Nanotechnology Potentials in Climate Change Mitigation and Socio-Cultural Acceptability Issues in Africa

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Abstract

Global warming and climate change remain the foremost environmental challenges worldwide, primarily driven by human-induced greenhouse gas (GHG) emissions. These emissions originate largely from the combustion of fossil fuels in industries, transportation, and power generation. Since the industrial era began, GHG emissions have steadily risen, with industrial processes alone contributing about 78% of the increase between 1970 and 2010, according to the IPCC. Developing countries, especially Africa, are particularly vulnerable to the effects of climate change due to low adaptive capacity, economic constraints, and weak institutional frameworks. In most Africa countries, challenges such as overpopulation, deforestation, poor waste management, poverty, desertification, and farmers-herders' conflicts, further compound the problem. The Africa continent, especially the West Africa sub-region, faces various climate-related impacts. In Nigeria for example, while southern part of the country experiences sea level rise, flooding, coastal erosion, the north part endures desert encroachment, heatwaves, reduced rainfall and marked rainfall variability. A stark example was the 2012 flood in Nigeria which displaced over 2.1 million people across 30 states. Amid these challenges, nanotechnology emerges as a promising tool for climate change mitigation and environmental management. It offers potential applications in carbon capture, renewable energy, pollution control, water purification, waste degradation, and energy storage. Innovations include photovoltaic solar cells, hydrogen fuel technologies and advanced insulation materials. Despite its promise, large-scale adoption of nanotechnology in Nigeria faces significant socio-cultural and economic barriers. Public skepticism, lack of awareness, inadequate regulatory frameworks, and high costs hinder widespread implementation. Cultural attitudes towards risk and innovation further influence acceptance. This review explores the potentials for nanotechnology applications in climate change mitigation and socio-acceptability issues in Africa. More so, it highlights the need for comprehensive socio-cultural and economic assessments to understand public perception, ethical implications, and financial viability. Emphasis is placed on aligning nanotechnology with local content development to ensure sustainability and inclusivity. For nanotechnology to effectively contribute to Nigeria's climate resilience, integrative strategies must be adopted. These should address public engagement, regulatory clarity, ethical considerations, and equitable access, ensuring that technological innovation complements the country's social and economic realities.

Keywords: Nano-Education, Global Warming, GHGs Mitigation, Socio-Cultural Issues

Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC, 2007). Climate change involves heightened temperatures, changes in precipitation trends, and other components such as atmospheric pressure and humidity levels in the surrounding environment across various regions of the world (Battisti & Naylor, 2009; Weisheimer & Palmer, 2005; Yadav *et al.,* 2015; Schuurmans, 2021). In addition to irregular weather patterns, retreating global ice sheets and the corresponding sea level rise have been widely reported as some of the most significant international and domestic effects of climate change (Lipczynska-Kochany, 2018; Murshed & Dao, 2020; Michel *et al.,* 2021). Since the beginning of the Industrial Revolution, the problem of Earth's climate has intensified significantly (Leppänen, *et al.*, 2014; Chausali, *et al.,* 2023), with anthropogenic activities now widely regarded as the primary drivers of global warming (Murshed *et al.,* 2022). These activities—such as excessive agricultural operations, the burning of fossil fuels, deforestation, and emissions from national and domestic transportation sectors—have increased the atmospheric concentrations of greenhouse gases (GHGs) such as CO_2, CH_4, and N_2O (Huang, *et al.,* 2016; Murshed *et al.,* 2020; Sovacool, *et al.,* 2021; Usman & Balsalobre-Lorente, 2022; Murshed, 2022). According to UNESCO (2021), climate change poses a general threat to humanity, with specific associated hazards including storms, flooding, oceanic changes, droughts, desertification, temperature anomalies, and other severe weather events and natural disasters. Climate change has become a serious environmental issue affecting humanity since the mid- to late-19th century, when human activity began significantly intensifying the greenhouse effect. These changes—typically marked by devastating impacts on ecological, environmental, socio-political, and socio-economic systems—constitute an intergovernmental challenge of global concern (Adger, *et al.*, 2005; Feliciano, *et al.,* 2022). The impacts of climate change are unevenly distributed between developed and developing countries. This disparity is particularly evident in energy consumption trends, as GHG emissions continue to rise due to fossil fuel-based energy production, especially in developing nations (Balsalobre-Lorente, *et al.,* 2022; Usman, *et al.*, 2022; Abbass, *et al.,* 2022; Ishikawa-Ishiwata & Furuya, 2022). Coupled with the low adaptive capacity of many developing countries—unlike their developed counterparts, these nations are disproportionately vulnerable.

Numerous researchers have demonstrated that the impacts of climate change vary from country to country and cannot be uniformly quantified (Goglio, *et al.,* 2020; Lezaun, 2021). These differences are often linked to the adaptation and mitigation strategies in place, as well as the availability of resources within individual countries (IPCC, 2018; Robinson, 2020; Ceci *et al.,* 2021). According to Khan *et al.* (2021), Sub-Saharan Africa (SSA) is expected to be more vulnerable than developed regions, further exacerbating income inequalities among affected countries. This is largely due to SSA's heavy dependence on agriculture and forestry, erratic rainfall, and slower technological advancement (Diallo *et al.,* 2020; Kaganzi *et al.,* 2021). The IPCC (2021) projects that SSA will become the most vulnerable region by 2100, with potential agricultural losses ranging from 5% to 15% of GDP. In Nigeria's Sahel region, there has already been an average 25% decline in precipitation over the 30 years preceding 2006 (Nkomo *et al.,* 2006). Reports also show that inflow to the Lake Chad Basin has diminished by 70–80% (Coe & Foley, 2001), and the lake's surface area has decreased from approximately 25,000 km² to about 2,000 km²—around a 90% reduction—over the past 40 years (Gao et al., 2022). Notably, in the 1980s, it shrank to as little as 300 km² (Gao, *et al.,* 2022). In contrast, southern Nigeria has experienced a steady increase in rainfall and flooding in recent decades (Okoronka, 2021), with rainfall patterns becoming increasingly unpredictable. According to Nigeria's First National Communication under the UNFCCC, 15% of the country's population is already affected in some way by climate variability and sea level rise (Mimura, 2013). These impacts are expected to be compounded by the rapid population growth in Sub-Saharan Africa, where the population is projected to rise from approximately 2 billion in 2005 to over 3.2 billion by 2050 (FAO, 2019). Some of the potential climate risks are illustrated in Figure 1 (Pandey *et al.,* 2024).

