Societal implications of nanoscience and nanotechnology in developing countries

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The historically unprecedented developments of nanoscience and nanotechnology, in view of their phenomenal expansion and growth, in conjunction with their convergence with information science and molecular biology, confront our society and natural environment with new challenges. Technological revolutions have shown that discoveries at the frontiers of science have the potential to pave the way for radically innovative and integrated approaches, providing new solutions for some of the most pressing problems. In order to enable decision-makers to respond to what is best for people at large, the societal implications of the newly emerging fields need to be known and understood. Nanotechnology, unlike any other technology, can find applications in virtually all areas of human life. In spite of being an infant at its evolution, some of the known issues related to nanotechnology suggest a wide spectrum of potential societal impacts. The current public nano-discourse provides sociology with a unique opportunity to switch from a merely passive, observational role to an active participating one, especially where the key players involved meet to find joint and concerted solutions for development.

Keywords: Developing countries, nanoscience, nanotechnology, societal implications.

THE objective of this article is to address the wider societal implications of nanoscience and its deriving technologies on society within the context of the developing world. To prepare readers for the novel scientific and technological terrain, we begin with an introductory historical retrospective of the scientific and technological evolution, from the first Industrial Revolution to the third and onwards to the newly emerging technologies of the 21st century, to illustrate the influence of technological progress on the evolution of the society. The rapid pace of discoveries and development in the realm of nano indicates that this newly emerging field is different from others and therefore gives rise to specific questions, although there are problems common to other advanced technologies. The aim of exploring the world of nano is to discover new properties and to translate new knowledge into the manufacturing process for obtaining enhanced structures and components with novel chemical, physical or biological properties. This futuristic manufacturing method can virtually invade and pervade all areas of human life, since it modifies the identity of all matter, animate and inanimate. It will, for sure, revolutionize human society in an ever unprecedented manner. Certain is that this new scientific branch and associated technology will generate desired but also undesired results, which will have consequences for the society at large and change its structure, organization and functioning in the longer term. Different aspects relevant to nanoscience and nanotechnology need to be woven into the nano-discourse and thus, we are looking into these specific aspects with focus on the developing world. We try to provide a comprehensive framework on issues relevant to nanoscience and technology and map the social, economic, political, legal and ethical aspects, which are applicable to the developed as well as the developing world. The emphasis in nanoscience and nanotechnology, hailed as the science of the future and the technology of the next generation and believed to possess infinite market potential, lies on the control, manipulation and construction of matter at the atomic and molecular level. Recent studies have revealed the significance and importance of nanotechnology for fostering economic growth, human health and incrementing wealth in the developing world. Possible applications of nanotechnology in the fight against poverty will be addressed and illustrated with practical examples.

From the first industrial revolution to the nano revolution

A historical retrospective

When James Watt invented the steam engine in 1765, he could not have imagined that his invention would unleash

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the first Industrial Revolution and transform society in a way only the invention of the wheel did in 3500 BC. The steam engine entered the history of technological evolution as the symbol of the era of mechanization. Transformation of the transportation sector, the advent of capitalism, rapid urbanization and gradual rise of the modern industrial society are landmarks of that period. The rapid expansion of the industrial sector, successive inventions and technological breakthroughs enabled extension of the factories to technology parks leading to increased production and all of these prepared the terrain for the next revolution to come. Industrial Automation, also known as the second Industrial Revolution started around the year 1870. Industrial robotics transformed the technological manufacturing process, since it enabled automated large-scale production at reduced costs. Introduction of the assembly line during the 20th century changed the whole organization of the manufacturing process and labour. Improved and more efficient production methods made mass production at a global scale possible. To satisfy the insatiable hunger of the post-modern society and upcoming consumer society, mass production at an ever-increasing productivity rate and speed became a must. Invention of the transistor and the gradually growing semiconductor industry paved the way for the third revolution, the Digital Revolution. Computerization, starting in the early 60s led to global large-scale production, higher cost efficiency and introduced flexibility into the manufacturing process. The era of post-modernism had just begun when in 1959, Richard Feynman delivered his speech, 'There is plenty of room at the bottom'. Most likely, he had imagined that his prognostics would lead to further transformations of the manufacturing process although he might not have thought of a new revolution, the nano-revolution in the new millennium. The technologies of the late 20th century and newly emerging technologies of the 21st century, namely information and communication technologies and biotechnology, have notably altered the industrial and service sectors, the production methods and society. They inaugurated the information age and biotechnology era and have given way to a new kind of society, the knowledge society. Since nanoscience and technology as well as manufacturing of nanomaterials are no longer futuristic fantasies but reality, we should inquire into how the 'disenchantment of the atomic world' will change our present societies. What comes next, the nano-society?

