



Global Sustainable Development And Societal Transformation Through Nano Science Technology Policy Framework: An Overview

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Abstract: Around the world, nanotechnology is being promoted as a technological revolution that will help resolve an array of problems. According to the current hype, nanotechnology promises to provide new ways of solving some of Africa's chronic challenges such as treating tuberculosis and malaria, making water drinkable, conserving food, and diversifying energy sources, among other hosts of applications. However, the potential risks and social implications of this new technology are not often discussed nor addressed. The overall level of awareness and capacity to address these issues remains very low, in both civil society and government, and prevents these actors from playing their social role in ensuring the public good. Research on nanotechnology, and increased commercialization of products containing engineered nanomaterials (generally called nano products), are currently happening in Africa (e.g., in South Africa, Sudan, Kenya, Zimbabwe, Egypt, Algeria). In several African countries, nanotechnology has been declared a strategic sector of scientific and technological development. In addition, graduate courses on nanotechnology have been initiated in some countries, such as South Africa, Egypt, and Algeria. Even though potential health and environmental risks of engineered nano-materials are scientifically documented and numerous uncertainties remain, the public funds dedicated to evaluating these risks are extremely low. As a consequence, the current policy in regards to this technology is far from precautionary as the products enter the market unregulated and unlabeled, neither guaranteeing the safety of the product, nor the information to the consumer. The Present review paper highlighted sustainable development Socio economic transformation through Nano Science technology various issues and challenges at global level policy framework

Key Words: Civil Society, Health, Policy, Technology, Scientific, Nanomaterials, and Research

1) Introduction

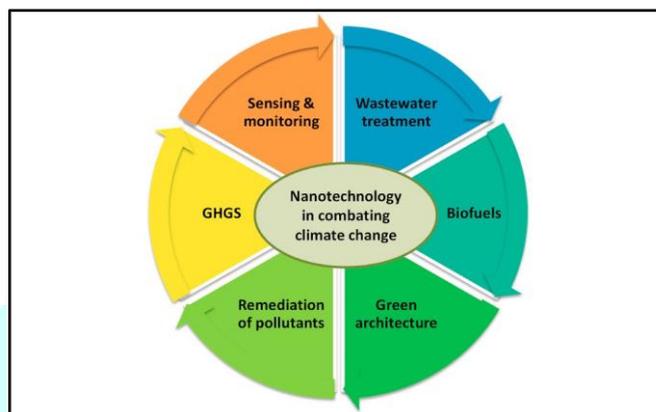
Every human being needs food, water, energy, shelter, clothing, healthcare, employment, etc., to live and prosper on Earth. One of the greatest challenges facing society in the twenty-first century is providing better living standards to all people while minimizing the impact of human activities on the global environment and climate as the world population reaches 8–10 billion by 2050 (Diallo et al. 2013). The ‘Brundtland Commission of the United Nations’ defined “sustainable development” as “that which meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland 1987). Currently, the world is facing great challenges to meet rising demands for basic commodities (e.g., food, water and energy), finished goods (e.g., cars, airplanes and cell phones) and services (e.g., shelter, healthcare and employment) while reducing the emission of greenhouse gases and the environmental footprint of agriculture and industry (Godfray et al. 2010; Diallo and Brinker 2011; Brinker and Ginger 2011; Diallo et al. 2013). Soon after the inception of the National Nanotechnology Initiative (NNI), it was envisioned that nanotechnology could provide more sustainable solutions to the global challenges facing society. During a presentation made at the Cornell Nanofabrication Center on September 15, 2000, Roco (2001) discussed how nanotechnology could help improve agricultural yields, provide more efficient and cost-effective water treatment and desalination technologies, and enable the development of clean and renewable energy sources including highly efficient solar photovoltaic cells. As nanotechnology continues to advance, the research agenda is increasingly focused on addressing two key questions related to sustainability over the next ten to twenty years – Prevention of nanotechnology-based adverse effects: Safe-guarding nanotechnology legacy in South Africa for social and economic development interlinked with systematic risk reduction approaches.

For example, the leaf of a lotus has a surface of hydrophobic nanoparticles, which could be stimulation for thin films that fend off water. Similarly, lizard’s feet have nano- hairs so Fig.1. Lotus leaf (hydrophobic) copies its functions.

small that they generate forces of molecular attraction that help the animal stick to vertical surfaces and even defy gravity.