Figure 1: some health-related risks of climate change
Source: Pandey et al., (2024)

These concerns, coupled with the desire of governments across developing countries to meet key Sustainable Development Goals (SDGs)—particularly those related to No Poverty (SDG 1), Zero Hunger (SDG 2), Clean Water and Sanitation (SDG 6), Affordable and Clean Energy (SDG 7), and Climate Action (SDG 13)—emphasize the urgent need for more aggressive action to address the causes and impacts of climate change through the reduction of greenhouse gas (GHG) emissions. Moreover, the accelerating threat of climate change demands urgent, innovative approaches that go beyond conventional mitigation strategies. One such innovation is the adoption of nanotechnology for sustainable environmental management. Indeed, nanotechnology is a game-changer that involves the manipulation of matter at extremely small scales- specifically, particles sized between 1 and 100 nanometers (nm) -and has found applications across diverse fields such as the environment, agriculture, and energy (Figures 2 and 3) (Chausali *et al.,* 2023; Pandey et al., 2024). Nanotechnology deals with the creation of nanosized particles, which significantly enhance their physical, chemical, and biological characteristics (Singh et al., 2017; Cerqueira *et al.,* 2018). These particles, often referred to as nanomaterials or nanoparticles (NPs), possess at least one dimension in the 1–100 nm range (Chausali, *et al.,* 2023). Nanotechnology enables the utilization of these nanostructures through nanoscale devices for addressing a myriad of environmental, industrial, and health-related challenges. Regarding environmental change, Rai, *et al.*, (2016) and Pandey (2024) reported that nanotechnology accelerates the growth of renewable energy systems—such as solar energy, biofuels, and fuel cells—thereby decreasing dependence on fossil fuels and helping to mitigate climate change (Figure 2). In environmental management, nanomaterials can significantly degrade dyes and other pollutants in water, and many are capable of adsorbing greenhouse gases (Yousefi, 2022). In agriculture, Tripathi et al. (2018) demonstrated that nanotechnology has introduced new materials such as nanofertilizers, nanopesticides, and nanosensors for agro-climatic and environmental monitoring. Agro-nanotechnology is considered an environmentally friendly or "green" technology for the future. Additionally, nanolubricants and nanocoatings reduce engine friction, significantly lowering CO_2 emissions and thus contributing to the mitigation of global warming (Subramanian *et al.,* 2020). Governments worldwide have set targets to decrease dependency on fossil fuels, which are a major contributor to global warming. Nanotechnology offers a viable solution, especially as nanomaterials are effectively absorbing greenhouse gases and hence can reduce global warming. Furthermore, nanostructured materials are gaining traction in green architecture. They promote the use of nanocomposites, nanocoatings, nanoglass, carbon nanotubes, nanosilica, and polymeric structures in roofing, windows, wall coatings, insulation, energy storage, and solar cells. In the future, they may also enable refrigerant-free cooling, paving the way for energy-efficient and sustainable buildings (Smith, 2011; Rezaei, 2018).

Also, as part of its efforts to meet global climate goals, Nigeria Government has pledged to achieve net zero carbon emissions by 2060, with a target set for 2030 detailed in its Nationally Determined Contributions (NDCs). The Nigeria's Energy Transition Plan (ETP) was unveiled in response to this commitment, a plan which focuses on the scale of effort required to achieve the 2060 net zero target whilst also meeting the nation's energy needs. Since the announcement, the Climate Change Act 2021 has been passed, the ETP has been fully approved by the Federal Government and an Energy Transition Implementation working group (ETWG) which is chaired by Former Vice President Yemi Osinbajo (SAN), comprising of several key ministers and supported by an Energy Transition Office (ETO) has been established (Nigeria Energy Transition Plan, 2025). In addition, with the support of the Sustainable Energy for All, the Nigerian Government designed the plan to tackle the dual crises of energy poverty and climate change and deliver SDG7 by 2030 and net zero by 2060, while also providing energy for development, industrialization, and economic growth. The ETP details pathways for significant low-carbon development of energy systems across 5 key sectors: Power, Cooking, Transport, Industry, and Oil and Gas (Nigeria Energy Transition Plan, 2025).

In achieving these global and national targets, the role of nanotechnology for GHGs emission reduction and adapting to climate change cannot be overemphasized. Nanotechnology, the technology of particle size of at least one dimension in the range 1–100 nm, has found applications as game changer in agriculture, environment, energy, medicine, and food industries (Singh *et al.,* 2017 and Chausali *et al.,* 2022). Subramanian *et al.,* (2020) argued that the advantages of nanotechnology in mitigating environmental challenges originate from special properties of nanoparticles (NPs), especially the relatively large surface area and surface-to-volume ratio, which improves contact, energy transmission, and gas adsorption. More so, materials of nanometer such as nanocatalyst, nanocoating, and nanolubricant, are sustainable alternatives to the conventional materials (Gaurav *et al.,* 2024). For instance, Subramanian *et al.,* (2020) reported that nanocatalysts improve fuel combustion efficiency, and reduce GHG emissions whereas nanolubricants and coatings, reduce engine friction and hence CO_2 release. The growth of renewable energy systems (like solar, biofuels, fuel cells), which helps us decrease the dependence on fossil fuels and minimize climate change are known to be accelerated by nanotechnology. In energy efficient buildings, nanomaterials including nanoglass, nanosilica, nanocoatings, and carbon nanotubes are incorporated for dry insulation, solar heat utilization, and potentially refrigerant-free cooling and this has the potential to improve energy efficiency and management in built-up environment. However, as important as nanotechnology in combating climate change and adaptation efforts, its wider implementation will depend on social and cultural acceptability. Its acceptability in climate change mitigation is deeply intertwined with socio-cultural values, risk perceptions, economic constraints, and institutional readiness. This is especially true in most developing countries where 70% of the workforce depend on agriculture for survival and where 60% of this workforce is illiterate and highly vulnerable to climate change impacts due to high poverty level, coupled with other socio-economic issues facing most rural communities including energy poverty, inadequate basic social amenities etc. There are also concerns about the environmental and health-related toxicity of nanomaterials. This paper therefore reviews the potentials for nanotechnology applications in climate change mitigation and adaptation initiatives, with a specific focus on its socio-cultural and economic acceptability as a cornerstone for achieving climate resilience in Africa, using Nigeria as case study.