Milestones on the trajectory of nanotechnology

The cornerstone of nano-scale science, and technology was laid when Feynman envisaged the possibility of arranging atoms to create new matter at the atomic and molecular level. In 1964, Glenn T. Seaborg, Nobel Laureate in Chemistry, patented two of the elements, americium and curium. This was the beginning of patenting atomically and molecularly engineered matter. The term nanotechnology was coined in 1974 by Norio Tanigutchi, professor at Tokyo Science University, who referred to precision manufacturing at the scale of nanometres. In his MIT doctoral thesis of 1981, Eric Drexler extended the term and studied the subject in depth. During the same year, Gerhard Binnig and Heinrich Rohrer were, awarded the Nobel Prize in Physics in 1986 for inventing the scanning tunnelling microscope, a novel measurement tool allowing the sensing of matter at nanometre scale. This was a significant technological breakthrough and therefore had a great impact on the future development of nano-scale science. In the early 90s, Warren Robinett, University of North Carolina and R. Stanley Williams, University of California established a virtual reality system and linked it with the aforementioned scanning tunnelling microscope to 'see' and 'touch' atoms. When D. M. Eigler placed xenon atoms to a shape, reflecting the logo of IBM in 1990, he rendered the proof of the possibility and feasibility of atomic-scale manipulation and this marked a further pioneering breakthrough in this newly emerging field[1]. In 1993, the first academic research centre dedicated to nanotechnology was institutionalized in USA, namely at the Rice University. Only five years later, Zyvex, the first molecular nanotechnology company, was established in USA and that marked the beginning of private nanotechnology venture capital companies. In 2000, one further step ahead was made, when Lucent and Bell Labs, together with Oxford University created the first DNA motor, the first nano-biotechnological gadget. Since the beginning of the 21st century, molecularly precise manufacturing, nanofactories, public and corporate investments in nanoresearch and public-private venture partnerships are rapidly expanding and increasing. The development in this newly emerging area suggests that the time-span between milestones on the trajectory of nano-technology is reducing considerably, the further we move on. Nano has gathered momentum and the nano-revolution has just begun.

The distinctness of nanoscience, engineering and technology

We have seen how the scientific discoveries and technological inventions of the past three centuries have revolutionized the manufacturing sector and society. The common traits of the new technologies that transformed human and social life between the first Industrial Revolution and the Digital Revolution were that they were designed for large-scale production which was capital and energy-intensive, in need of large manufacturing infrastructures and competing in the global markets. Big became beautiful and the manufacturing processes and methods were aligned along the macro principle. The transistor and semiconductor industry inaugurated a change in that trend, and small became beautiful and manufacturing began to focus on micro and then on nano.

Nanoscience and technology requires nanomaterials. Manufacturing of nanomaterials is not just a step further down in size; it is about using the knowledge of the atomic realm to produce novel artefacts in a cheaper and cleaner way, with reduced capital and energy inputs and with more precision. The unparalleled development of nanotechnology and the dissimilar preconditions for nano show that nano-scale science and technology is different from the precedent and other newly emerging sciences and technologies. We highlight a few of the most salient peculiarities that explain the distinctness of nanoscience and manufacturing of nanomaterials. First, at the nanometre scale, science and technology converge and therefore go beyond the traditional boundaries of disciplines. Nanoscience is of trans-disciplinary nature since it involves chemistry, physics, mathematics, cognitive science and life sciences, in particular genomics and proteomics. Nanotechnology fuses with other recent technologies like information and communication technologies and biotechnology. Second, control and manipulation of the very elementary building blocks of all objects of the living and non-living world – atoms and molecules – enable modifications of the same, which can influence every area of life. In other words, the core novelty in science and technology on the scale of the nanometre is that scientists and technologists do not invent the world *ex novo*, as in the past, but *de novo*, since the new artefacts are made of components which have no natural analogues. Third, the term nano refers to measurement, the nanometre as it indicates the size of the matter being observed and manipulated and the term does not refer to any object per se. This explains the unlimited spectrum of nano since all physical matter, irrespective of its nature, can be measured, and the only condition is that measurement facilities for that size regime exist. Fourth, manufacturing of nanomaterials does not need the enormous initial capital outlays for industrial infrastructure that other technologies require and therefore gigantic technological parks have become obsolete, at least in cases where shape control of the nano object is not a stringent condition. Factual examples substantiating the assumption that production can be cost-effective and tailored to local needs – either large or small – are available. These examples include the production of nanomaterials through biology. We will come back to this argument later. A further novel aspect with regard to nanotechnology that gives a practical expression to the pace of technological change is the reduction in time from the scientific discovery to the application of the new knowledge.

Implications of nanoscience and nanotechnology on society

Science and technology changes society

In order to understand the nexus between nanoscience, nanotechnology and society in the context of social change, a few preliminary concepts having general character and hence, applicable to other technologies as well, will be briefly outlined. Science, technology and society are intrinsically interlinked and characterized by mutual interdependency and since technology is firmly imbedded, it cannot be looked at in isolation. Application of scientific knowledge and associated developments are two of the major factors determining social progress and prosperity. Social change is as dynamic and complex as social systems are and with regard to social evolution, it is both the essential ingredient and the driving force. A myriad of factors determine the technological, social and cultural evolutionary processes of the society. Advances in any discipline inevitably lead to changes in social relations, meanings and societal patterns. Earlier, we have seen how scientific discoveries and technological inventions had literally revolutionized societies with time. Considering the time factor, technological and social changes may not occur contemporaneously, since the social system requires its own time to respond to alteration and to find its new equilibrium. Today's coexistence of several forms of societies and the analogous coexistence of technologies, from pre-industrial to state-of-the-art technologies across the globe again illustrates the above facts. Progressive technological and social changes do not necessarily eradicate previous forms and historically, science and technology have been used by all kinds of societies irrespective of their stage of development and belief. With regard to social and technological change, as far as nanoscience and its deriving technologies are concerned, it is likely that their potential impacts will be stronger, because nano has the incomparable force to pervade all societies and economies, from the pre-industrial to knowledge societies, from ancestral to highly industrialized economies and is not necessarily subjected to a nation's current development stage and/or geographical location. Nanotechnology has the asset of both, to bypass and to bridge yesterday's missing technological link between the developed and the developing world.

