nations Sustainable Development Goals (UN-SDGs), particularly in areas such as clean water and sanitation, affordable clean energy, and climate action. Despite the progress made, more efforts are required to enhance awareness, foster collaborations, and implement green technologies across the continent. With the continued adoption and integration of green chemistry principles, Africa can achieve sustainable industrial practices and environmental stewardship, contributing to global sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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