NANOTECHNOLOGY AND ITS POTENTIAL APPLICATIONS FOR ENHANCING PAKISTAN'S ECONOMIC SECURITY

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Abstract

Due to persistent underperformance, Pakistan's national economy may be considered an Achilles heel of the country's security, which needs immediate course correction towards sustainable growth. Cutting-edge technologies like Nanotechnology (NT) are one avenue which presents the promise to provide our national economy with desired growth stimulus if efficiently employed. NT is a broad-based technology with potential applications in nearly every sector of the national economy. It can radically transform various sectors by creating an environment where responsible and societally responsive innovation can improve productivity and enhance economic opportunities. However, there are challenges associated with the acquisition and use of nanotechnology. This paper is envisaged to highlight the importance of nanotechnology, present viable recommendations to avail the potential opportunities, and indicate how to overcome the associated challenges.

Keywords: Nanotechnology, Economic Security, Economy, Institutions.

Introduction

Nanotechnology refers essentially to the ability to develop techniques that can make it possible to manipulate material properties at a tiny scale. It is the ability first to observe and measure the matter, followed by managing and manufacturing things at the nanometer scale. One nanometer is one billionth of a meter, essentially the size of atoms and molecules. This capability to observe and work on nano-sized materials has unlocked a world of possibilities in various industries and scientific endeavours. Owing to this ability, it can have a wide array of applications in diversified fields. In essence, NT is not about the miniaturization of things but about exploring and unlocking the potential of existing materials at the atomic and molecular level to develop new things and, consequently, create opportunities for economic expansion and thus stimulate the national economy.

This article uses qualitative data to briefly trace the evolution of nanotechnology and its impact in developed countries and then concentrate on its potential applications for enhancing Pakistan's economic security. The article focuses on two major sectors of Pakistan's economy: agriculture and manufacturing.

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Evolution of Nanotechnology

The invention of the microscope, which for the first time helped the study of living organisms using visual tools in the 17th Century, was regarded as one of the significant breakthroughs in the history of sciences as it further led to the creation of many new disciplines like microbiology etc. The subsequent endeavours for discoveries resulted in the refinement and advancement of such instruments, which enabled the scientists in the 1930s to detect materials at the sub-microscopic level using tools like the *Scanning Electron Microscope* (SEM), the *TransmissionElectron Microscope* (TEM) and the *FieldIion Microscope* (FIM). The electron microscope was invented in 1931 by Ernst Ruska and Max Knoll, both German scientists, who used a beam of electrons to illuminate an object and yield a much-magnified image up to 1 million times than optical microscopes, that had the magnification capability of up to 1500 times only.[1] This era can be termed as primitive NT era, in which nanoscale objects could be observed with some success, but any modification or manufacturing process at the nanoscale was impossible.

The conceptual foundation of NT is attributed to a renowned physicist Richard Feynman, who mentioned seeing, altering and manufacturing matter at the nanoscale during his lecture titled "There's Plenty of Room at the Bottom" at the California Institute of Technology (CalTech) on December 29, 1959.[2] During his talk, he described a method which could enable scientists to deal with atoms & molecules individually and, while doing so, would also be able to control and manipulate them. A decade before, professor Norio Taniguchi coined the term 'NT' during his explorations of ultra-precision machining.[3]However, it wasn't until 1981 that the era of modern NT commenced with the ability to see individual atoms after the invention of the Scanning Tunnelling Microscope.

The Scanning Tunnelling Microscope (STM) was developed by Gerd Binnig and Heinrich Rohrer in 1986, who also earned Nobel Prize in Physics for this invention. It is a primary instrument that allows scientists to view and control nanoscale particles. Gerd Binnig and others in 1986 also developed Atomic Force Microscope (AFM). To gather the required information, AFM uses minute, accurate actions to conduct a thorough mechanical probe and feel/detect the nanomaterials.

Subsequently, the nano-scientists could craft various ways and means to deliberately engineer the matter at the nanoscale and modify its properties to create more durable, lighter, reactive, and colourful substances than their larger-scale originals. This peculiar ability of NT led to the novel developments of nano-products ranging from gold-coated silicon nanoparticles used for cancer treatment to highly efficient solar cells and other efficient energy storage devices.