Society and the scientific and technological innovation process: Protecting, improving and preserving life using new findings is intrinsic to scientific and technological research, since the very premise of science is to serve humanity. Society reacts to technological change with new forms of institutions and develops its own responses to technological innovation, and that is valid for nanoscience and technology as well. Similar to all other cybernetic systems, a change in one of the systems will generate alteration in the others because these complex organic systems are linked by multiple feedback loops and therefore the social world always responds to technological innovations. The innovation process shapes the evolution of society, and therefore it is essential to understand the societal implications of nano-scale science and technology in order to know and understand in what direction society is advancing. The current infant stage of this technology limits reliable or accurate prognostics; but in spite of these limitations, a historical retrospective on how technologies of the yester centuries revolutionized the social organization, structure and value systems can help understand and predict the potential impacts of nanoscience and nanotechnology.

Forecasting the nanofuture: How will society respond to the distribution and diffusion of engineered nanomaterials, including commodities, instrument facilities and services and how will these change society? As nanoscience and nanotechnology move forward, it has become a necessity to ask such questions. Commonly, it is believed that the social implications in the developed as well as in the developing world will be similar to other newly emerging technologies of the 21st century like biotechnology and information and communication technologies. This assumption neglects two facts: first, nanotechnology is a fusion technology and therefore incorporates, for instance, bio and information technologies. Synergy effects will amplify the complexity and inevitably exceed the hypothetical consequences of one single technology. Second, the world is going into nano, even where information and communication technologies yet have not pervaded society at large. In developing countries, where pre-industrialized and post-modern forms of technologies coexist with newly emerging technologies, nano-engineered commodities and services can be designed for the needs of people belonging to pre-industrialized, post-modern or knowledge societies, since no preclusions apply. As far as predictions of the future of nano are concerned, global trends suggest that it is gathering momentum. Expansion in research and development, public and corporate investments, public-private partnerships, media coverage, patents, services and devices all clearly indicate that nanotechnology is on a sharp rise. From these positive projections one can conclude that nano has the potential to become the flagship of the industrial production methods of the new millennium in developed as well as in the developing world. Nanotechnology will certainly not replace all other technologies, but coexist and borrow from the technological inventions of the past. Thus, it is unlikely that the nano era will replace the digital era. It is more realistic that the digital age will converge with the nano and their synergy effects will lead to fundamental and irreversible alterations of cultures and institutions, societal organization, mechanisms and patterns, including the demographic structure. In view of its pervasiveness, it is likely that the magnitude of this new technology at the frontiers of discovery will exceed those of precedent technologies because the intensity of the impact of a phenomenon is positively correlated to its pervasiveness. These, up to now known circumstances suggest that the possible impacts of nanotechnology will even go beyond those of the first Industrial Revolution.

Issues – an outlook

Artificial evolution – how green is green nanotechnology? The term ‘green nanotechnology’ apparently seems a paradox per se, as it challenges both nature and the ecosystem, because as a result of controlling and manipulating matter at its very elementary level, new matter not present in the realm of nature is created. Since the concept of ‘green’ refers primarily to environmental protection and not to the evolutionary process, nanoscience and technology are not inconsistent with ‘green’. ‘Green nanotechnology’ has in fact the potential to play a pivotal role in the struggle against the world’s most pressing environmental problems. Bio-nanotechnology, for instance offers a wide spectrum of new possibilities for mitigating the adverse effects of environmental degradation, having indisputably many causes and sources. In particular with regard to soil, air and water pollution and the unsustainable exploitation of natural resources, bio-nanotechnology can provide viable solutions (e.g. support of cleaner production methods, provision of alternative and renewable energy sources, reduction of input into the manufacturing process, purification of water, etc.). The interface of bio and nanotechnology however, does not only generate positive results. The potential risks inherent to the convergence of life sciences and nanoscience and the deriving technologies need to be addressed and understood. Threats may arise from the increased chemical reactivity of materials at the nano-scale, the toxicity of nanoparticles and the yet unknown side effects of the atomic and molecular engineered materials. The release of atomic and molecular engineered matter into the biosphere poses additional problems to human beings and nature, since test results obtained in the laboratory may differ from those carried out in an open environment. Yet it is unknown, how humans and the environment will respond with regard to the distribution and accumulation of novel materials. The lifecycle of products containing nanoparticles is difficult to establish, since the degradation process of nanomaterials and components is only estimated. The identified hazards with regard to health are chiefly related to the absorption of nanoparticles by the human body and their distribution as well as the risk of accumulation in organs. It is further unknown, how the human (and animal) metabolism will react to the intake of nano-engineered food and nanoparticles, since once dispersed in the ecosystem, these will enter the food chain. Research into the downsides of bio-nanotechnology is essential and transparent communication of the results will, in the near future, become of crucial importance in view of the credibility and plausibility of green nanotechnology. However, recent results obtained suggest that the benefits far outweigh the risks (e.g. applied nanotechnology techniques for water purification systems).

Crossing land – melting of the traditional boundaries of natural and human sciences: The realization of the possibility to explore and control the world at the nanometre scale has given life to new scientific fields, and blurred the traditional boundaries of disciplines and even led to fusion and convergence amongst natural sciences. These new circumstances present a unique chance for the sciences, hard and soft, to meet and to overcome C. P. Snow's paradigm of the two cultures, dividing the scientific from the human sciences[2]. Despite the scientific tradition of hard and soft sciences to use different methodologies and jargons, at the nano-scale there seems to be a trend of convergence of the two apparently opposing scientific cultures. Scientists belonging to the first category have recognized that at the atomic and sub-atomic level an organic world view becomes extremely useful since observation, control and manipulation of matter in realms inaccessible to human's ordinary senses not only demand new instrumental facilities but also novel approaches[3]. This revolutionary shift in the scientific mentality of natural scientists has the potential to overcome both the two culture paradigm postulated by Snow and the long-lasting *Methodenstreit* (disputes about methodologies) between the natural and human (cultural) sciences. This new situation frees the various disciplines from their life in isolation and gives natural and human scientists the chance to meet. That does, of course not mean that a physicist becomes an ethicist or vice-versa, but that both are needed in finding solutions that contribute to the qualitative enhancement of human life. Recent conferences held on nanoscience and technology bear witness to the paradigm shift and revealed that the scientific fraternity has recognized the importance of bridging the cultural gap. Today's scientists seem to be prepared and willed to cross the borders of their own disciplines.