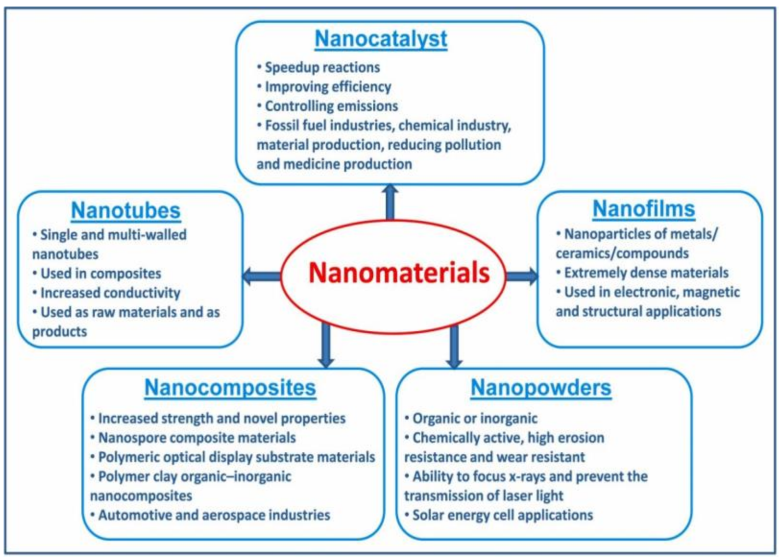

Figure 2: Different nanomaterials with their important features and potential applications
Source: Chausali et al., (2023)

Nanotechnology in Climate Change Mitigation

Nanotechnology is applied in several areas of life that serve to mitigate climate change. Some of these areas of application are illustrated in Figure 3.

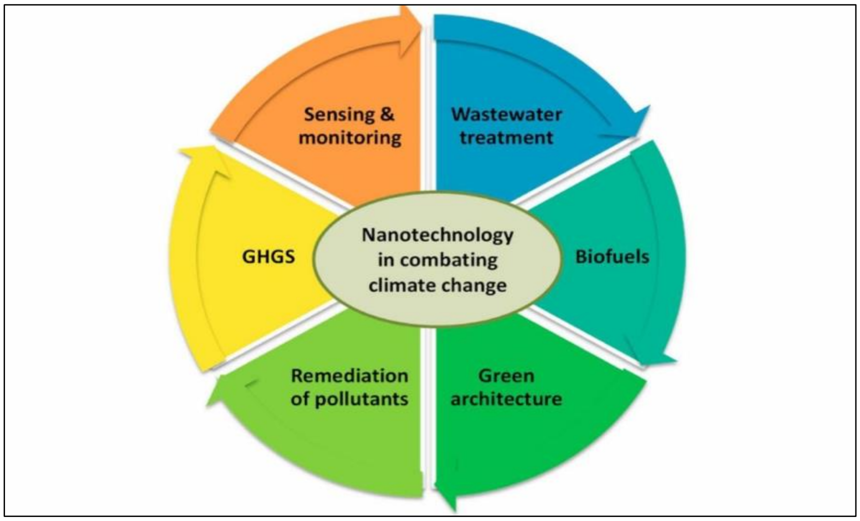

Figure 3: Nanotechnology and areas of applications in climate change mitigation:
Source: Pandey et al., (2024)

Serious attention and interest have been ignited at the intersection of nanotechnology and climate change. In line with this, a workshop was organized in February 2023 to deliberate on key questions regarding the future needs and potential opportunities of nanotechnology in climate change mitigation (Jones *et al.,* 2024). The output from the workshop included five high-level characteristics of future research that are instrumental in addressing climate change through nanotechnology within the U.S. context, but which can be extended to other regions as well (Jones et al., 2024). These key recommendations include the following:

- Long-term foundational research in nanotechnology should be guided by practical relevance. That is, it must be aligned with targeted solution areas that address specific climate change challenges.
- Adopt a system-level perspective is essential for driving breakthroughs and innovations in nanotechnology that are not only sustainable but also viable for societal implementation.
- Conduct of convergence research is crucial, as it enables the integration of multiple disciplines to collaboratively tackle well-defined and urgent research questions.
- It is vital to engage stakeholders in setting research priorities and shaping project designs, as their input helps ensure the relevance, effectiveness, and sustainability of nanotechnology research efforts.
- Nanotechnology infrastructure—including tools, staff, and facilities—must evolve to meet the needs of a growing interdisciplinary user community, which is increasingly focused on addressing complex, multifaceted systems.

Jones *et al.,* (2024) added that although these recommendations are distinct, they are nevertheless complementary; nano-safety and risk governance research should be considered alongside them. Some important areas of nanotechnology research related to climate change are discussed below, including ethical concerns and factors affecting the social acceptability of its application.

Carbon Capture and Storage (CCS)

Carbon capture and storage (CCS) is a climate change mitigation technology where CO_2 is captured from fossil-fuel powered plants and other industrial processes instead of being emitted to the atmosphere. The captured CO_2 is then stored in forests, oceans, and soil as part of the carbon cycle. With development in modern technology, captured CO_2 can be stored deep underground in geological formations like saline aquifers, depleted oil and gas reservoirs, and un-mineable coal seams. CCS serves as a bridge technology, allowing for the continued use of fossil fuels in electricity generation and industry until low-carbon alternatives can be implemented in line with international commitment to CO_2 reduction targets of 1.5°C and 2°C. For CCS to significantly reduce carbon emissions, large quantity of CO_2 will need to be captured and stored. Pacala and Socolow (2004) developed the concept of "wedges," where each wedge represents a carbon emission reduction of 25 Gt (10^{12} kg) over 50 years; about 10 such wedges would be required to limit the global temperature increase to below 3°C. The authors estimated that all carbon emissions from 800 large coal-fired power plants would need to be captured and stored to achieve one 25 Gt wedge. Celia *et al*. (2011) estimate that this would entail a stored CO2 volume of 2×10^{11} m^3, equivalent to total global oil and gas production over a 50-year period. Studies have also shown that reaching the climate change targets of 1.5 or 2°C temperature increase without CCS would be significantly more expensive, if it is at all possible (Wennersten *et al.,* 2015; Kazlou *et al.,* 2024). Carbon capture and storage (CCS) has the potential to play an important role in managing global warming in the near future. Nanomaterials have emerged as transformative agents in enhancing the efficiency, selectivity, and scalability of carbon capture and storage (CCS) systems (Liu, 2024). Nanomaterials like metal-organic frameworks (MOFs), graphene-based materials, carbon nanotubes and nanoscale zeolites have demonstrated enhanced CO_2 adsorption capacity and selective interaction with CO_2 molecules (Liu, 2024), offering scalable solutions for industrial carbon capture. Nanomaterials offer important benefits in improving the efficiency and cost-effectiveness of carbon capture processes (Liu, 2024). These materials offer additional advantages of converting the captured CO_2 into useful products. Notwithstanding the numerous benefits and potentials of nanotechnology, their wide applicability still faces some challenges such as how to scale up production, cost reduction and environmental concerns with regards to nano waste disposal (Liu, 2024). Hybrid nanomaterials exhibit superior stability and durability. They, especially nanoscale zeolites have potential to selectively adsorb CO_2 in the presence of other gases like nitrogen, methane, facilitating purity of captured CO_2. Similarly, bio-inspired nanomaterials mimic natural processes, such as enzymes by selectively binding CO_2 in biological systems (Liu, 2024). Nanotech plays a critical role in climate change mitigation by converting CO_2 into valuable goods.

