<https://doi.org/10.36293/sfj.2019.0008>

SUSTAINABLE NANOTECHNOLOGY DEVELOPMENT IN NIGERIA – HAZARDS AND POLICY DIRECTIONS

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Abstract

The emergence of nanotechnology is shown to be a useful tool for socio-economic transformation of nations. The hazardous effect of nanoparticles in mice is presented here as an evidence for public health concerns on exposure to nanoparticles. This paper takes a review of literatures to study the efforts that the forefront nations in nanotechnology development have put into the health safety and environmental concerns of nanotechnology. We have used scientific publications on nanotechnology, country investments in nanotechnology, patents and nano-products commercialization to provide an oversight and an apparent correlation to the expected volume of nanowastes and exposure to nanoparticles. Our results show that the less conscious nations on nanotechnology development stand to be more exposed to nano-hazards due to poor policy framework for nanotechnology development and management. There is currently no policy framework that directly addresses the management of nano-wastes and associated nano-hazards in Nigeria. National Environmental Standards and Regulations Enforcement Agency, (NESREA), Standard Organization of Nigeria (SON), and the National Agency for Food and Drug Administration and Control (NAFDAC), have been identified as major government bodies to checkmate workplace exposure to nanoparticles, importations and local production of engineered nanomaterials in Nigeria. The inclusion of safety assessment and funding of environmental impact research are considered as very important components in the roadmap for nanotechnology development in Nigeria.

Keywords: Nanotechnology, Nanowastes, Toxicity, Nanoparticles, Policy framework

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Abbreviations

NOA: National Orientation Agency
NAFDAC: National Agency for Food and Drug Administration and Control
SON: Standard Organization of Nigeria
NESREA: National Environmental Standards and Regulations Enforcement Agency
NIOSH: National Institute for Occupational Safety and Health
REACH: Registration, Evaluation, Authorization, and Restriction of Chemicals
NNI: National Nanotechnology Initiative
NASERI: National Environmental Standards and Regulations Enforcement Agency
CSIR: Council for Scientific and Industrial Research

DEAT: Department of Environmental Affairs and Tourism
IARC: International Agency for Research on Cancer
USPTO: United State Patent and Trademarks Office
ISI: International Scientific Indexing
SCI-E: Science Citation Index Expanded
EPO: European Patent Office
ISO/TS: International Standard Organization/Technical Specification
BRIICS: Brazil, Russia, India, Indonesia, China, and South Africa
NNS: National Nanotechnology Strategy
OECD: Organization for Economic Co-operation and Development

Introduction

Science and technology (S & T) have been the bedrock of industrial revolutions. Innovation has however, played a significant role in advancing S & T from the first industrial revolution that is characterized by uneconomically large and heavy machineries to the fourth industrial revolution where miniaturization of machineries and electronic appliances is predominant (Adlakha-Hutcheon *et al.* 2009; Hobson, 2009; Otegui and Maria, 2014). These technological revolutions have generated associated challenges such as solid waste which has become a concern to public health and the environment (Sasikumar and Krishna, 2009; Durgeter, 2016). Most of the developed countries are the main inventors of the technologies and the poor management of the associated wastes to the unintended detriment of developing nations gave rise to international policies like the Basel and the Bamako conventions (Shearer, 1993). Recent solid wastes contain some forms of nanomaterials (Holder *et al.*, 2013) which have engineered the miniaturizations of electronics, enhanced material applications and the efficiency of service delivery.

The ISO / TS 27687: 2008 defined nanomaterials as nano-object in the size range of 1-100 nm that could have one, two or three dimensions in its external structure (Wilson *et al.*, 2017). This is a billion part of nanometer which can penetrate the pores of membranes (Holder *et al.*, 2013). They contain materials that could be toxic to human body and the ecosystem (Bystrzejewska *et al.*, 2009; Jennifer and Maciej, 2013; Kunhikrishnan *et al.*, 2015). The waste generated from nanomaterials and related activities are referred to as nanowastes. They could be generated from research activities, items contaminated by

nanomaterials, production of commercial nanoproducts or the expiration and disposal of products containing nanomaterials (Hull *et al.*, 2009; Marcoux *et al.*, 2013).

The nano-size nature of the materials makes it easier for escape into the air, water and soil (Keller and Lazareva, 2013). There are evidences of their possible harmful effects when released into the environment (Gould, 2014; Raquel, 2015; Wilson *et al.*, 2017). The size-effect poses many difficulties in the management of nanowastes and exposure to nanoparticles because they have unique properties different from their bulk counterparts. They are more chemically reactive and resistant to harsh environment with the tendencies of exhibiting new physiochemical properties (Faunce and Kolodziejczyk, 2017). Nevertheless, due to the socioeconomic benefits of nanotechnology in almost all the sectors of the economy, much attention has been focused on the development of new products and the enhancement of the existing ones using the technology.