Education and training in nano-scale science and technology: Frontier science and technology represents a true opportunity to enhance a country's qualitative and quantitative level of human capital, since altered ways of manufacturing require the development of new capabilities and skills and that creates new job opportunities. Enhanced human capital strengthens a country's competitiveness, spurs economic growth and prosperity, all essential ingredients for a more sustainable economic, human and social development. These factors are of paramount importance to developing countries, since they are rich in human capital. In recent years, academia has begun to react to the upsurge of the nano-phenomenon and started preparing the future workforce for the emerging opportunities arising in the nano realm by offering multidisciplinary curricula that complement basic natural science education with specialized courses in nanoscience, materials science and molecular biology as well as sponsoring continuing education and training. Since the socio-economic situation of a country conditions its public expenditure in education, research and training, most educational and scientific activities in nano-scale science, engineering and technology are offered in highly industrialized countries. Since nano-manufacturing is possible in developing countries, it is vital to develop the necessary human intellectual resources for nano-manufacturing in the developing world. Educational, research and training programmes in nanoscience and its related fields of application, analogous to those of highly industrialized economies, have become a necessity. That this is possible in the developing world as well, can be illustrated by the existing strategic partnerships between government agencies, industries and businesses established for starting nanotechnology research centres of excellence. It is widely shared that scientific education, training and research have the potential to narrowing the gap between the developed and the developing world, even if not within the society itself. It is a matter of fact that if the developing world does not catch up with the scientific progress of the industrialized world, the risk of being further marginalized becomes real and it would aliment the public fear of a new gap between the haves and have-nots: the nano divide.

The nano economy: Technology has often played a central role in wealth generation and the emerging nanotechnology market has the potential to transform and reshape all economic sectors, from the primary to the tertiary. The assumption that nanoscience and its deriving technologies will change the world must stem from a basic premise, namely that novel findings and innovations in the nanometre scale will have a visible and significant impact on productivity. The projected consequences of rapidly advancing technologies on the nanometer scale will see the rise of new industries and the fall of those stuck to conventional or sustaining technologies of the past[4]. Marketing of scientific discoveries at the frontiers of science and technological innovations in the nano realm will become the driving force of the nanomarket. We can assume that in the years to come, this relatively new economic phenomenon will contribute to an increase of the global Gross Domestic Product (GDP) as projected by global economic institutions like the World Bank and International Monetary Fund. A comparison of the economic performance of the nano industry and business with the development of the national and global GDP could reveal possible correlations between the two and provide an answer to the question if nanotechnology truly contributes to economic growth in quantitative terms.

The nanobusiness and finance: Since the nanobusiness is still in its infancy even in the developed world, it is difficult to assess its possible economic impacts in the developing world. In highly industrialized economies, like USA, commercial spin-offs of nanoscientific research, start-ups and venture capital enterprises, together with multinational companies reaching out for nanotechnology and competing for market shares of the newly emerging nanotechnology market will shape the national and world economies. Still in its nascent phase but rapidly growing, the nanobusiness encompasses a wide spectrum of well-established and solid manufacturing branches, from biotechnology, materials, electronics, energy, healthcare, textiles, sensors and many others and does not preclude any business segment. The ongoing globalization process tends to amplify the importance of nanotechnology use, since manufacturing of nanomaterials provides the link to international capital markets and global technology and production networks. Not only is the future nano-market impressive in size, so also the potential clientele of nanotechnology derivates, products, devices and services. Since every matter is ultimately composed of atoms and elements, theoretically all people could become exposed to the nearly unlimited nanomarket and become its benefactors. To put it into perspective, the US National Science Foundation (NSF) estimates[5] the total global market for nanotechnology-related products and services to reach US$ 1 trillion by 2015. Based on these projections, the Nanobusiness Alliance forecasts[6] the global nanotechnology market to reach US$ 225 billion by 2005 and expect it to be US$ 700 billion by 2008. By confronting these figures with the projected world GDP, the share of the nanomarket[7] will exceed 1% by 2008. The ever-increasing number of private nanotechnology companies and the sharp rise in patent filings from public and private institutions testify the upward trend in commercially exploiting innovations made in the field of nano-manufacturing and the run into nanobusinesses. To illustrate what is stated before, the US Patent and Trademark Office issued until the first half of 2005, 3818 patents with reference to nano and 1777 patent applications were handed in and awaiting to be transformed into lucrative licences[8]. The private nanobusiness was born only in 1997, when nano pioneers started the first venture capital company in USA. Not only large and well-established trans-national companies (TNCs) followed Zyvex and started diversifying and integrating attributes of nanotechnology techniques into their manufacturing activities, but also small and medium sized enterprises (SMEs) entered the arena of the upcoming nanobusiness. Preliminary findings of business experts suggest that the latter have already conquered niche markets and by consolidating their positioning at the global level, these challenge the big market leaders. A look at the companies and sponsors present at the 8th Nanotech Conference and Trade Show in May 2005 in Anaheim, California reveals who the contenders in the newly emerging market are. More than 100 corporate companies, both TNCs and SMEs are in some way involved in nanomaterial manufacturing[9]. As far as the capital market is concerned, nano-stocks are already traded at the world's major stock exchanges and financial institutions as well as insurance companies nurture vast interest in this novel technology and its derivates. With regard to private investments, and risk management they already play a significant role. At the micro-economic level it is still difficult to express prognostics because of two major reasons, namely the absence of hard data about the cost structure of nano-engineered products, devices and services and secondly, nanotechnology commodities are yet not an integral part of everyday life in any part of the world (primarily because there are only a few commodities for mass consumption).