Renewable Energy Enhancement in Built-up Environment

In today's world, the continuous rise in energy demand, increasing carbon emissions, and reliance on fossil-based fuels significantly compound health, environmental, and economic risks in addition to ongoing climate change (Sangkakool, *et al.,* 2028). Across the World, energy consumption in buildings (residential and commercial) accounts for 16–50% of overall energy use (Monna *et al.,* 2021), highlighting the critical importance of effective energy management in this sector. The pressing need to mitigate climate change has heightened the focus on reducing carbon emissions and improving energy efficiency in the built environment. The 2016 Paris Agreement established an ambitious goal of limiting the annual global ambient temperature increase to less than 1.5 K. Achieving this target requires a 45% reduction in global emissions from the 2010 levels by 2030 and reaching net-zero emissions by 2050 (Bouckaert, *et al.,* 2021).

This will necessitate substantial cuts in global CO_2 emissions alongside active measures to remove CO_2 from the atmosphere. Nanotechnology is one of the most recommended renewable energy choices for mankind to solve the energy problems of this century (Hussein, 2015). Nanotechnology has great potential for enhancing renewable energy in the built environment through improved solar energy harvesting, energy storage, and building materials. More so, Nanomaterials can enhance the efficiency of solar cells, improve the performance of energy storage devices, and create more energy-efficient building materials. Nanotech is revolutionizing photovoltaics through the development of quantum dots and perovskite solar cells, boosting efficiency and reducing production costs (Hussein (2015).

The creation of nanomaterials for solar cells is considered as a very promising area within the field of nanotechnology for renewable energy and energy efficiency. These nanomaterials have the potential to enhance the efficiency, stability, and cost-effectiveness of the process solar-to-electricity conversion process. Solar cells in photovoltaic systems are capable of transforming photons derived from light into electrical current (Fukuda *et al.,* 2020), a process known as the photoelectric effect. First-generation solar cells employ a thick coating of crystalline silicon (Qazi 2016), while second-generation solar cells employ thin film coatings of semiconducting compounds with a thickness of 1 to 2 nanometers (ElKhamisy *et al.,* 2023). The utilisation of nanomaterials such as silicon-based nanoparticles, nanocrystal-based quantum dots and carbon-based nanotubes (CNTs) are potential nanomaterial types for enhancing the efficiency of second-generation solar cells (Lina *et al.,* 2022). Carbon nanotubes (CNTs) improve the performance of solar cells by enhancing the mobility of electrons (Poobalan and Natarajan 2023). Studies have shown that quantum-based dots exhibit a higher electron emission per photon in comparison to conventional materials, hence enhancing the efficiency of solar cells (Nozik 2022). In the dye-sensitized solar cells, the enhanced light absorption characteristics of solar cells are attributed to the substantial surface area shown by titanium nanoparticles (Hendi *et al.,* 2023). In addition to carbon nanotubes, graphene, and perovskites, various other nanomaterials have been found to possess the capability to augment the efficiency and lifetime of solar cells (Poobalan and Natarajan 2023). Nanomaterial use in solar cell efficiency is environmentally friendly as it is accompanied by reduced pollution, and finally its use leads to boost in the economy with an estimated revenue of 2.5 trillion dollars as at 2015. It is estimated that nano production will reach about 1 trillion dollars in 10-15 years (Khan *et al.,* 2025). There are several ways nanotech can be utilised efficiently ranging from enhancing wind farms to boosting energy storage. Nano-porous materials like zeolites can be used to boost thermal energy storage to be used as heat storage in both residential and industrial complexes (Hussein, 2015).

In Hydrogen production process for energy, nanotechnology also has a role to play in operational optimization. Hydrogen is considered an energy carrier rather than serving as a primary energy source (Poobalan and Natarajan, 2023). The power is generated by the utilisation of fuel cells, which convert renewable energy sources into usable form (Renewable Energy, 2023). Nanotechnology has the potential to be employed in the process of hydrogen production via artificial photosynthesis (Kathpalia and Verma, 2023). The hydrogen that is generated thereafter undergoes electrochemical processes, wherein it is chemically mixed with oxygen in the absence of burning. The aforementioned chemical reaction yields a flow of electrical current in the form of direct current. Nevertheless, this particular procedure necessitates a substantial amount of energy and costly catalysts (Poobalan and Natarajan, 2023). Nanoparticles have the potential to address these difficulties through the reduction of energy input and enhancement of catalytic activity. One approach to mitigating the high cost associated with electrodes is achieved through the reduction of the quantity of platinum (Pt) catalyst utilized (Dao *et al.,* 2019). Various catalyst supports, including carbon-based nanotubes, nanodiamonds, conductive-based oxides and carbon-based nanofibers are employed to accomplish this objective (Poobalan and Natarajan, 2023). More so, nanoparticles can be used for collecting and storing solar energy for subsequent electrolysis. In electrolytes, nanoscale range hydrophilic inorganic substances are used to increase the hydrogen ion conductivity of membranes (Rosli, *et al.,* 2020). The performance of membrane fuel cells can be improved by incorporating titania and tin dioxide (SnO_2) into ordinary membranes (Abbaraju, *et al.,* 2008). Hydrogen storage systems is another application of nanotechnology with respect to hydrogen production. Hydrogen is difficult to store because it must be liquefied with elevated pressures and reduced temperatures (Poobalan and Natarajan 2023). Alternative method has been the use of physisorption (Bnard and Chahine, 2007) and chemisorption (Avery, 2022) techniques. Both applications can be made more efficient through the application of nanotechnology. Physisorption is a process which involves the chemical binding of molecules through weak interactions between adsorber and adsorbent. The efficiency of physisorption is further enhanced in large surface regions and porosity of nanomaterials (Poobalan and Natarajan, 2023). In physisorption, carbon-based nanomaterials such as carbon nanotubes, carbon aerogels and carbon nanofibers are typically employed (Mohammad *et al.,* 2021).