Recent research efforts towards the toxicity of nanomaterials have produced some data which experts still argue to be insufficient in understanding the robust and dynamic properties of nanomaterials from which an informed and definitive policy framework could be drawn. Due to the fact that the 21st century electronics and devices are dominated by components made of nanomaterials, there could be a correlating volume of nanowastes generated from the over 14 million tons of electronic waste that is generated annually on a global scale (Chen *et al.*, 2010). This poses more danger for developing countries that are either deficient in human resources or in research capabilities in nanotechnology. Such

countries will largely depend on the consumption of engineered nanomaterial products rather than production and management of nanotechnology. The threat to public health and the environment will be inherent in the poor knowledge in handling or usage of nanomaterials and the import of nearly end of life-cycle products also known as “second-use”.

Exposure to nano-hazards has been categorized into five major groups namely, workers in the manufacturing industry, research institutions, the consumers, the general population and the ecosystem (Erbis *et al.*, 2016). Leading nations in the development of nanotechnology are making efforts to protect these various groups from nano-hazards. However, there are no clear established protocols to manage the export of engineered nano-products into developing countries. The Basel and Bamako conventions are international policy frameworks intended to mitigate the export of hazardous materials across nation's borders but there are shortfalls in the provisions of the frameworks. It is such an oversight shortfalls of the Basel convention that necessitated the Bamako convention, because radioactive wastes were not captured in the Basel convention (Shearer, 1993). The current work is to provide a conceptual narrative on global nanowastes and exposures to nano-hazards, examines the outlook on the risks associated with nanowastes in developing nations with emphasis on Nigeria.

Materials and methods

A correlation can be drawn between the volume of nanowastes in relation to indices that are critical indicators for nanotechnology development such as the efforts geared towards nanomaterials-

research as evident by scientific publications, government and private investments in the development of nanotechnology, patents and the commercialization of nano-products (Hullmann, 2006; Palmberg *et al.*, 2009). These are critical indicators to the potential increase in the volume of nanowastes and exposures to nanoparticles. The discussion on these indicators in this paper is not an attempt to provide a detailed representation of them, but to provide an overview on the potentials of using them as a tool in speculating the possible increase in nano-hazards.

Analysis and Discussion

Nanomaterials Scientific Publications and Country Investments

Nanotechnology has been identified as a rapid growing emerging area of research globally with an average growth rate of 11% and 4 times more than the world's average in all fields in the same period (Elsevier, 2015). Nanoscience has shown an outstanding publication growth of about 80% compared to other fields (Bhattacharya, 2016). It has significantly changed the growth pattern of the world paper publication since around year 2000 as shown in Figure 1 (Gorjiara and Baldock, 2014; Ghosh and Krishnan, 2014; Bhattacharya, 2016). The doubling time of the publications output for USA and China has been predicted at 7.4 years and 3.2 years, respectively (Gorjiara and Baldock, 2014; Ghosh and Krishnan, 2014). It shows a clear reflection in the efforts put into nanomaterials research which is expected to span through basic research, applications and health hazard management.

Figure1: Worldwide publication trend on research output from 1990 – 2012 (Source: SCI-E)

For example, the conscious funding of nanotechnology development by the establishment of the National Nanotechnology Initiative (NNI) in USA in the year 2001 gave rise to the significant research efforts in nanotechnology as shown in Figure 2. The drop around year 2011 could be attributed to the decrease in investment within the period as shown in Figure 3. The slight decrease in the funding of NNI puts China at the number one position. Both countries now occupy the first 5% positions in the world publications record as shown in Figure 4, whereas there is no African country that meets the world average position. However, a more accommodating data in Figure 5 reflects an emerging contribution from South Africa which could be attributed to the National Nanotechnology Strategy (NNS) that was launched in 2006 (Cele *et al.*, 2009).

The NNS has enabled South Africa's collaborations with most of the member states of the BRIICS (Brazil, Russia, India, Indonesia, China, and South Africa) for the development of nanotechnology capacity. Although, it shows a very weak position for Africa, such effort beacons hope for Africans in this emerging technology. The contribution of Nigeria is so insignificant that it is difficult to identify in Figure 5. On an overall assessment, it showed the current poor state of African engagement and a

disadvantageous position of the continent in the ongoing development and management of nanotechnology. Human capacity development, expertise for nanotechnology and management could become a major challenge in Africa. As such, the continent would be largely classified as consumers of nanoproducts rather than active players in nano-product development.