Public and private investments in nano research and development: Public and private research funding in nanoscale science and technology has progressively increased over the past years in both the developed and developing world. Research and development activities are as yet generally segregated in relatively large industrial, government and academic laboratories; but the latest trend suggests, to a smaller but not less remarkable extent, that the private sector and in particular SMEs, are investing into the nanometer scale technology. The public sector still holds the lion's share of research and it has been growing at an unprecedented rate in the last years. The global public spending in nanoscience and technology exceeded US$ 3 billion in 2003 and it will increment, since more countries, including developing countries are planning or have already launched national nano-initiatives[5,10]. A look at the government funding for the next five years in USA confirms the progressive trend in public investments into nanoresearch and development. For the year 2005, US$ 809.8 million has been approved and the figure for 2008 exceeds an annual spending of US$ one billion[11]. Developing as well as newly emerging economies have started realizing the inherent opportunities of nanoscience and nanotechnology and the importance to compete from the beginning and not, as it was the case with information and communication technologies, to wait that these will be transplanted from the developed world at a later stage. For a good performance in the global R&D arena, public and private investments into nano is a precondition. The trend of increasing public spending into nano in the developing world goes parallel to that of highly industrialized; the only reservation is that their investments are lower than those of the developed world, if compared to the respective GDPs.

Reliability, safety and risks – assessment and management: Systematic identification and assessment of the risks of a new technology are essential. The idea of a system getting out of control is the nightmare of every conscientious scientist and technologist and not only of technophobes and those predicting a cataclysmic end of humanity, because of the release of toxic nano-engineered artefacts from the laboratory into the environment. The potential risks might arise as a result of the characteristics of the nanoparticles themselves, the properties of products manufactured with nanoparticles along with the manufacturing process. Systematic research into the downsides of this new technology, especially into the risks and perils is essential, chiefly because of two reasons. First, because if unintended consequences, including negative side effects and counter intuited results are known, it is possible to calculate the risk and to take precautions. The development of worst-case scenarios which include the necessary mechanism and measures for managing such striking situations serves to limit or mitigate the adverse effects on society and its natural habitat. Several existing instruments and methods used in technology management, like the Environmental Impact Assessment (EIA) help in evaluating the reliability, safety and risks of new products, services and devices using atomic or molecular engineered matter. Secondly, the fear of derailing nano-scale science and technology, because it is evolving faster than the researchers' ability to keep pace with the development, independent of whether it applies or not, is undermining the research and development process and gives rise to anti-nanotechnology feelings and attitudes. Therefore, it is indispensable to foster methodical research in the fields of safety, reliability and risk management of nanocommodities, devices and services. The apocalyptical worst-case scenario involving nanotechnology, named by Eric Drexler, as the 'Grey goo', has contributed little towards broadening our societal understanding and knowledge of the potential risks of molecular engineered artefacts[12]. Since people are more receptive to fictional representations as they shape their imaginaries, the 'nanomania' has rather alimented the entertainment and leisure industry, giving rise to misconceptions, misunderstandings and distorted views regarding this particular technology rather than contributing to a rational and genuine discussion.

Nano policies and institutions: When we look at the nano-phenomenon from the political perspective, in general we look principally at issues relating to long-term strategic policies, including intellectual property reforms, international cooperation, monitoring and regulation of research and development. Because of its unlimited potential, nano-scale science and technology requires the adoption of national and international policies. The management of research and development in nanoscience and technology, in terms of administration and control by the public authorities is to guarantee for the responsible use of the potentials both exemplify. The claim for formalizing a regulatory regime over nanoscience and technology reflects that a minimum of coercive intervention by the state is needed, especially vis-à-vis responsible nanotechnology. Scientists, politicians, the private sector and representatives of the civil society have opposing views as far as the intensity of the public interference into scientific and technological research and development is concerned and even within these groups the views do not converge. The opponents, the nano sceptics, an utmost heterogeneous flock, call for a regulatory and institutional framework that limits the scope of scientific activities and the diffusion of atomically and molecularly engineered commodities and services. Despite the competing interests and colliding opinions, the two blocks agree on three central issues in the public nano discourse, namely the non-interference into privacy, preservation of human dignity and protection of the society and natural environment from hazards. The first two, since they have strong ethical connotations, will be addressed apart and the third has already been addressed. To counter misuse, including activities and actions that are in net contradiction with the universally shared ethics and principles, a minimum of a regulatory framework has become a necessity to guarantee responsible use of nano-scale science and its deriving technologies. The current scenario suggests that the institutionalization of a supranational body with a standing committee exercising a minimum of international control, monitoring the technological development in the atomic realm and providing a legal framework to which the countries doing nano research and development conform their activities, makes sense. Despite differing value systems, political and legal traditions and systems, the international community should agree at least on a minimum political control and administration in order to ensure that nano-scale research and development is consistent with the ethical principles present in all universal value systems. Defining the perceived benefits and risks of nano-scale science applications, as perceived by the scientific community, industry and business and public, becomes valuable while policymakers decide what is best for their community and the nation.