Water Purification and Desalination

Water treatment facilities can be made more energy-efficient to lower carbon footprints, and better water management practices can enhance carbon sinks and reduce reliance on energy-intensive processes. More so, most energy production requires substantial amounts of water, and this includes large water use in renewable energy: hydropower, bioenergy, and thermal energy generation from solar, geothermal, and nuclear power, prompting the need for water use efficiency and conservation. Research has also shown that a water-wise perspective in climate mitigation can therefore present an opportunity to improve climate mitigation potential, while also enhancing other benefits such as water security and both human and ecosystem health (Ingemarsson *et al.,* 2022). Hence climate change mitigation and water purification are intertwined, as water management plays a crucial role in both reducing greenhouse gas emissions and adapting to climate change impacts. Nanomaterials such as carbon nanotubes and nano-membranes enhance the efficiency and energy performance of water treatment systems, which are crucial under climate stress conditions. In this era of climate change, exacerbated by increasing pollution, nanotechnology plays a significant role due to its high potential for treating contaminated water and rendering it safe for use (Nishu, 2023). Innovative products and processes include nanoadsorbents, nano zero-valent iron, nanobiocides, nanofiltration, magnetic nanoparticles, and hybrid technologies for catalytic wet air oxidation (Nishu, 2023). Nanomaterials such as carbon nanotubes (CNTs), graphene oxide (GO), and metal oxide nanoparticles (e.g., titanium dioxide, iron oxide, and zinc oxide) possess high surface areas, reactivity, and tunable surface functionalities. These properties enable them to effectively adsorb or degrade a wide range of contaminants, including heavy metals (lead, arsenic, mercury), dyes, pesticides, and pharmaceutical residues. Silver nanoparticles (AgNPs), in particular, are well known for their potent antimicrobial properties and are widely incorporated into filtration systems to inactivate bacteria, viruses, and other pathogens—offering an effective method of disinfection. Nanotechnology also contributes to the development of advanced membranes for filtration processes such as reverse osmosis and ultrafiltration. Embedding nanomaterials into polymeric membranes can significantly improve their mechanical strength, permeability, fouling resistance, and selectivity. For instance, membranes enhanced with TiO_2

nanoparticles exhibit self-cleaning and photocatalytic properties, thereby increasing operational efficiency and lifespan. Photocatalytic nanomaterials, particularly titanium dioxide, harness solar energy to break down organic pollutants and deactivate microorganisms. This method provides an energy-efficient and chemical-free alternative to conventional purification techniques, making it particularly suitable for off-grid or low-resource settings. Beyond purification, nanotechnology facilitates real-time water quality monitoring through the development of nanosensors capable of detecting pollutants at extremely low concentrations. These sensors can identify heavy metals, pathogens, and organic compounds, providing critical information for early intervention and system optimization.

Agriculture and Soil Management

Greenhouse gas emissions from agriculture come from livestock such as cows, agricultural soils, and rice production. Indirect emissions from electricity use in agricultural activities (e.g., powering buildings and equipment) (Chalise and Naranpanawa, 2016; Outhwaite *et al.,* 2022) and this agriculture accounts for nearly 12% of global anthropogenic GHG emissions (Linquist, *et al.,* 2012). The current situation is linked to the use of agricultural machinery and the gases they emit, or interference with the structure and chemical composition of the soil through various chemical agents. The global food system alone is estimated to be responsible for approximately 21–37% of annual emissions (Lynch *et al.,* 2021). Similarly, the food system in the Sub-Sahara Africa (SSA) (crop production and livestock farming) is responsible for about 40–60% of annual emissions of GHG (Omotoso, and Omotayo, 2024). More so, Ogunbode *et al.* (2020) and Robinson (2020) reported that in 2014, agriculture in SSA comprised 15% of primary energy consumption, while in 2018, methane emissions from livestock production, carbon dioxide emissions from soil carbon loss and fossil fuel use, and nitrous oxide emissions from nitrogenous fertilizer application on farmland accounted for 60% of total GHG emissions (Chabbi et al. 2017; Chalise and Naranpanawa 2016). In the last 20 years, about two-thirds of SSA's GHG emissions is majorly from agriculture, forestry, and land-use change (Ogunbode *et al.,* 2020). Recent studies further report that if not actively addressed, these emissions will probably rise by 60% as the population rises due to being highly dependent on agricultural production in terms of food needs (Thornton *et al.* 2018; Henry 2020).

The 6th assessment report of Intergovernmental Panel on Climate Change stated emphatically that a drastic approach to limit change in climate impact to 1.5 °C is needed (Robinson 2020; Kanitkar *et al.,* 2022). This approach requires limiting the cumulative carbon budget in the atmosphere to 570 Giga tonnes of carbon dioxide ($GtCO_2$ eq/yr) by significantly reducing the emissions of other gases like nitrous oxide and methane (Leitner *et al.* 2020; Robinson 2020). Interestingly, agriculture is one of the major contributors of methane (CH_4) and nitrous oxide (N_2O) (non-CO_2 GHGs), which have a greater global warming potential (Robinson 2020). Effective soil management plays a crucial role in reducing greenhouse gas (GHG) emissions and mitigating climate change by enhancing carbon sequestration and minimizing harmful emissions from the soil. Sustainable practices like reducing tillage, optimizing fertilizer use, and promoting crop rotations can significantly impact GHG emissions and improve overall health of soil. By enhancing nutrient use efficiency, reducing reliance on chemical fertilizers, and promoting carbon sequestration, nanotechnology can play a significant role in mitigating climate change Nano-fertilizers and nano-sensors optimize resource use and monitor soil health, contributing to climate-smart agriculture. Nanotechnology has the potential to positively impact the agri-food sector by improving food security and promoting socioeconomic equity (Fraceto *et al.,* 2016). Unlike conventional agricultural practices, it is environmentally friendly. Nanotechnology holds great promise for the development of novel tools that ensure sustainable agriculture (Fraceto *et al.,* 2016; Usman *et al.,* 2020). Nanotechnology can also mitigate eutrophication by reducing nitrogen leaching into groundwater. It is used to enhance pesticide performance by improving their solubility and resistance to hydrolysis (Fraceto *et al.,* 2016; Usman *et al.,* 2020). Technologies such as hydrogels and nanoclays improve the water-holding capacity of soils, while others can be utilized to absorb environmental contaminants and enhance soil remediation (Fraceto *et al.,* 2016). Nanomaterials also positively influence soil organic matter (SOM) (Usman et al., 2020) and tend to have less harmful effects on soil microbes compared to chemically synthesized analogues (Usman *et al.,* 2020). However, despite these benefits, the application of nanomaterials can also be phytotoxic (Usman *et al.,* 2020; Mazaheri-Tirani and Dayani, 2020). The positive or negative effects largely depend on the dosage, particle size, and nature of exposure to the nanomaterials.