Importance of Nanotechnology

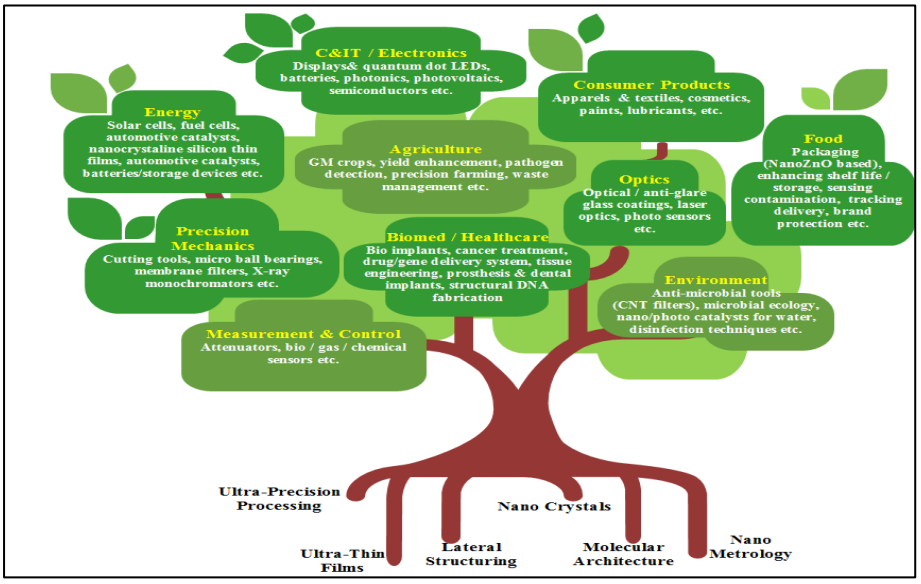
NT studies matter at the sub-microscopic level and can be used for various engineering applications, integrating multiple physical and chemical phenomena. It is an emerging technology wherein the possibilities of its broad applications in many fields are still being researched worldwide.

NT is also of enormous significance because most of the anatomy in our bodies happens at the nanoscale. Many nanoscale materials exist in the human body, e.g., haemoglobin (the oxygen-transporting protein) is present in our red blood cells, which are only about 5.5 nanometers in diameter. Many nanomaterials are also present naturally in our surroundings, like water vapours, fire smoke, volcanic ash etc. In contrast, several nanomaterials around us are non-natural and created due to our actions, like welding fumes and automobile exhaust.[4]

The existence of nanomaterials or nanoparticles, naturally occurring or man-created, is not new relatively. The recent advancement in the field of microscopy enabled scientists to recognize the possibility of altering the matter based on simple physical effects (like expanded surface area) or 'quantum effects'.[5]Similarly, the existence of most of our biological processes at the nanoscale offers scientists a chance to understand many of these processes, which was previously impossible, and after that, conceive new applications in many related scientific fields ranging from medicine to material synthesis to chemical catalysis etc.

As highlighted at the beginning that matter demonstrates unique properties at the nanoscale. This difference in physical, mechanical, optical and chemical properties can be in terms of strength, change in colours, heat or electric conduction, light reflection and chemical behaviour during the reaction. Moreover, at the nanoscale, this variety of properties can be coupled with the possibility of tune-ability of these properties, i.e. scientists can fine-tune any matter as per their requirements by simply changing its properties like size, colour and reactivity etc., at the nanoscale. In short, NT has the potential to provide the means and ways to capitalize on the distinct chemical, physical, optical, mechanical and biological properties for future novel innovations.

Figure-1: Martin Meyer's Nano Bonsai Tree



(**Source**: Martin Meyer's Nano Bonsai Tree)

One ideal way to appreciate the utilization of NT since its emergence in early 2000 is through the figure, which has continuously been expanded based on ever-increasing NT uses in the contemporary world.