Nano rules and regulations: The laissez-faire approach of the past has led to a lack of rules and regulations regarding research, development and deployment of atomically and molecularly engineered products. The absence of appropriate norms at both, the international and national level, reflects what W. F. Ogburn described as the cultural lag[13]. According to his theory of technological evolutionism, there is a gap between the technical development of a society and its moral and legal institutions. It is a social fact that while scientific and technological development in nanomaterials manufacturing is leaping ahead, legal regulations lag behind and open a gap of trust between the people and public authorities. The present situation has the potential to generate social tensions and problems since misuse of nanotechnology for destructive purposes is yet not ruled out explicitly. There is a need for new forms of regulations and international standards to direct research, development, manufacturing and commercialization of nanotechnology. However, the mere establishment of a legal framework or standards is not enough, since the laws and regulations need to be enforceable. A better understanding of the legal implications of nanotechnology would help policymakers in the establishment of a regulatory framework and standards that are consistent with the dominant value system of their society. This is particularly valid and important for developing countries, where during the colonial and post-independence times new laws and institutions had been introduced, without taking into consideration the local culture, institutions and traditions. Since control and manipulation of the genetic signature imprinted in the DNA of each human being has become possible and manipulation of human cells, including stem cells is done in laboratories, a regulatory framework setting limits to the exploration of human nature is a necessity. However, none of the regulations should delay or inhibit the growth of knowledge aimed toward the betterment of humankind.

Nano ethics – a deontological code for the nano-community: Not all what can be done, should be done; this is the nucleus of the ethical dimension with regard to research and the technological innovation process in general, and it applies to nano in particular. Since science and technology on the scale of the nanometre is not restricted to the domain of materials science but reaches out to life sciences, it is important to understand the ethical implications. The formalization of a deontological code is needed to prevent nanoscience and technology from derailing and heading into the wrong direction. Ethical guidelines related to research procedures and activities in the realm of atoms and molecules are in fact needed to bridge the present gap between science and ethics. One of the core tenets of such a deontological code is the observation, respect and protection of human dignity and non-interference into individuals' privacy. From a purely scientific point of view, humans do not enjoy a higher status than other living creatures but from the ethical perspective, humans have a different status because of their highly complex nature due to the genetic endowment and consequently possess faculties other living beings do not have. This is where ethics and science clash. Little systematic research into the ethical consequences of nanotechnology has been undertaken so far. The ethical community needs to be actively involved into the nano debate because the expertise of ethicists is required for softening the frontiers of the two blocks. The big ethical controversies will not focus on the threats to the dignity of the average grown-up adult, but will be concerned with foetuses, children, terminally sick, elderly and disabled, all belonging to the most vulnerable groups of society.

Nanotechnology and war – nano arms race

The military plays a crucial role in the scientific and technological innovation process, and this applies to discoveries and development in the nanometre scale as well. In the developed as well as the developing world, large investments are made into national security and defence. Especially in the current world-political scenario, the strive for more powerful instruments to secure the national integrity and interests is a common phenomenon, independent of a country's economic status. The use of nano-engineered materials for weaponry and the potential use of atomically manufactured matter and devices for weapons of mass destruction is not science fiction, but reality. In view of today's increased political instability and diffused feeling of uncertainty, the safeguard of a nation's interests has gained importance. Therefore, it is possible that weapons equipped with nanotechnology will be deployed in present and future armed conflicts, since there is yet no international or national ban on weapons using nanoparticles and nanotechniques. It is the direct link between nanotechnology and ballistic studies that frightens people and also the potential abuse of nano-engineered weaponry[12]. However, we must state here that research for military use produces innovations that later could be utilized for civilian purposes as well. It is yet too early to speculate about a possible technological fallout of nano commodities designed for defence, but one cannot preclude it.

Public perception and public involvement in the nano discourse

One of the most pressing issues in science is the involvement of the public. The triple helix, i.e. academia, government and industry, needs to be extended to a fourth dimension, the civil society, because of the latter's relevance. The public plus the print and electronic media need to be involved from the beginning, since news and information regarding nano-scale science and technology will shape the public perception and determine to a large extent people's knowledge, attitude and behaviour towards this new technology. Consumer acceptance is the key when it comes to commercially-developed nanotechnology products because ultimately it is the end-users who will influence the trajectory of nanotechnology. Therefore, it is of paramount importance to include the public from the very beginning, so that people understand the novelty of atomically and molecularly engineered products and services. The underestimation of consumer acceptance and consumer resentments with regard to biotechnologically engineered organisms in the past revealed the importance of social acceptance, since knowledge and perception finally direct the people's attitudes vis-à-vis new technologies. Studies conducted in USA have already shown that artificially created matter having the attributes of living creatures, namely the ability to adapt, cooperate, learn and adjust to change occurring in their, or another system frightens people[12]. It is therefore important that such studies are conducted in the developing world as well, and especially where nanoengineered products intend to be applied. People's apocalyptical predictions with regard to nanotechnology do not find any foundation in rational reasoning. Uncertainty and unpredictability are however, effective instruments for manipulating the public opinion and to undermine trust in science and technology.