Fig.2. Lotus leaf (hydrophobic)



Nanosensors as a key player provide several benefits in agriculture farms by offering the detection of agro-climatic conditions necessary to augment productivity of food crops and supervision of environmental situation and other parameters, pesticides, herbicides, fertilizers etc. (Choi, J.Y.; Ramachandran, G.; Kandlikar, M. 2009). In addition, nano bio-sensors have emerged as a new application of nano- technology in the field of food packaging for the detection of pathogens, contaminants (i.e. drugs, heavy metals etc.) and related toxins (Davis SC, Diegel SW, Boundy RG 2008). Further, food sector is going to be benefited by the applications of bio- based nanopackagings to replace the conventional non-degradable packaging which is a threat to the environment (Federici, Gillian; Shaw, Benjamin J.; & Handy, Richard D. 2007). Thus agro-nanotechnology is considered to be an environment friendly or green technology for future. Moreover, nanostructure materials such as nanocomposites, nanocatalysts, nanocoatings, nanolubricants etc. have enormous potential' to replace conventional counterparts in an environment friendly manner. By storing oxygen, nanocatalyst helps in complete combustion of fuels, thus reduce the greenhouse gas emission. In contrast, nanolubricants and nanocoatings help to decrease friction in engine which significantly reduces CO₂ emission (Köhler, A.; Som, C.; Helland, A.; & Gottschalk, F. 2008). Nanotechnology based products or NPs are mainly engaged in the production and improving the efficiency and use of renewable energies (e.g., bio-fuels, solar and hydrogen fuel cells). Thereby, decreasing the dependency on fossil fuels is one way to decelerate global warming. Nanotechnology also plays an important role in environmental remediation by degrading dyes and other colourless pollutants in wastewater streams Fromer N, Eggert RG, Lifton J 2011). Since a range of nanomaterials has been reported to absorb greenhouse

gases, thus may help to reduce global warming. Also, nanostructure materials have been involved in green architecture by applying nano-composites, nano-coatings, nano-glass, carbonic nano-tubes, nano-silica, and polymeric structures in roof, windows, wall coatings, insulation, energy storage, solar cells and in future may offer refrigerant free cooling for energy efficient sustainable constructions/buildings (Ling M M, Chung T S 2011). However, the toxicity of nano-materials for the environment and the health is a matter of concern. Mercury and tin NPs are found to be more stable and non-degradable, thereby causing various environmental issues due to their toxicity. Therefore, the guidelines for the safety should be followed strictly.

There are a number of reviews available on the subject but comprehensive information on the role of nanotechnology in alleviating or combating the effects of climate change is almost lacking, therefore in the present paper we have tried to cover all such aspects related to climate change and nanotechnology as one of the potential solutions to fight against climate change effects with recent trends in this research.

2) Effects of Climate Change:

Climate change has entirely altered the climatic system of our earth. Major changes that are encountered are warmer land and air, warming of ocean, changes in ocean currents, ocean acidification, rising sea levels, changes in hydrological cycle, melting glaciers and sea ice and extreme weather conditions.