Potential Applications in Agriculture Sector

Pakistan's rich arable land houses a significant portion of the total population (37%) in its rural areas. Which mainly rely on agriculture for their economic well-being.[6]This sector serves as the backbone of our economy by feeding the rapidly growing population, earning foreign exchange through exports, and providing raw materials for our industries. It contributes 22% towards our GDP and about 40% of the total employment/livelihood for almost 24% male & 15% female workforce.[7]

Unfortunately, despite being an agriculture-based economy with a significantly trained workforce and resources, today's growth of agriculture in Pakistan is facing many problems. In 1947, the agriculture sector's contribution to our national GDP was more than fifty per cent, which has shrunk to 22%.[8] The benevolence of prevalent challenges is undoubtedly declining our productivity growth and causing food security concerns, thereby impeding our economic growth. A few challenges include.[9]

- Despite the availability of alluvial soil, Pakistan is producing almost 50% below agricultural potential. Of all arable land, 52% is irrigated, accounting for more than 90% of overall agriculture productivity.
- Introducing new varieties and chemical fertilizers has increased crop yields. Nevertheless, intensive cultivation, increased use of fertilizers, and pesticides, conventional soil management practices, and improper irrigation water use have deteriorated land and water resources, leading to poor crop yields.
- Large fertile areas have fallen prey to water logging and salinity, making small farmers more food insecure.
- There is a need to increase the production of primary agricultural products like food, feed, fibre, sugar, edible oil, meat, milk, poultry, and fish to feed the growing population and generate modest export surpluses.
- The increase in production needs to be achieved with efficient use of available water and land. At the same, it should be enhanced by making more arid land cultivable, e.g. in Pothohar, Eastern Sindh and most of Baluchistan etc.

Existing NT-based Research in Agriculture Sector

Pakistan has yet to practically start NT in agriculture, including food processing, fisheries and livestock. No worthwhile indigenous R&D effort has produced a visible difference, and most R&D steps are in the very initial stages and are yet to be commonly adopted. Moreover, despite the availability of many agriculture research institutes, few, like the National Institute for Biotechnology and Genetic Engineering

(NIBGE) & the University of Agriculture Faisalabad (UAF), are busy exploring introducing NT in agriculture-related sectors. However, there is a steady increase in research articles suggesting recognition of the importance of NT in the agriculture and food sector by researchers. Still, translation of the same in terms of substantial outcomes has yet to see the light in Pakistan.

Available International Trends in Agriculture and Food Industry

With the ever-growing population, the demand for food will continue to enhance with limited natural resources. Diversified applications of NT in the agriculture sector will likely address such issues by providing ample and delicious food, feed and fiber. However, as per estimates, only one-tenth of the applied pesticides are utilized for the desired protection of the crops, while the remaining chemicals remain surplus and are wasted by spreading in the surroundings. Nanoscale carriers have been invented to redress this issue, which can efficiently and precisely deliver chemicals and monitor crops' growth through NT-based plant growth regulators. Such methods also assist in reducing all kinds of chemical wastes and associated hazards.[10]

Naturally formed clay nanotubes are also being used as a cost-effective method for spraying pesticides, which reduces the requirement for pesticides by up to 80% and ensures extended-release and better contact with plants. In addition, through this technique, undesired impact on surroundings is also minimized.[11] Furthermore, genetically modified crops and nano-genetic engineering are emerging areas in agricultural research. In these methods, specific nanoparticles and chemicals, like silica, transport DNA and other valuable substances into plant and animal cells. Apart from extending the growth of the crops, it can also enable year-round productivity of various crops rather than specific seasons. Furthermore, this method can also be used to add the requisite qualities to the crops, like improving softness and changing the colour of cotton.[12]

On average, Pakistan produces more than five million tons of vegetables annually and currently ranks among the top 20 countries in the world in fresh farm produce.[13] However, the pace needs to be enhanced vertically and horizontally using NT-based methods to improve our exports and fulfil the growing needs of the rising population. A few measures to achieve the same can be.