Patents and Nano-products Commercialization

Patents in nanotechnology based on the ISO/TS 18110 by the nanoscience, technology and industry information, are usually considered when at least one of such claims is related to nanotechnology or if such patents can be coded based on the code from the International Patent Classification for the field of nanotechnology (ISO, 2015). The two important and widely accepted patent offices in the world- the US Patent and Trademarks Office (USPTO) and the European Patent Office (EPO), have shown the volume of patents ongoing in nanotechnology. The sums of 19,563 patents were published in USPTO with United States having about half of the patents in the year 2016. The granted patents put at 8,484 and 11,079 are published patents (StatNano, 2017).

Figure 2: Highly productive countries in nano-publications (Gorjiara and Baldock, 2014)

Figure 3: USA national nanotechnology initiative: supplement to the president's 2017 budget (NNI, 2016)

Figure 4: Top 30 most prolific countries in nano-publications (Gorjiara and Baldock, 2014)

Figure 5: ISI Indexed nanotechnology articles by country
Source: Web of Science (ISI Web of Knowledge)

A comparison figure for patents and growth rate, relative to year 2015 in nanotechnology patents and published nanotechnology patent applications are given in Figure 6. The top ten countries are presented in Tables 1 and 2

for nanotechnology patents and published nanotechnology patent applications. There is a very significant increase in the growth rate for nanotechnology patents by the EPO (StatNano, 2017).

Figure 6: Growth rate of the number of nanotechnology patents in USPTO and EPO in 2016 in Comparison with 2015 (StatNano, 2017)

Table 1: Highly productive countries in Nanotechnology Patents in USPTO in 2016 (StatNano, 2017)

Rank*	Country	No. Nanotech Patents in USPTO	No. Nanotech Patents in EPO	Growth in USPTO Patents comparing to 2015 (%)	Growth in EPO Patents comparing to 2015 (%)
1	USA	4316	577	-1.12	37.05
2	South Korea	914	105	8.94	101.92
3	Japan	819	188	-9.20	43.51
4	Taiwan	514	19	2.80	58.33
5	China	416	59	5.85	110.71
6	Germany	301	289	-1.95	26.20
7	France	210	208	-13.22	36.84
8	Netherlands	136	71	-12.82	65.12
9	UK	123	81	9.00	0
10	Canada	106	22	-3.54	0

Table 2: *Ranking according to the number of published patents in USPTO (StatNano, 2017)

Rank*	Country	No. Nanotech Patents in USPTO	No. Nanotech Patents in EPO	Growth in USPTO Patents comparing to 2015 (%)	Growth in EPO Patents comparing to 2015 (%)
1	USA	5635	282	5.90	5.67
2	South Korea	1326	273	5.83	26.37
3	Japan	805	268	-7.79	-7.46
4	Taiwan	591	97	-14.10	69.07
5	China	566	25	2.17	-280.00
6	Germany	413	165	-9.03	-15.15
7	France	284	92	-12.88	-35.87
8	Netherlands	196	8	2.62	-37.50
9	UK	187	47	-11.79	29.79
10	Canada	132	47	11.86	-42.55

The Uncertainty in the Volume of Nanowastes and the Current Risk Management Approach

Globally, the risk management approach to nanowastes and exposures to nanoparticles have been put at a precautionary level arguably due to insufficient cytotoxicity data. Despite the absence of global statistics on nanowastes, there are anticipations that engineered nanomaterials are expected to increase from 1000 metric tons in 2004 to 58000 metric tons per year from 2011 to 2020 (Aslani *et al.*, 2014). This gives an idea of the expected relative volume of nanowastes. Although, there are some natural nanomaterials that have been in existence, the deliberate efforts made in the advancements of S & T have led to the development of engineered nanomaterials. There are already existing commercialized products that contain engineered nanomaterials as shown in Table 3 (Zhang *et al.*, 2015). A database for nanotechnology products and applications has been created and its update is continuous because of the emerging nature of nanotechnology (NanoWerk, 2018).

China as one of the leading countries in nanotechnology development has mapped out safety strategies and implementation to protect the environment and mitigate exposures to nanoparticles and nanowastes (Jarvis and Richmond, 2011). The periodical reviews of these strategies has given rise to stakeholders discussions such as the “Toxicological Effects of Carbon Nanomaterials” (2004-2008), “Environmental Activity and Health Impact of Ambient Superfine Particles” (2006-2010) and the “Nano-safety Project on Health and Safety Impacts of Nanotechnology”. Similar technical workshop program sponsored by Consumer Product Safety Commission in collaboration with the National Nanotechnology Initiative-2015 of the United States of America has equally identified the enormous tasks in quantifying exposures to nanomaterials hazard (NNI, 2015).