Socio-Cultural Acceptability and Ethical Concerns

Cognizance of sociocultural and ethical issues surrounding the acceptance of nanotechnology are significant for the sustainability of technology implementation. This is because people's attitudes towards nanotechnology are complex, with both positive and negative perceptions influenced by factors like cultural background, religiosity, trust in science, and media representation. While some understand nanotechnology to hold solutions to global challenges like climate change mitigation and adaptation efforts, others express concerns about potential risks, ethical dilemmas, and social inequalities. More so, as a transformative field with implications across health, environment, industry, and daily life, wide adoption of nanotechnology raises a number of important concerns. In the past, societal responses to new technologies have played a crucial role in the success (e.g. mobile phones, internet) or failure (e.g. food irradiation; genetically modified foods) of such technologies (Frewer *et al.* 2004, Gupta *et al.,* 2012). It is likely that, just as has been the case for some other new technologies, socio-psychological factors will influence the societal response to nanotechnology (Gupta et al. 2011). Studies have found that such socio-psychological factors will shape the commercialisation trajectory of technology but also facilitate allocation of resources in areas of application relevant to the wider needs of society (Gupta *et al.,* 2012; Salamanca-Buentello and Daar, 2021). Some studies have reported that the general public has limited, or no, knowledge or awareness about nanotechnology, and that public involvement in the debate surrounding nanotechnology development is rare (Priest 2006; Pidgeon *et al.,* 2009; Vandermoere *et al*. 2010, Ronteltap *et al*. 2011;). There have been some studies highlighting lack of trust, institutions, risks issues and benefit perception as factors that likely to affect consumer acceptance of agrifood nanotechnology products (Besley *et al.* 2008; Corley *et al.* 2009; Ho *et al*. 2011). From the ongoing, it can be seen that an important element in determining how nanotechnology will be implemented depends on public perceptions and societal acceptance of both the technology and its specific products across different domains of applications. Although expert view on societal response to new technologies may not align with actual societal attitudes, (Webster *et al.* 2010), those expert views on societal responses, are likely to influence technology implementation and commercialization (Gupta *et al.,* 2012). Social issues with acceptability of nanotechnology can be broadly categorized as follows:

Public Perception and Trust

One of the primary sociocultural barriers to the acceptance of nanotechnology is public understanding and perception. Many people lack knowledge about what nanotechnology entails, which often leads to fear or skepticism. Concerns about "tampering with nature" or creating artificial materials at an invisible scale can result in social resistance, especially when media coverage emphasizes risks rather than benefits. Some scholars have assessed the acceptability of and willingness to pay for these innovative technologies (Correia Carreira *et al.,* 2016). However, awareness creation has not kept pace with these inventions, as the majority of people are still unfamiliar with the term nanotechnology (Carreira *et al.,* 2016). Another important factor influencing the acceptability of nanotechnology is the issue of social justice and vulnerability—an argument rooted in moral reasoning (Conti *et al.,* 2011; Gupta *et al.,* 2015). Most consumers tend to accept its application in the medical field, based on the perception that such uses are highly valuable and ethically justified (Priest and Greenhalgh, 2011; Gupta *et al.,* 2015). According to Breggin and Carothers (2006), the assumption of the responsible development of nanotechnology implies sensitivity to public perceptions and public trust at an early stage of technology development. Boholm and Larsson, (2019) considered a responsible technology development is further understood to have the capacity to counteract failure due to public lack of acceptance of, or opposition to, new technology. At an early stage of innovation, US scientists and policymakers worried that the public might turn against nanotechnology (Friedman and Egolf 2005). Similar experience happened in Europe with genetically modified organisms (GMOs): concern over risk and lack of trust in science, experts, and regulators were factors that turned the public against the technology as such, the industry, and the products (Wynne 2001). In order to avoid repeat of history in the form of public distrust of regulatory agencies and scientific experts, consumer boycotts of products and companies, citizen pressure on policymakers and regulators, and amplification of risks in the media, Sylvester *et al.,* (2009) maintained that foresight and sensitivity to public concern have been recurrent mantras regarding the development of nanotechnology. It is argued that developers and industry, as well as policymakers and regulators, must be aware of possible public concerns and of the societal dynamics of media and interest groups before they manifest as protests and social movements (David and Thompson, 2011).

Risk and Safety Concerns

Uncertainty about the long-term health and environmental effects of nanomaterials continues to fuel ethical debates. Nanoparticles can penetrate biological membranes, and their interactions with human cells or ecosystems are not yet fully understood. The above concern raises ethical concerns about the release of inadequately tested nanomaterials and the potential for unintended consequences. Similarly, the application of nanotechnology in water purification presents its own challenges. The potential toxicity of certain nanomaterials to humans and aquatic life remains a significant concern. Another example of risk and safety concern towards nanotechnology is the hesitance to accept COVID 19 vaccination. The COVID-19 pandemic brought about devastating health, social and economic losses worldwide and was one of the most challenging global health threats in modern history. However, advances in nanotechnology come to the rescue in the form of rapid diagnostic tests and, perhaps more importantly, swiftly developed vaccines against SARS-CoV-2 (Salamanca-Buentello and Daar 2021). At the same time, numerous non-technical issues have complicated the deployment of these novel technologies such as, social and cultural acceptance especially in developing countries. Study revealed that social issues jeopardized most countries' ability to achieve the WHO-recommended 70 percent coverage target for all countries, which would halt the pandemic by creating global herd immunity (Ayeni *et al.,* 2022). The lack of trust in scientific process has been shown to be particularly important as an explanation for public attitudes toward nanotechnology (Ho et al. 2010). Some studies suggest that public opinion on nanotechnology is guided by general attitudes toward science and technology, and that broad ideas about the value and use of technology in society guide the formation of attitudes toward nanotechnology (Priest 2009; Priest *et al.,* 2011). Very few people have personal experience of and familiarity with nanotechnology, an advanced broad transdisciplinary natural science field that is difficult for non-specialists to comprehend. Therefore, it makes sense that deference to scientific authority (Ho *et al.,* 2010). More so, interest and trust in science, and a general belief that scientific knowledge is beneficial all influence attitudes toward nanotechnology (Retzbach *et al.,* 2011).

Cost, Scalability and Regulatory Oversight

Additionally, issues related to cost, scalability, and regulatory oversight must be addressed to ensure safe and sustainable implementation. Life cycle analysis and environmental impact assessments are essential for the responsible deployment of nanotechnologies. Studies have also shown that nanotechnology tends to be perceived as relatively risk-neutral compared to biotechnology, genetic engineering, or nuclear energy (Carreira *et al.,* 2016). Moreover, the health risks associated with nanotechnology are considered lower than those from smoking, pesticide residues in food, alcohol consumption, or cloning (Carreira *et al.,* 2016). On the whole however, the risks and benefits associated with nanotechnology application are assessed differently depending on the area of application (Pidgeon *et al.,* 2009; Siegrist 2010). These attitudes differ a lot depending on the area of application is clear from many studies (Cacciatore *et al.,* 2011; Gupta *et al.,* 2012 & 2015; Larsson and Boholm 2018). For instance, Macoubrie (2006) argued that people are more favorable toward nanotechnology applications to remedy water quality, nanotechnology developments in medicine, and nanotechnology addressing problems in developing countries. On the other hand, applications such as cosmetics are regarded as poorly justified and are generally not approved (Macoubrie 2006; Larsson and Boholm 2018). The public has also been found to be skeptical or doubtful toward nanotechnology in the food sector (Bostrom and Löfstedt 2010; Duncan 2011). To address some of these fears Siegrist (2010) focused on public views of the labeling of nanoproducts, which is understood to be an important regulatory tool to manage consumer products containing nanomaterials. According to Brown and Kuzma (2013), labeling is expected to have an important role in risk communication in the field of nanotechnology. The public is favorable toward the labeling of nanotechnology used in food (Boholm and Larsson, 2019). The study wants labeling for all types of food and are also willing to pay for this, since they believe that labeling facilitates informed decisions related to risk management. Consumers also believe that they have a right to be informed (Brown and Kuzma 2013; Yue *et al.,* 2015).