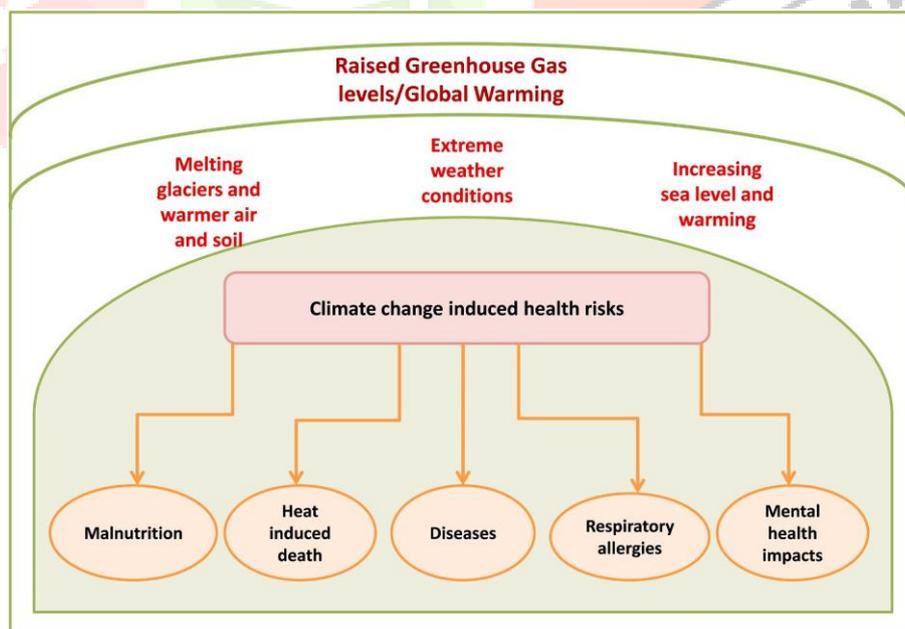


Fig. 3 Climate change induced health effects.

3) Role of Nanotechnology in Sustainable Development:

3.1. Environmental Benefits:

Pollution Reduction: Nanotechnology can lead to the development of materials and processes that reduce pollution. For example, nanomaterials can be used in water purification systems to remove contaminants more efficiently than traditional methods.

Energy Efficiency: Nanotechnology contributes to energy efficiency through the development of better energy storage systems, such as advanced batteries and supercapacitors, and more efficient solar cells.

Resource Conservation: By enabling the creation of stronger, lighter materials, nanotechnology can reduce the amount of raw materials needed in manufacturing, thus conserving resources.

3.2. Economic Growth:

Innovation and Competitiveness: Nanotechnology drives innovation across various sectors, including healthcare, electronics, and materials science, enhancing competitiveness and economic growth.

Job Creation: The growth of the nanotechnology sector can lead to new job opportunities in research, development, and manufacturing.

3.3. Social Impact:

Healthcare Improvements: Nanotechnology offers advancements in medical diagnostics and treatments, potentially leading to better health outcomes and reduced healthcare costs.

Education and Skills Development: As nanotechnology becomes more prevalent, there is a growing need for education and training programs to equip the workforce with the necessary skills.

4) Policy Frameworks for Sustainable Development:

4.1. Regulatory Frameworks

Safety and Standards: Establishing safety standards and regulations is crucial to ensure that nanotechnology products are safe for consumers and the environment. This includes guidelines for the production, use, and disposal of nanomaterials.

Risk Assessment: Policies should include comprehensive risk assessment procedures to evaluate the potential impacts of nanotechnology on health and the environment.

4.2. Research and Development Support:

Funding and Incentives: Governments can support sustainable nanotechnology through funding for research and development, as well as incentives for companies that adopt sustainable practices.

Public-Private Partnerships: Collaborations between public institutions and private companies can accelerate the development and commercialization of sustainable nanotechnologies.

4.3. *International Collaboration:*

Global Standards: International cooperation is essential to develop global standards and regulations for nanotechnology, ensuring consistency and safety across borders.

Knowledge Sharing: Sharing research findings and best practices internationally can help countries develop effective policies and leverage nanotechnology for sustainable development.

5) Prospect Policy Framework for Nano Science and Nanotechnology:

5.1. *Integration into Economic Development:*

Innovation and Competitiveness: Policies should encourage innovation in nanotechnology to enhance competitiveness in global markets. This includes supporting research and development (R&D) and facilitating the commercialization of nanotechnology products.

Job Creation and Skills Development: As nanotechnology advances, there will be a need for a skilled workforce. Policies should focus on education and training programs to prepare workers for new job opportunities in the nanotechnology sector.

5.2 *Environmental and Health Safety:*

Risk Assessment and Management: Establishing comprehensive risk assessment frameworks is crucial to evaluate the potential impacts of nanomaterials on health and the environment. This includes developing standardized testing methods and safety protocols.

Regulatory Standards: Creating clear regulatory standards for the production, use, and disposal of nanomaterials is essential to ensure safety and public trust. These standards should be adaptable to accommodate new scientific findings and technological advancements.

5.3. *Social and Ethical Considerations:*

Public Engagement and Transparency: Engaging the public in discussions about nanotechnology and its implications can help build trust and address ethical concerns. Policies should promote transparency in nanotechnology research and development.

Equity and Access: Ensuring equitable access to the benefits of nanotechnology is important. Policies should address potential disparities in access to nanotechnology innovations, particularly in healthcare and education.