There are some studies on the toxicology of nanoparticles where evidence of hazardous effects from exposures are reported (Tejral *et al.*, 2009; Aslani *et al.*, 2014; Ze *et al.*,

2014; Bressot *et al.*, 2015; Yekeen *et al.*, 2017a, b). For example, the exposure of mice to titanium dioxide (TiO₂) nanoparticles suggests a possible damage to the central nervous system after a prolonged exposure to a diseased skin (Ze *et al.*, 2014). Nanoparticles of TiO₂ have also been reported to cause damage to the bone marrow and sperm cells of mice (Bakare *et al.*, 2016). The International Agency for Research on Cancer (IARC) has classified TiO₂ under the group 2B as a possible carcinogenic agent (IARC, 2018).

Some environmental and human health protection organizations from the forefront countries are developing frameworks for addressing the uncertainties associated with nanowastes and related nano-hazards. The USA is making efforts in addressing this situation through the Environmental Protection Agency, which has a regulatory activity on nanomaterials under the Toxic Substances Control Act (US EPA, 2015). The National Institute for Occupational Safety and Health (NIOSH) is making consistent safety research efforts through health and safety initiative for nanotechnology development (NIOSH, 2018). European Union has made significant efforts to develop a common framework through the NANoREG project to address the potential hazardous effects that could arise from nanotechnology development (Gottardo *et al.*, 2017).

The REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) is one of such robust framework aim at implementing the protection of the ecosystem and public health from the EU chemical industry. The REACH strongly advocates for a “no data no market” policy. The USA and EU regulatory frameworks have largely been adopted as a model by most Asian countries. However, individual

countries in the Asian continent are also making efforts in improving these regulations with a consideration to their respective domestic peculiarity.

South Africa has identified the need to pay attention to the challenges that are associated with development of nanotechnology such as nanowastes. A policy document prepared for the Department of Environmental Affairs and Tourism (DEAT) titled, “Emerging Issues Paper: Hazardous and New waste types 2008” clearly indicates the readiness of South Africa to develop a positive approach in handling the uncertainties of the hazardous nature associated with nanowastes. The Nanotechnology Ethics Committee and the Nanotechnology Health, Safety and Environment Committee are the two committees constituted by the Department of Science and Technology to address issues related to the responsible usage of nanomaterials and related issues (CSIR, 2013; S & T SA). It is on this platform that the Council for Scientific and Industrial Research (CSIR) organized the first stakeholders’ workshop for “Nanotechnologies and Nanosciences Risk Assessment” in 2013 (CSIR, 2013).

The approach to safety concerns on nanotechnology development is still largely precautionary in South Africa. However, with the collaborative efforts of the various stakeholders in this emerging technology, there seems to be a robust roadmap before the government in the management of nanowastes, courtesy of CSIR. Brazil is another developing country that has identified the early need in addressing the potential hazardous effects that could arise from nanowastes generated by nanotechnology development. Through her National System of Nanotechnology (SisNANO), Brazil has established a

scientific network for toxicity assessment and regulations of nanoparticles (Ávila *et al.*, 2016). An example is her collaboration

with the Global Research Area, and the adoption of the OECD model for nano-risk management.

Table 3: Examples of commercialized nanoproducts and applications (Zhang *et al.*, 2015)

Nano-products	Property applications	Area of application
Ag	Antimicrobial protection, electrical properties.	Textiles, food packaging, medical devices, water treatment process, surface coating, electronics such as transparent conducting films, transparent electrodes for flexible devices.
TiO ₂	Absorption of ultraviolet radiation Catalytic properties.	Electronic devices, sunscreen, cleaning, water treatment, solar cell, health and fitness.
Al ₂ O ₃	Capability of polishing, light absorption, antimicrobial protection and an adsorbent.	Cleaning, cosmetics, water treatment, coatings, food additives, catalysts, ceramics, electrical insulators.
ZnO	Sun protection, antimicrobial protection.	Sunscreen, cleaning, paints, cosmetics, food packaging, personal care products/sprays
CNTs	Hardness and strength, light with high density, conductivity, metallic property, mechanical and magnetic property.	Probing electronic devices, catalysts, adsorbent in water treatment, detection devices, molecular filtration membrane, detection sensor or probe, automotive, sporting goods, clothing, food packaging.
Zr/ZrO ₂	Good absorbability and hydrophilicity, bio-corrosion resistant and bio-compatible.	Drug delivery, water treatment, coatings, fuel, battery, pigment, abrasive material, medical implant.
SiO ₂	Extend life of paints and coatings	Paints, coatings, food packaging
CeO ₂	Sun protection, catalytic and optical properties.	Coatings, paints, automotive/fuel catalysts, biomedicine.
Fe/Fe _x O _y	Hardness and strength, magnetic and catalytic properties.	Food and beverage, home and health/sporting, goods, environmental remediation, water treatment, catalysts.