- Availability/provision of NT-enabled products like anti-microbes, controlled-release coatings etc., must be worked upon for farmers to kill pathogens and reduce chances of food contamination. The same will also complement the quality of the crop.
- Nano-enabled fertilizers can be procured or produced locally to improve the yields of our essential crops like wheat, rice, sugarcane, cotton, maize, and fruits while at the same time reducing reliance on other resources such as water and chemicals.
- NT can also be used for monitoring crop growth and well-being. Nano-sensors, which work as external monitoring devices and have no chance

of food contamination, can timely detect plant diseases and pest activity to help augment crop production and ensure food security.

- The effectiveness of our domestically produced pesticides can also be improved if the same is enclosed in nano-capsules, which only open and release the pest control medicine when triggered by pests. It would result in substantial cost savings in the use of pesticides and in addressing contamination issues due to excessive use.

Water Disinfection & Purification and Waste Management Techniques

Globally, the demand for treated or desalinated water is increasing due to the rising scarcity of fresh water, and the trend will likely persist in the future. However, the conventional method of using Reverse Osmosis membranes in the desalination process requires considerable energy and hence, is out of reach for most developing countries, being expensive. As a substitute, NT is essential in providing novel and cheap solutions for improving water quality with low energy requirements. NT-based solutions include aligned-carbon nanotube membranes, protein-polymer bio-mimetic membranes, thin film nanocomposite membranes, etc.

Nanoporous foams/fibres and nanoparticles of Titanium Oxide are used for water disinfection and purification. Similarly, certain nano-coating has also been developed, which can be used for effective microbial disinfection and removal of heavy metals.

The growing trend of urbanization in Pakistan is not only shrinking the workforce available to work on agricultural land, but it is also giving rise to the problem of the availability of water for crops and clean & sufficient drinking water for people in cities. Cities like Karachi, Lahore, Faisalabad, Rawalpindi, Islamabad, Peshawar and Hyderabad host millions of people, many of whom have limited access to clean drinking water. It is, therefore, imperative that NT-based water disinfection &purification methods be applied to reuse wastewater generated in large cities for agricultural needs. Furthermore, it can help us address the water shortage challenges and ensure food security by making more water available for growing crops.

One of the most effective waste management techniques for water treatment is Bioremediation, which involves the usage of specific organisms to either neutralize or remove toxins from any polluted water source. These organisms are mainly composed of nanoparticles which slowly and gradually offset various elements mixed with water, e.g. pesticides, which tend to form part of the food chain with harmful effects on our bodies.[14] Therefore, NT can be effectively used for waste management by managing waste and hazardous materials, ensuring environmental protection.

Feedstock Production and Livestock/Poultry Applications

NT has vast potential applications to enhance the quality of feedstock, which are essential to provide desired nutrients required for healthy and nutritious livestock, poultry and fisheries for human consumption. Currently, micronutrients developed and

optimized using NT are being used to improve animals' health and achieve their optimal physical state. NT methods, like nanoscale food delivery methods, are being adopted in this regard.[15]

NT has been effectively applied in all stages of the food processing cycle, from farm to platter. A few such applications are described below:

In food processing, new membranes comprising nano-sieves are being used, which have filtration pores in the nanometre range rather than the conventional visible pores, generally in the millimetre scale. This nano-sieve is long-lasting and has multiple uses in food processing, e.g. for cheese production through milk filtration, for removing fat from milk for producing low-fat milk and for retaining essential minerals in the food during cooking.[16] In addition, it may be possible to create efficient nano-filters for preparing low-fat milk with the same taste as whole-fat milk.

With excessive quantities of food transported worldwide covering ever more distance, food safety is a growing concern for food producers and consumers alike. It includes a range of methods for preparation, handling and preservation during storage so that food remains safe for human consumption till its expiry date and does not cause any form of illness. In this regard, nano-sensors are very effective, especially in conducting fast food safety-related quality control checks and testing in food processing plants and during storage. This method includes the integration of nano-sensors with the food monitoring equipment, which keeps the sensors out of the food without introducing any nanoparticles into the food itself.[17]