5.4. *International Collaboration:*

Global Standards and Cooperation: International collaboration is necessary to develop global standards and regulations for nanotechnology. This can help ensure consistency and safety across borders and facilitate international trade.

Knowledge Sharing and Partnerships: Encouraging partnerships between countries can enhance knowledge sharing and accelerate the development of sustainable nanotechnologies.

6) Countries are leading in establishing nanotechnology regulatory frameworks:

Several countries are at the forefront of establishing regulatory frameworks for nanotechnology, each taking unique approaches to address the challenges and opportunities presented by this rapidly advancing field. Here are some of the leading countries:

6.1. United States

The United States has been proactive in developing regulatory frameworks for nanotechnology through various agencies, including the Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA). These agencies focus on assessing the safety and environmental impact of nanomaterials, with the FDA providing guidance on the use of nanotechnology in food and medical products.

6.2. European Union

The European Union (EU) has implemented comprehensive regulations for nanomaterials under existing frameworks such as REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) and CLP (Classification, Labelling, and Packaging). These regulations ensure the safe use of nanomaterials by requiring detailed safety assessments and labeling.

6.3. China

China has been actively developing its regulatory policies for nanotechnology, focusing on both safety and innovation. The Chinese government has prioritized nanotechnology as a key area for scientific and industrial development, leading to the establishment of standards and guidelines for the safe production and use of nanomaterials.

6.4. Canada

Canada, in collaboration with the United States, has established the Canada-United States Regulatory Cooperation Council (RCC) Nanotechnology Initiative. This initiative aims to harmonize regulatory approaches and promote economic growth through coordinated efforts in nanotechnology regulation.

6.5. Australia

Australia has been involved in developing regulatory frameworks for nanotechnology, focusing on the potential health and environmental impacts. The country has participated in international efforts to standardize nanotechnology regulations and has implemented guidelines for the safe handling and use of nanomaterials.

These countries are leading the way in creating regulatory frameworks that balance the promotion of innovation with the need to protect public health and the environment. Their efforts are crucial in setting global standards and ensuring the safe and sustainable development of nanotechnology.

How do public perceptions of nanotechnology influence regulatory decisions in different countries?

Public perceptions of nanotechnology significantly influence regulatory decisions across different countries. These perceptions can shape policy priorities, regulatory frameworks, and the pace at which nanotechnology is adopted and integrated into various sectors. Here's how public perceptions impact regulatory decisions:

6.6. Risk Perception and Safety Concerns

Public concerns about the potential risks associated with nanotechnology, such as health and environmental impacts, often drive regulatory bodies to adopt precautionary measures. In countries where the public is more apprehensive about the risks, regulators may implement stricter safety standards and more comprehensive risk assessments to address these concerns.

Example: In the European Union, public concerns about the safety of nanomaterials have led to stringent regulations under frameworks like REACH, which require detailed safety evaluations and labeling of nanomaterials.

6.7. Trust in Government and Industry

The level of public trust in government and industry can influence regulatory approaches. In regions where trust is low, there may be greater demand for transparency and public involvement in the regulatory process. This can lead to more participatory approaches in policy-making and stricter oversight of nanotechnology applications.

Example: In the United States, public engagement and transparency are emphasized in regulatory processes, with agencies like the FDA and EPA providing guidance and seeking public input on nanotechnology-related issues.

6.8. Economic and Innovation Considerations

Public perceptions of the economic benefits of nanotechnology, such as job creation and technological advancement, can also influence regulatory decisions. In countries where the public views nanotechnology as a driver of economic growth, there may be more supportive policies and incentives to foster innovation and commercialization.

Example: In China, the government has prioritized nanotechnology as a key area for economic development, leading to supportive policies that encourage research and industrial applications, despite potential public concerns.

6.9. Ethical and Social Implications

Public concerns about the ethical and social implications of nanotechnology, such as privacy issues and equitable access, can shape regulatory frameworks. Policymakers may address these concerns by incorporating ethical guidelines and ensuring that the benefits of nanotechnology are distributed fairly across society.

Example: In Australia, public discussions about the ethical implications of nanotechnology have influenced the development of guidelines that address both safety and social considerations.