Nanotechnology and the media: In the age of emerging knowledge society in many parts of the world, including the developing world, mass media plays a crucial role and hence shall not be neglected. With regard to nano, it is even more important to envisage the social function of mass communication tools. The print and electronic media, including the Internet, known respectively, as the fourth and fifth power, are the most influential to shape the public perception and people's understanding of nano. Scientific and technological breakthroughs find their way to the public in general through the media, and thus it is important to inform people in a way they understand. To assess the trend of the nano presence in the media, there are two possible ways of action. If we use the number of scientific publications about nano as a variable indicator over a certain time-span, we can assess the trend and trace its development over the past years and forecast future trends. The same can be done with publications in popular science, business media and entertainment. The rapid increase in publications in scientific literature over the past ten years is striking (Figure 1). To put it in perspective, in 1995, 4372 nano* references were recorded in English scientific publications; in 2000, there were already 11,447 and in the first five months of 2005 alone, there were 16,518 titles. These figures, made available by the Institute of Scientific Information (ISI) Webofknowledge, do not leave any doubt about the rise in the number of scientific publications and this tendency will certainly grow progressively. The analysis here refers only to English language publications traced by ISI and does not therefore reflect the global scenario, and further includes titles that may not be purely nano-specific, but include hybrids.

With regard to the popular science literature, business media and entertainment a similar trend stands out, although it could not be quantified. Broadcasting, television and film industries and also the computer game industry have already developed great interest in nano for increasing their clientele and turnovers. Science fiction literature about nano is not only fascinating adults, but also youth; video games have already paved the way for nano to enter children's rooms. The media hype about new discoveries in the atomic and sub-atomic world gives rise to distortions and reflects commercial exploitation of an event, rather than the aim to popularize the potentials of nanotechnology or to inform the public of the latest discoveries or achievements made. Without any doubt, the media has become a platform where scientists, government officials, pressure and advocacy groups and social activists voice their stance and forge the minds of the uninitiated audience.

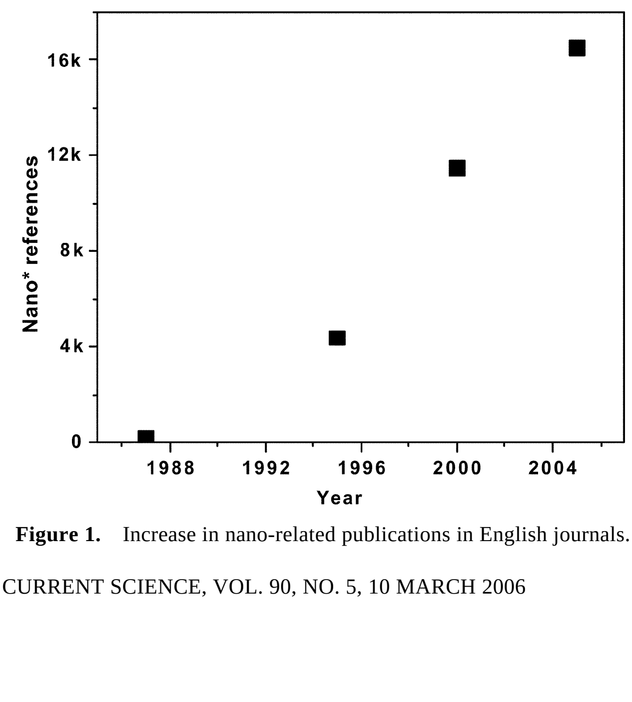

Figure 1. Increase in nano-related publications in English journals.

The public eye on nanotechnology: The exclusion of the civilian society in a dialogue on the potential positive and negative implications of nanotechnology and the course on which academia, public and private research funding agencies, and the industry is navigating, will have disturbing consequences and cause a public opinion backlash. Therefore, the triple helix must become aware about the role of the public in advances in science and technology. Participation of the civil society in the current public debate on nano is without any doubt a sensitive issue. Public fears, possible negative social response or even rejection of nanotechnology indicate that the involvement of the civil society, i.e. social movements, non-governmental organizations (NGOs) and community-based organizations (CBOs) is no longer an option, but a must. Resentment and social discontent about nanotechnology have been openly voiced by the call for a moratorium on the deployment of nanomaterials and the leverage of nano-critics and nano-sceptics can no longer be ignored. The mobilization against nanotechnology of certain social activist groups is a first, but alarming sign that public acceptance cannot be taken for granted. The primary intention of the anti-nano community is to heighten public awareness on possible negative impacts of nano and influence the policy-makers to jeopardize technological advancement. With regard to the developing world, it is less likely that these groups will be influential since the democratic instruments to challenge national policies are limited. Further, social acceptability is more likely, where people are willing to accept the risk of new technologies and generally have a positive view about science.

Harnessing nanotechnology for economic and social development

Nanotechnology and the developing world

The way industrialization advanced in the developing world has no parallels in the highly industrialized countries. In the former, various kinds of technologies – from indigenous to state-of-the-art technologies – coexist and analogous to that, a plurality of different kinds of societies live together, ranging from pre-industrial to emerging knowledge societies. The ongoing industrialization and modernization trend in the developing world has generated a variety of problems that culminated in the global phenomena of environmental pollution, widespread diseases and urbanization[14]. The situation in the developing world has not significantly improved and in certain countries, the state of the people's conditions has even deteriorated. The world's most pressing problems are manifold and they project a myriad of issues. Extreme poverty, lack of education, high rates of mortality and morbidity, widespread epidemics and environmental problems predominate. Innovative and holistic approaches and strategies need to be developed and implemented when addressing these highly complex and intertwined problems, and no technology should be considered irrelevant. We stated earlier that nanotechnology can find applications in societies and economies, irrespective of their development or status. This tells us that at least theoretically, everyone could benefit from its potential applications. Nanoscale techniques have the potential to be in harmony with traditions and in synchrony with technology and this is what makes them become a valid tool in the struggle against poverty. They could indeed make a significant difference in the current scenario and contribute to a more sustainable economic and social development as we will see hereafter. Several developing countries have recognized nanotechnology as a catalyst for economic, human, social, technological and environmental development and launched national nanotechnology initiatives. Worldwide, more than one third of all nations are promoting research and development, including education and training of nanoscientists and nanotechnologists and more than seven countries belong to the developing world[15]. To put it into prospective, in India for instance, the Department of Science and Technology has allocated in the present five-year plan US$ 20 million for the national Nanomaterials Science and Technology Initiative. Several academic institutions in India already possess the necessary facilities to compete at a global level and become research centres of excellence, with highly educated and trained workforce, state-of-the-art research infrastructure and possible links to the industry and business. In Figure 2, we present the investment in nano research in a number of countries, grouped separately. It is clear that the investment in India is low in comparison to other countries in the region.