Nano packaging is a food preservation method that can substantially increase food's shelf life and is particularly effective in enhancing fresh articles like fruits and vegetables from days to weeks. It helps create an improved food preservation atmosphere with controlled gas and water loss inside the packaging. These nanoparticles can be used either to enhance the quality of existing packaging materials like paper and plastic or by directly coating the food with defined layers of specific nanomaterials. This way, the food can stay fresh during transportation in packaging or display shelves in supermarkets for longer.[18]

NT offers a great deal of opportunity for food companies to enhance food quality through taste, flavour, colour, shape, size etc. NT has made modification possible in naturally occurring food ingredients for better savour and digestion per the specific nutritional needs of people from all age groups. Once used, these microscopic carbon dioxide bubbles create the same feeling as effervescent tablets. Similarly, a range of low-fat products like cheese, milk, ice cream, and diet fizzy drinks can be made with the same tastes as full-fat products.[19]

Measures may be adopted at the Food Industry level to incorporate nano-packaging materials to extend our export items' shelf life, reduce food loss due to spoilage, etc. The same will also assist in addressing the issue of local food shortages. To create

new value-added products, taste improvements and other value-addition techniques can be employed through nanomaterials to enhance the variety and quality of existing food products. In addition, it should be especially helpful in improving the export of our food brands.

Pakistan's manufacturing sector accounts for approximately 19% of the GDP.[20] It is further divided into large-scale manufacturing, with a share of about 80%. Small and medium-scale manufacturing with a share of 14%, while slaughtering contributes 6% in this sector.[21] Significant industries in the manufacturing sector include textiles and clothing, cement and construction materials, refineries, fertilizers, dairy products, beverages and paper products. Realizing the potential of NT for the industrial sector of Pakistan, more than twenty-five institutions/organizations are conducting R&D activities in different fields of NT. Researchers in manufacturing have also contributed significant work in international research publications on NT for the last ten years. Key institutions involved in the research and education of NT in Pakistan include PINSTECH, PCSIR, PIEAS, NUST, GIKI, QAU, LUMS, PINSAT, COMSATS etc. However, like agriculture, no beneficial impact on the manufacturing sector has been noticed due to these efforts.

Application of NT in Global Industries

NT is being applied in global industries to enhance quality and value addition to the existing products/devices. Such developments in industrial products forecast possibilities of economic prosperity at the worldwide level; hence, NT is regarded as another Industrial Revolution by many economic/industrial experts. With improvement in technology, the production and fabrication of efficient nanomaterials are finding new applications in defence, electronics, energy, engineering, sports, transport and other industries. These improvements include high-performance nanomaterials for developing novel components/devices that endure high temperatures and adverse environmental conditions. These components are employed in devices ranging from microchips to memory devices to robots and aerospace structures.

To demonstrate advancement in nano-manufacturing processes in 2010, a silicon tip only a few nanometres wide, which is used in atomic force microscopes, was used to create a 3D relief map of the world at the nanoscale. It was achieved by carving away material from a substrate of organic molecular glass in a record time of a few minutes at a fraction of the cost. This achievement opened up prospects for creating nanoscale patterns/structures in electronics, optoelectronics, medicine etc., at a significantly reduced cost.

Common Materials and Processes

Even today, many ordinary and specialized commercially available products employ nanoscale materials or processes. A few of these have been mentioned:-