7) Socio-economic framework and their challenges in Nanoscience and nanotechnology future policy;

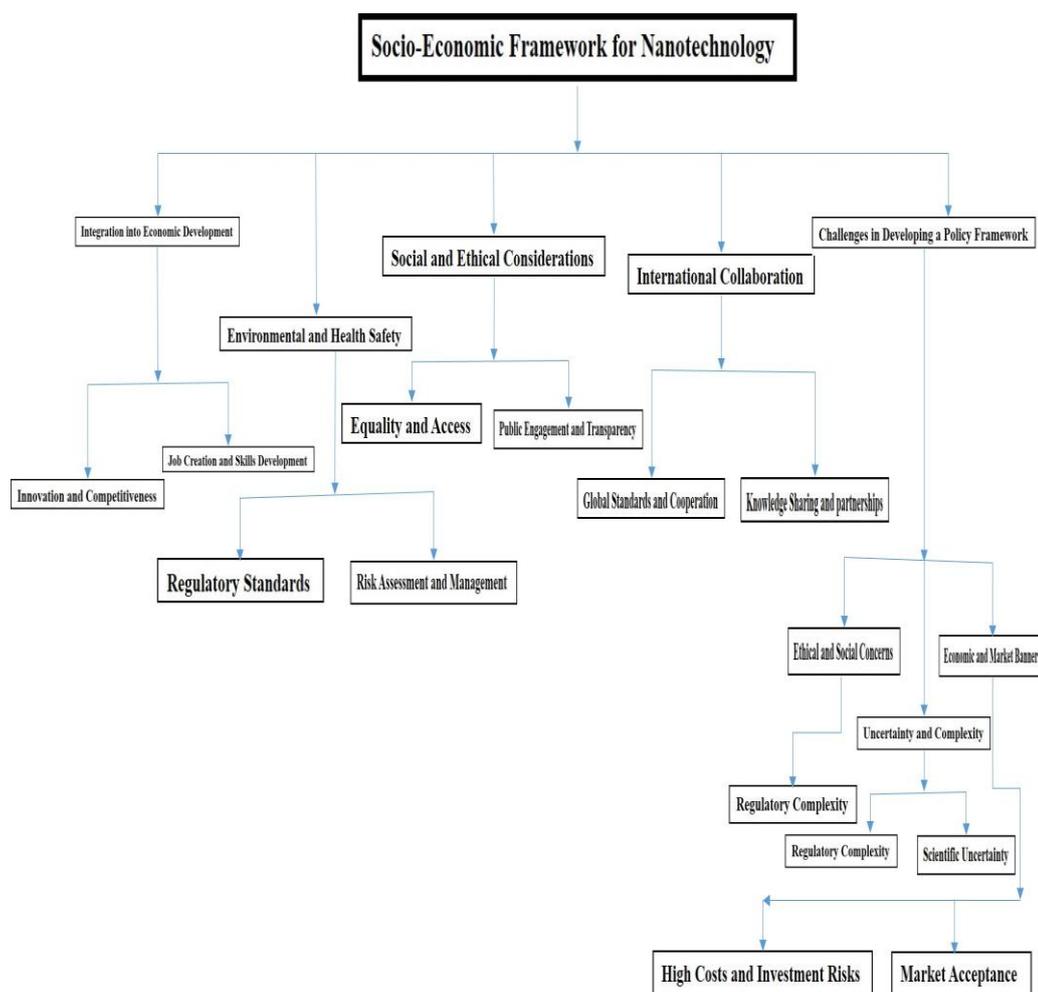


Fig: 4 Socio-economic framework and their challenges in Nanoscience and nanotechnology future policy

The socio-economic framework for nanoscience and nanotechnology is essential for guiding the responsible development and application of these technologies. This framework encompasses various aspects, including economic growth, environmental sustainability, public health, and social equity. However, several challenges must be addressed to ensure effective policy implementation. Here's an

overview of the socio-economic framework and the associated challenges in the context of future policy for nanotechnology.

7.1. Economic Growth and Innovation

Investment in R&D: A robust socio-economic framework should prioritize investment in research and development (R&D) to foster innovation in nanotechnology. This includes funding for both public and private sectors to explore new applications and improve existing technologies.

Job Creation: The framework should focus on creating high-quality jobs in the nanotechnology sector, emphasizing the need for a skilled workforce through education and training programs.