Privacy and Surveillance

Nanotechnology enables the development of highly sensitive sensors and tracking devices. While useful in fields like medicine and security, this also opens the door to intrusive surveillance, raising questions about personal privacy, consent, and data ownership. Ethical frameworks need to guide the balance between societal benefit and individual rights. Privacy has also been considered as one of the major moral issues in connection with the development and applications of nanotechnology (Gutierrez, 2004; Mehta, 2003). Privacy has already been an important theme in our thinking about information technology in the last decades (Van den Hoven, 2005). Nanotechnology incorporates and integrates different technologies including information technology (Van Den Hoven and Vermaas, 2007). Hence, by these information-technological applications, nanotechnology will give rise to a panoply of privacy issues (Van Den Hoven and Vermaas, 2007).

Access and Equity

There are concerns that nanotechnology could deepen existing global and social inequalities. These concerns boarder access and equity and can be discussed under the following.

- Unequal distribution of benefits: The benefits of nanotechnology may not be evenly distributed, with some groups or communities reaping more benefits than others. This perception will manifest between the high-income earners and the have-not, developed and least developing economies, rural and urban centres.
- Limited access to information: The lack of awareness and understanding of nanotechnology among certain groups, especially farmers in communities of SSA may limit their ability to access its benefits in mitigating Climate and climate adaptation efforts.
- Economic constraints: The high cost of nanotechnology-based products may make these technologies inaccessible to low-income communities in developing countries.
- Infrastructure limitations: The lack of infrastructure, such as clean water and sanitation, may limit the potential benefits of nanotechnology in certain regions. Most developing countries are already faced with water crises and sanitation-related issues. This has implications for wider application of nanotechnology in addressing climate change and adaptation efforts.

Access and equity in nanotechnology refers to the fair and just distribution of the benefits and potential risks associated with nanotechnology, ensuring that all individuals and communities have the opportunity to benefit from its positive impacts. If access is limited to wealthy countries or individuals, it could exacerbate the technological divide. Ethical adoption requires policies that promote fair distribution and access to nanotechnology innovations, especially in healthcare and clean energy. This is particularly important for innovations and technologies aimed at climate change mitigation and adaptation (Jones *et al.,* 2024). Therefore, further studies are critical to ensure equitable access and to prevent a scenario where only the wealthy can benefit from such innovations. More so, to ensure equity entails addressing potential disparities in access to nanotechnology-based products and services, as well as ensuring that vulnerable populations are not disproportionately impacted by its risks.

Ethical Governance and Regulation

A lack of clear regulatory frameworks for nanotechnology raises issues of accountability and responsibility. Who is liable if nanotechnology causes harm? What ethical standards should govern its development? Transparent and inclusive regulatory processes are essential to ensure safe and responsible innovation. A major limiting factor to its acceptance is the lack of ethical guidelines and a well-formulated legislative framework (Somesan and Copoeru, 2024). Ethical governance and regulation in nanotechnology aims to provide standards for the responsible development and application of nanotechnology, addressing potential risks and perceived societal impacts. Ethical governance involves establishing principles for sustainability, safety, transparency, and equity, ensuring that nanotechnology benefits society without causing harm. In February 2008 for example, the European Commission adopted the recommendation for the Code of Conduct for responsible nanosciences and nanotechnologies research, which provides principles and guidelines for actions to be taken by the EU Member States in the course of formulation of their nanosciences and nanotechnologies (N&N) strategies, and development of sectoral and institutional research and development standards. The Code is voluntary and there are no authoritative sanctions for failure to adopt it. It was intended to facilitate and underpin the regulatory and non-regulatory approaches indicated in the 2005-2009 N&N Action Plan for Europe, improving the implementation of existent regulation and coping with scientific uncertainties. The Code sets out general principles and guidelines on actions to be taken in order to achieve good governance of N&N research. In Africa, though there are regulatory bodies for example Standard Organization of Nigeria (SON), in Nigeria, efforts in developing regulatory frameworks for nanotechnology is under-developed. Effective governance and regulation of nanotechnology are critical to addressing the social fears and misconceptions associated with technology. For most African countries key challenges in governing and regulating nanotechnology are:

- Lack of standardization: The lack of standardization in nanotechnology hinders development of effective regulations. For most developing countries regulatory frameworks do not exist.
- Limited public engagement: There is limited public engagement and awareness of nanotechnology, and this makes it difficult to develop effective governance and regulation to address social issues with technology.
- International coordination: The global nature of nanotechnology requires international coordination and cooperation to develop effective governance and regulation. There is at the moment no international or regional framework for effective governance and regulation.

Cultural and Religious Beliefs

In some cultures, nanotechnology may be perceived as unnatural or morally questionable, particularly when it involves human enhancement or gene editing at the nano level. Cultural sensitivity and open dialogue are necessary to navigate these deeply held beliefs and to foster informed, respectful acceptance. Research shows that the more religious a person is, the less likely they are to support funding for nanotechnology development (Carreira *et al.,* 2016). For example, a 2009 survey found that strength of religious beliefs in the US is negatively related to support for funding nanotechnology. A study of the same year found that the more religious a country is, the less it tends to find nanotechnology morally acceptable (Guardian News & Media Limited (2025). More evidences have emerged to show higher levels of religiosity are associated with less positive perceptions of emerging technologies such as nanotechnology (Brossard, *et al.,* 2008; Scheufele, *et al.,* 2009), embryonic stem cell research (Nisbet, 2005; Nisbet and Goidel, 2007), and when it concerns benefits, individuals with creationist beliefs are less likely to have optimism about medical genetics (Allum, *et al.,* 2008; 2013).