Implications for Nigeria and Recommendations

Due to the infancy nature of nanotechnology research and development in the country, Nigeria has not really developed a robust framework for the development and management of nanotechnology. The National Agency for Science and Engineering Infrastructure

(NASENI), initiated the Nigerian Nanotechnology Initiative (NNI) in 2006. The initiative is focused on four areas namely: Nano-medicine, Nano-electronics, Nano-Structured and Nano-porous materials (NASENI, 2018). There are currently no existing domestic research frameworks or deliberate policies in Nigeria that locally

address the global concerns on nanowastes and the exposures to nanoparticles.

The extant Nigerian environmental laws as currently coordinated and enforced by the National Environmental Standards and Regulations Enforcement Agency-, (NESREA, 2018), do not address the emerging concerns on nanowastes and exposures to nanoparticles, neither does the Standard Organization of Nigeria (SON) that is saddled with the responsibility of commercial products certification, has a clear precautionary protocol on imported or local products containing some forms of engineered nanomaterials (SON, 2018). Nevertheless, in a renewed effort by the Nigerian government in engaging the use of nanotechnology to address societal and economic challenges, a recently inaugurated national steering committee on nanotechnology development have been saddled with the responsibility of creating a roadmap for the development of nanotechnology by consulting with relevant stakeholders (NTA-NEWS, 2018). This should create the opportunity to incorporate the management of nanoparticles and nanowastes as a major component for consideration in the road map.

A synergy should be developed among stakeholders from relevant ministries and government agencies. Examples are the Ministries of Education, Health, Agriculture, Environment, Science and Technology, National Agency for Food and Drug Administration and Control (NAFDAC), National Orientation Agency (NOA), Policy research agencies and associated committees. The outcome of recommendations should facilitate legislations that would enable the traceability of engineered nano-products by appropriate labeling with content volume. This will ensure an effective risk

communication strategy. Orientation programs should be made available to the general public for enlightenment on nanotechnology development and associated precautionary measures for responsible use.

There should be a government-industry partnership in collaboration with the tertiary and research institutions to carry out researches on the risk assessments and mitigations against nanowastes and exposures to nanoparticles at work places. Sustainable and deliberate efforts are required through government and private partnerships in funding students and academic grants for researchers. The nations' research institutions, manufacturing, construction, and service delivery companies that work with some forms of nanoparticles should be made to have at least a safety officer with renewable certifications on precautionary risk management of nanowastes and nano-exposures. There is the need to treat every engineered nanomaterial as a potential hazard until sufficient data are available to prove otherwise.

Conclusion

Nano scale materials behave very differently from their bulk counterpart. Their very fine particle size nature allows possible penetration of pores. Due to data gaps, leading nations on nanotechnology development are initiating precautionary measures to address the challenges of possible exposures to nanomaterials and the management of nanowastes. For example, REACH (registration, evaluation, authorization, and restriction of chemicals) framework was developed by the European Union as a mitigating approach. The United States of America through frameworks under the Environmental Protection Agency and the National Institute for Occupational

Safety and Health (NIOSH) has a strategy to also checkmate nano-hazards. Most Asian countries and developing nations like Brazil have also adopted some of the EU and USA frameworks.

Indicators such as scientific publications on nanotechnology, country investments in nanotechnology, patents, and nano-products commercialization showed the poor engagement of Africa and developing nations in nanotechnology development which have put them at a disadvantage for the effective management of nanotechnology. An example of Nigeria has been discussed, where the current chemical and environmental protection laws are not sufficient to manage the importation, production, exposure, and disposal of engineered nanomaterials.

We propose a nano-safety protocol and policy directions for incorporation into the roadmap for nanotechnology development in Nigeria. National Environmental Standards and Regulations Enforcement Agency, (NESREA), Standard Organization of Nigeria (SON), the National Agency for Food and Drug Administration and Control (NAFDAC), National Orientation Agency (NOA), industries, tertiary and research institutions have been identified as major stakeholders that can curb the potential hazards associated with nanotechnology development in Nigeria.

Acknowledgments

The authors wish to thank the National Centre for Technology Management for providing the logistics for this work.

Declaration of Conflict of Interest

Authors declare no competing interest.

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