7.2. Environmental Sustainability

Sustainable Practices: Policies should promote sustainable practices in the production and use of nanomaterials, ensuring that environmental impacts are minimized. This includes developing guidelines for the safe disposal and recycling of nanomaterials.

Life Cycle Assessment: Implementing life cycle assessments (LCA) for nanotechnology products can help evaluate their environmental impact from production to disposal, guiding more sustainable decision-making.

7.3. Public Health and Safety

Risk Assessment: A comprehensive risk assessment framework is necessary to evaluate the potential health impacts of nanomaterials. This includes establishing safety standards and protocols for their use in various applications, particularly in healthcare and consumer products.

Public Awareness: Increasing public awareness and understanding of nanotechnology is crucial for building trust and acceptance. Educational initiatives can help inform the public about the benefits and risks associated with nanotechnology.

7.4. Social Equity

Access and Equity: The framework should address issues of access to nanotechnology benefits, ensuring that advancements do not exacerbate existing inequalities. Policies should promote equitable access to nanotechnology innovations, particularly in healthcare and environmental applications.

Ethical Considerations: Ethical implications of nanotechnology, such as privacy concerns and the potential for misuse, must be integrated into the socio-economic framework. Policymakers should engage with stakeholders to address these ethical challenges.

8) The key socio-economic challenges facing nanotechnology policy development:

The development of policies for nanotechnology is accompanied by several socio-economic challenges that must be addressed to ensure the responsible and effective integration of these technologies into society. Here are the key challenges:

8.1. Public Awareness and Acceptance

Limited Knowledge: There is a general lack of public awareness regarding nanotechnology and its potential benefits and risks. Many people have limited or no understanding of nanotechnology, which can lead to skepticism and resistance to its adoption.

Societal Acceptance: The success of nanotechnology applications often hinges on societal acceptance. If the public perceives nanotechnology as risky or unnecessary, it can hinder commercialization and regulatory support.

8.2. Ethical and Social Implications

Ethical Concerns: Nanotechnology raises various ethical issues, including privacy concerns related to nanoscale surveillance technologies and the potential for misuse in military applications. Policymakers must navigate these ethical dilemmas while developing regulations.

Equity and Access: Ensuring equitable access to the benefits of nanotechnology is crucial. There is a risk that advancements could exacerbate existing social inequalities if certain populations are unable to access new technologies or if benefits are disproportionately distributed.

8.3. Regulatory Frameworks

Fragmented Regulations: Different countries have varying regulatory approaches to nanotechnology, leading to a fragmented landscape that complicates international collaboration and trade. Policymakers must work towards harmonizing regulations to facilitate global cooperation.

Balancing Innovation and Safety: Policymakers face the challenge of balancing the need for innovation with the necessity of ensuring public safety. Overly stringent regulations may stifle innovation, while lax regulations may pose risks to health and the environment.

8.4. Economic Considerations

Investment and Funding: Securing adequate funding for nanotechnology research and development is a significant challenge. Policymakers must create incentives for both public and private investment to foster innovation and commercialization.

Measuring Economic Impact: Evaluating the socio-economic impacts of nanotechnology can be complex. Policymakers need effective metrics to assess the economic benefits and risks associated with nanotechnology applications, which can inform better decision-making.

8.5. Scientific and Technical Uncertainty

Knowledge Gaps: There are significant gaps in understanding the long-term effects of nanomaterials on health and the environment. This uncertainty complicates risk assessment and regulatory decision-making, making it difficult to establish clear guidelines.

Rapid Technological Advancements: The fast pace of innovation in nanotechnology can outstrip the ability of regulatory frameworks to adapt, leading to potential safety and ethical issues being overlooked.

9) Investment in R&D addresses job creation in the nanotechnology sector:

Investment in research and development (R&D) plays a crucial role in addressing job creation in the nanotechnology sector. Here are several ways in which increased R&D investment can lead to job growth:

9.1. Development of New Technologies and Products

Innovation and Commercialization: R&D investment fosters innovation, leading to the development of new nanotechnology-based products and applications. As companies create and commercialize these products, they often require additional personnel for research, development, manufacturing, and marketing, thereby creating jobs.

Emergence of Startups: Increased funding for nanotechnology R&D can stimulate the formation of startups focused on innovative applications, such as nano medicine, nanomaterials, and energy solutions. These startups contribute to job creation by hiring researchers, engineers, and support staff.