Recommendations

A public acceptance of, or attitude toward, a given technology will significantly impact its development and implementation (Somesan and Copoeru, 2024). This means that the success or failure of a new technology largely depends on public opinion. If public sentiment turns against such technology, its chances of success are significantly jeopardized (Somesan and Copoeru, 2024). Therefore, to boost its acceptance—particularly in the context of mitigating and combating climate change—the following recommendations have been suggested:

Promoting Public Awareness

The limited public engagement and awareness of nanotechnology, especially on perceived risks can make it challenging to develop effective governance and regulation. From the conception that the public has a low level of knowledge nanotechnology, making communication problematic, it has been argued that education must be part of any successful communication strategy (Boholm and Larsson, 2019). People's knowledge and capacity for critical reasoning must be improved (Wiedemann *et al.,* 2011). Gardner *et al.,* (2010) suggested that educational programs to improve "risk literacy" in the public should be developed. Risk literacy applied to nanotechnology, it is argued, should engender the understanding that nanotechnology is heterogeneous and includes many applications that can have specific controversial aspects (Boholm, and Larsson, 2019). Public education to address the public perception of risks associated with nanotechnology. More so, limited awareness and understanding of nanotechnology can limit access to its benefits

- Education and awareness: Investing in education and awareness will enhance public understanding of nanotechnology, promoting greater confidence in the technology and access to its benefits. Educating the public about nanotechnology can enhance awareness and understanding, promoting greater access to its benefits.
- Conducting public engagement: Conducting public engagement and awareness campaigns can enhance public understanding of nanotechnology, promoting greater access to its benefits.
- Investing in research and development: Investing in research and development can help identify and mitigate the potential and perceived risks associated with nanotechnology. There is also need for research on public understanding of the technology across different sectors and income levels.
- Develop targeted audience-specific communication: Research is also required to develop targeted audience-specific communication. When considering solutions to nanotechnology social acceptability, the focus is on targeted communication based on an understanding that the public is fragmented (Literates and illiterates etc) and that different audiences respond to information in different ways. More so, targeted nanotechnology communication is usually tailored to the understandings, values, needs, and knowledge of particular groups, with the aim of helping them understand nanotechnology and gain the tools needed to make well-balanced decisions for themselves (Yue *et al.,* 2015; Pillai and Bezbaruah, 2017).

Enhance Public

Engagement to ensure inclusive and equitable development: Public engagement is vital to the social acceptance and ethical governance of nanotechnology. Historically, technological advancements have often overlooked the voices of marginalized communities, leading to uneven benefits and unaddressed concerns. To ensure inclusive and equitable development, it is critical to:

- Conduct participatory consultations that include Indigenous peoples, rural communities, women, and youth in nanotechnology discussions.
- Use accessible language and media to demystify nanotechnology and foster informed community-level dialogue.
- Build trust through stakeholder's engagement that promotes transparency about risks, benefits, and uncertainties of nanotech applications.
- Encourage citizen science and local stewardship in projects involving environmental nanotechnology (e.g., nano-enabled water purification or soil remediation).

- Developing inclusive innovation policies: Developing policies that promote inclusive innovation will promote the benefits of nanotechnology and ensure that the benefits of technology are more evenly distributed.

By embedding social values into scientific discourse, we can co-create technology that meets real needs and reflects diverse perspectives.

Incentivize R&D Investment

Innovation in nanotechnology requires sustained investment, often beyond the risk tolerance of private investors due to long development cycles and regulatory uncertainty. To unlock the full potential of nanotech:

- Governments should provide targeted grants, subsidies, or tax incentives to support nanotech research in climate, water, and health sectors.
- Establish public-private partnerships (PPPs) to combine academic expertise with industrial scale-up capabilities.
- Use innovation challenge funds or venture capital de-risking models to stimulate private sector participation.
- Support early-stage technology incubators focused on socially beneficial nanotech applications.

These approaches will foster a vibrant innovation ecosystem where risks are shared and rewards are directed toward the public good.

Develop Adaptive Regulations

Nanotechnology poses unique regulatory challenges due to its novel properties, cross-sectoral applications, and potential long-term risks. Traditional regulations are often too rigid or outdated. An adaptive regulatory approach should:

- Employ evidence-based policy that evolves with emerging research on nanotoxicology and environmental impacts.
- Create multi-stakeholder regulatory bodies that include ethicists, scientists, industry, and civil society.
- Develop tiered risk assessment protocols that account for nanoscale behaviors different from bulk materials.
- Promote international regulatory harmonization, while allowing flexibility for local context and culture.

Responsive regulation ensures that innovation is not stifled while public safety and ethical considerations remain central.

Foster International Technology Transfer

Global disparities in research capacity and industrial infrastructure can prevent developing countries from accessing or benefiting from nanotechnology. International technology transfer should:

- The Human Development Index (HDI) is a key metric used to differentiate between developed and developing countries, measuring average achievements in health, education, and standard of living. Generally, developed countries generally have higher HDI scores, while developing countries have lower scores. This gap is also seen in the research output, both in terms of quantity and impact. There is therefore the need to facilitate North-South and South-South collaborations in nanotech research and deployment.
- Encourage open science platforms and patent pooling for humanitarian nanotech applications (e.g., clean water, disease diagnostics).
- Provide technical assistance and capacity-building in less-developed regions to support local adaptation and governance.
- Align with UN Sustainable Development Goals (SDGs) to ensure that nanotechnology deployment contributes to inclusive development.
- Equitable access enhances global resilience and ensures that no country is left behind in the nanotech revolution.
- Encourage international cooperation: There is need to encourage international cooperation and collaboration that can facilitate the development of effective governance and regulation, promoting greater accessibility.

Embed Nanotechnology in Climate Policy

Integrate nano-based solutions into national adaptation and mitigation plans. Nanotechnology can play a key role in tackling climate change by enabling cleaner energy, efficient resource use, and better environmental monitoring. Yet, many national climate strategies do not explicitly incorporate nanotech. To close this gap there is need for.

- Recognize nano-enabled technologies (e.g., nano-coatings for solar panels, carbon capture nanomaterials, nano-sensors for emissions) in Nationally Determined Contributions (NDCs) and climate adaptation strategies.
- Invest in cross-sectoral research to explore how nanotechnology intersects with agriculture, energy, and water systems under climate stress.
- Use nanotechnology to support low-carbon development in emerging economies by improving energy efficiency and waste reduction.
- Integrate nano-related risks into climate-resilience planning to avoid unintended environmental or health consequences.
- Proactively embedding nanotech into climate policy enhances technological readiness and aligns innovation with long-term sustainability goals.

Conclusion

Nanotechnology presents a powerful suite of tools for mitigating climate change, with applications spanning energy, agriculture, industry, green building and water systems. However, its success hinges not solely on scientific progress, but on societal readiness and acceptability. The ideal of the sustainable development of nanotechnology implies sensitivity to public perceptions and public trust from an early stage of technological development to deployment. Socio-cultural perceptions and economic structures must be considered integral components of this technological feasibility. This is to ensure development and deployment that safeguards the environment, human health, and safety, and to ensure that nanotechnology benefits society more than negative impacts. This review highlighted the need for a multidimensional strategy—grounded in ethics, inclusivity, and socioeconomic pragmatism—to ensure that nanotechnology can fulfill its promise in the global fight against climate change. Indeed, if these measures are put in place, nanotechnology is critical and will remain critical to mitigating and adapting to climate change especially in the most vulnerable part of the world like Nigeria.

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