- Nanoscale additives for the surface treatment of fabrics can provide lightweight personal body armour or help them resist wrinkling, staining, and bacterial growth.
- Nanoscale materials are beginning to enable washable, durable "smart fabrics" equipped with flexible nanoscale sensors and electronics with capabilities for health monitoring, solar energy capture, and energy harvesting through movement.
- Transparent nanoscale films on eyeglasses, computer and camera displays, windows, and other surfaces can make them water and residue-repellent, antireflective, self-cleaning, resistant to ultraviolet or infrared light, antifog, antimicrobial, scratch-resistant, or electrically conductive.
- Nano-engineered materials make superior household products such as degreasers, stain removers, environmental sensors, air purifiers, and filters.
- Nanoscale materials are also incorporated into various personal care products to improve performance. For example, Nanoscale titanium dioxide and zinc oxide have been used for years in sunscreen to protect from the sun with no visible appearance.
- Nanoscale additives in composite materials are used to produce efficient, durable and lightweight sports products like bats, rackets, bicycles, etc., ranging from automobile parts to helmets to other housing tools.
- CNTs are also very useful for manufacturing products because of their properties like lightweight and enhanced conductivity. These qualities make CNTs suitable for novel applications like thermal management, electromagnetic shielding etc. Accordingly, using CNTs and other lightweight nanomaterials for manufacturing light automobiles, boats, and air/spacecraft has increased product durability and led to significant fuel savings.
- The conversion of cellulose, a natural product found in plants, into ethanol has been made possible only through the nano-engineering of enzymes. As a result, ethanol has found wide applications as fuel, especially in North America. Moreover, these cellulose-based nanomaterials have found wide-ranging applications in other industries. They demonstrate notable qualities like cost-effectiveness and better strength-to-weight ratio, making them suitable for energy, electronics, construction, packaging, food, health care and defence applications.
- Many nanomaterials are finding growing applications in the automotive industry. For example, various nanomaterials produce electric car batteries that can be recharged quickly and hold large quantities of charge for longer. In addition, with the increased automation of vehicles, the use of sensors in automobiles has also grown exponentially. Many of these intelligent sensors are nano-engineered and use multiple nanomaterials to sense and transmit data to various computers reliably. For example, a new type of tire has been created that lasts longer and produces less rolling resistance, resulting in significant fuel economy. In

addition, various catalysts and petroleum additives have been nano-engineered to reduce emissions from vehicle engines for environmental protection.

Textile Industry

The textile industry of Pakistan, being considered the backbone of the country's economy, must realize the importance of NT becoming one of the world's leading suppliers. There is a massive opportunity for Pakistan's textile industry in geotextiles, medical textiles, construction, agriculture textiles, sportswear, home textiles, etc. The textile industry of Pakistan is mainly cotton-based, after which polyester has the highest consumption. There are several NT applications on cotton, nylon and polyester fibre to improve various properties. Anti-static properties of nylon and polyester can also be enhanced by utilizing NT. All applications of NT in the textile sector discussed in the preceding paragraphs must be adopted by Pakistan to retain a much larger share of the global textile export industry.

By using the NT knowledge base, Pakistan can build capabilities of industry and research institutions to manufacturing high-tech textile products through the formulation of national-level policies and prioritizing technological R&D. Primary focus in the textile sector can be on production and synthesis of nanomaterials, design, fabrication & characterization after strengthening and upgrading the existing facilities. To facilitate our LSM and SMEs in producing cost-effective yet reliable products, R&D work in composite nanomaterials is essential for developing new products and structures. It would help in new product development, value addition, technology transfer and import substitution for industries like engineering, manufacturing, electronics, steel, tobacco, chemicals, machinery, leather processing, chemicals, cement and construction materials, paper merchandise and petroleum products in Pakistan. For the sports industry, it is also of immense significance to enhance our focus on developing carbon fibres and CNTs-reinforced nanocomposites for sports items and other composites for a wide variety of high-end and professional export-oriented markets.

Medical Instruments

Pakistan already has a solid foundation for the export of medical instruments across the globe, reaching about 107 nations in 2017 (PCA, 2018). However, despite this significant global presence, the scope of our exports is limited to traditional medical instruments, which are not fit for use in exact medical machines.[22] On the other hand, NT can be effectively utilized to produce highly sophisticated and precise medical devices, opening up a new export market for our medical instruments industry.

Various nano-components are being imported by spending considerable foreign exchange to meet the advanced technological demands of automotive and other engineering industries. This issue can be addressed by upgrading existing facilities to develop nanomaterials locally, especially for our engineering and electrical industries. Although several nanomaterials were developed in Pakistani institutions for potential

applications as nano-catalysts, their subsequent commercial production has not been ensured. Therefore, the same must be provided through the most economical methods to ensure their viability for commercial use. Moreover, using cost-effective techniques, the indigenous development of nanostructured catalysts must also be worked out for the pharmaceutical and petrochemical industries.