9.2. Expansion of Existing Companies

Scaling Operations: Established companies that invest in nanotechnology R&D may expand their operations to incorporate new technologies. This expansion often necessitates hiring more employees, particularly in specialized roles such as nanotechnology engineers and technicians.

Interdisciplinary Collaboration: Nanotechnology often requires collaboration across various scientific disciplines, leading to the creation of multidisciplinary teams. This collaboration can enhance job opportunities in sectors such as materials science, biology, and engineering.

9.3. Economic Growth and Competitiveness

Boosting High-Value Industries: Investment in nanotechnology R&D can enhance the competitiveness of high-value industries, such as electronics, healthcare, and renewable energy. As these industries grow, they create jobs not only within the sector but also in related fields, such as supply chain management and sales.

Long-Term Economic Impact: The National Nanotechnology Initiative (NNI) has reported significant economic impacts from nanotechnology, estimating that it contributes between \$67 billion and \$83 billion to the U.S. economy annually. This economic growth translates into job creation across various sectors as new markets and opportunities arise.

9.4. Education and Workforce Development

Training Programs: Increased R&D investment often leads to the establishment of educational and training programs focused on nanotechnology. These programs prepare a skilled workforce capable of meeting the demands of the industry, thereby facilitating job creation.

Partnerships with Educational Institutions: Collaborations between industry and educational institutions can enhance research capabilities and provide students with practical experience in nanotechnology, leading to job placements upon graduation.

9.5 . Government Support and Policy Frameworks

Federal and State Initiatives: Government initiatives that support nanotechnology R&D, such as grants and tax incentives, can stimulate private sector investment. This, in turn, can lead to job creation as companies respond to increased funding opportunities.

Strategic Planning: Policymakers can develop strategic plans that prioritize nanotechnology R&D as a means to drive economic growth and job creation. By aligning public investment with industry needs, governments can create a favorable environment for job growth in the sector.

10) Conclusion:

- Nanoscience and nanotechnology have significant potential for sustainable development by enhancing environmental protection, economic growth, and social well-being. However, realizing this potential requires robust policy frameworks that address safety, promote innovation, and encourage international collaboration. By integrating these considerations into socio-economic planning, policymakers can ensure that nanotechnology contributes positively to sustainable development goals.
- The development of a socio-economic policy framework for nanoscience and nanotechnology involves addressing both the opportunities and challenges these technologies present. As nanotechnology continues to evolve, it holds the potential to significantly impact various sectors, including healthcare, energy, and manufacturing. However, realizing these benefits requires careful consideration of the socio-economic implications and the establishment of effective policy frameworks.
- Addressing these challenges requires a collaborative approach involving scientists, industry stakeholders, and regulatory bodies to develop flexible, science-based regulations that can adapt to new discoveries and technological advancements. International cooperation and standardization efforts are also essential to create a coherent global regulatory framework for nanotechnology.
- Public perceptions play a crucial role in shaping regulatory decisions related to nanotechnology. By influencing the focus on safety, transparency, economic benefits, and ethical considerations, these perceptions help determine the regulatory landscape in different countries. Policymakers must balance public concerns with the potential benefits of nanotechnology to develop effective and responsive regulatory frameworks.
- The socio-economic framework for nanoscience and nanotechnology is vital for guiding the responsible development and application of these technologies. However, challenges such as

scientific uncertainty, regulatory complexity, and public perception must be addressed to ensure that policies are effective and equitable. By fostering collaboration among stakeholders and prioritizing transparency and education, policymakers can create a supportive environment for the sustainable advancement of nanotechnology.

- Addressing these socio-economic challenges is crucial for the successful development of nanotechnology policies. Policymakers must engage with stakeholders, including the public, industry, and scientific communities, to create informed and balanced regulations that promote innovation while ensuring safety and equity. By fostering public awareness and trust, developing harmonized regulatory frameworks, and addressing ethical concerns, policymakers can facilitate the responsible advancement of nanotechnology.
- Investment in R&D is a vital driver of job creation in the nanotechnology sector. By fostering innovation, expanding existing companies, enhancing workforce development, and supporting strategic initiatives, R&D investment can lead to significant employment opportunities. As the nanotechnology field continues to evolve, sustained investment will be essential for maximizing its economic potential and creating a skilled workforce ready to meet future challenges.

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