Conclusion

This paper has pointed out the importance of enhancing productivity in some of the vital sectors of Pakistan's economy and the role of a robust economy in the country's national security. The sectors include agriculture, water disinfection and purification and waste management techniques, feedstock production and livestock/ poultry application, food industry, manufacturing sector, textile industry and medical instruments. If Pakistan wants such sectors to contribute more robustly towards enhancing our national economy, there is perhaps no alternative to invest in NT. Such investment will stimulate industrial growth in Pakistan. Given that NT is still a developing technology, it may not be too late to invest in NT, which offers enormous prospects for all vital sectors. Emphasis on above mentioned areas will cater for domestic and export requirements for high-tech and value-added products/components in the country.

Pakistan needs to pay attention to this emerging technology to keep pace with the world and maintain its competitiveness in the global agri-food sector. Almost all the existing international NT trends in the agriculture/food industry can quickly be introduced in our agriculture sector and food industry to harness Pakistan's available agrarian potentials optimally. Global warming and climate change exasperate food security challenges due to population explosion and water scarcity. Unfortunately, our current orthodox agricultural techniques do not adequately address these unusual challenges. Thus, novel solutions based on NT are required to ensure optimal utilization of all types of resources in various promising sectors.

Endnotes

[1] Jennifer Hamilton.(2015). The Evolution of Nanotechnology. theigist, The Glasxow Insights of Science & Technology Available at https://the-gist.org/2015/03/the-evolution-of-nanotechnology/

[2] R. Feynman.(1992).There's Plenty of Room at the Bottom. *Journal of Microelectromechanical Systems,* Vol. 1, No. 1. pp. 60-66,, http://media.wiley.com/product_data/excerpt/53/07803108/0780310853.pdf.

[3] Ibid.

[4] Ibid.

[5] Ibid.

[6] H. Plecher.(2020) "*Pakistan - Urbanization 2019*," Statista, October 28, 2020, https://www.statista.com/statistics/455907/urbanization-in-pakistan/.

[7] "Pakistan Bureau of Statistics," Pakistan Bureau of Statistics, accessed September 12, 2020, http://www.pbs.gov.pk/.

[8] Nasir Jamal, "*Need for Innovation in Agriculture*," DAWN.COM, August 10, 2020, https://www.dawn.com/news/1573496.

[9] Ibid

[10] Joginder Singh Duhan, et al.(2017). Nanotechnology: The new perspective in precision agriculture. *Biotechnology Reports*, Vol.15, pp. 11-23

[11] Ibid

[12] Suresh Chand Mali, Shani Raj & Rohini Trivedi (2020). Nanotechnology a novel approach to enhance crop productivity. *Biochemistry and Biophysics Reports,* Vol.24

[13] "Technology Foresight Expert Panel Report on Nanoscience and Nanotechnology," *PCST*, 2014, https://www.pcst.org.pk/TFPReports.php

[14] Dimitris Dermatas, et al.(2018).Application of Nanotechnology for waste management: Challenges and limitations. *Waste Management & Research*, Vol. 36, Issue 3, pp.197-199

[15] El Sabry, M., McMillin, K., & Sabliov, C. (2018). Nanotechnology Considerations for Poultry and Livestock Production Systems - A Review. Annals of Animal Science, 18 (2), 319-334.

[16] Z.H Mohammad, *et al.* (2022).Application of nanotechnology in different aspects of the food industry. *Discover Food* 2, 12. https://doi.org/10.1007/s44187-022-00013-9

[17] Ibid

[18] Ibid.

[19] Ibid.

[20] "Industry (Including Construction), Value Added (% of GDP) - Pakistan," Data, accessed September 19, 2020, https://data.worldbank.org/indicator/NV.IND.TOTL.ZS?locations=PK.

[21] Finance Division: Government of Pakistan, "*Economic Survey of Pakistan 2017-18*", accessed December 12, 2020, http://www.finance.gov.pk/survey/chapters_18/03-Manufacturing.pdf

[22] Danny Hamrick and Penny Bamber, *Pakistan in the Medical Device Global Value Chain*, January 2019, https://gvcc.duke.edu/wp-content/uploads/PakistanMedicalDeviceGVC.pdf