Developing countries are rich in human capital and their brainpower in the medium and long-term, will reshape the imbalance between the North and South. Nanotechnology offers a new opportunity to the manufacturing industry in the developing world. The wide range of possible applications of nano-scale technologies suggests that if the industrial sector of developing countries is involved in the manufacturing of nanomaterials, it will enhance its competitiveness in manufacturing at the global level.

Harnessing nanotechnology for sustainable development: Development and application of technology, if expected to be successful, need to be designed to the needs of the target group and be suited for the socio-economic context. Nano-scale science and its deriving technologies can virtually enhance the lives of nearly everyone, the rich and the poor, because of its pervasive benefits and its suitability in resource-limited settings[16]. It has the potential to provide most innovative tools and strategies in fighting poverty-related issues. Five billion people live in the developing world and their living conditions could be enhanced by the diffusion of applications of discoveries made in this area. To substantiate our optimistic views with concrete examples, we have identified seven core areas where nanotechnology can make a significant difference in the developing world.

(a) Economic development: Nanobiotechnology, involving the biological production and utilization of nanomaterials, is a promising new field, especially in the developing world with its unparalleled biodiversity. This asset of the developing world can be harnessed through nanomaterials synthesis using microorganisms, including bacteria, viruses, fungi as well as plant and animal-based products. Several examples of nanomaterials synthesis using biology have

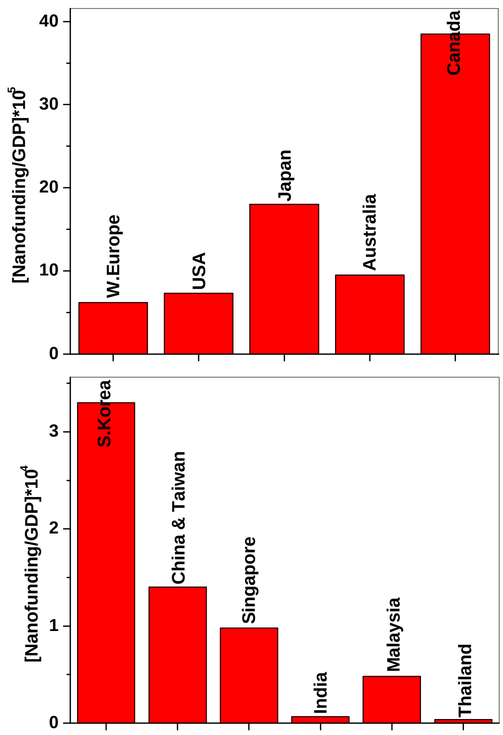

Figure 2. Investment in nano research for the year 2003 in some countries, given as a fraction of their GDP. Data from http://www.nano.gov/html/res/IntlFundingRoco.htm, www.imf.org/external/pubs/ft/weo/2004/01/pdf/,www.ics.trieste.it/Documents/Downloads/df2625.ppt.

been reported[17]. Techniques related to nanobiotechnology do not require large investments and infrastructure and can therefore be developed on the site of application itself. The green and cost-effective solution to nanomaterials manufacturing is one example that proves that with the necessary knowledge and skills, nanotechnology can be developed and diffused in the developing world. This approach has been applied to the synthesis of nanoparticles and nanotriangles of gold as well as various other inorganic nanoparticles such as those of CdS and $CaCO_3$. These methodologies can be suitably adapted for the large-scale synthesis of materials for applications such as cancer therapy, IR absorbing coatings, etc. Synthesis of nanoparticles in human cells added a new dimension to this research[18]. It is also likely that an understanding of the underlying processes may permit us to alter the chemistry such that shape and size control of nanomaterials becomes possible. The biochemical events may be transplanted to other organisms so that processes similar to the bulk production of enzymes become feasible. All of these could happen in the very foreseeable future, with lower investment than that necessary for chemical or physical routes.

(b) Safe drinking water: Among the numerous applications of nanotechnology one can visualize, the most widespread impact as far as the developing world is concerned is perhaps in the area of water purification. Access to safe drinking water is one of the major concerns in the developing world, since almost half of the world population has no access to safe drinking water and basic sanitation. Water purification systems, equipped with nanomaterials and using new kinds of membrane technologies with variable pore sizes as filters could provide people in any area with safe drinking water. These are easy in application and maintenance and already available in the market; the forward-osmosis membrane technology of Hydration Technologies[19] is one technique utilizing nanotechnology. Thus a combination of nanotechnologies will be useful in providing cost-effective and safe drinking water, which will have less dependence on energy. Although the product is right now marketed for emergency water supply, large-scale water purification is indeed feasible. To substantiate the validity of these suggestions, we mention the following. Carbon nanotube-based filters could be developed for water purification. The development of a filter which can separate petroleum hydrocarbons from crude oil has been demonstrated[20]. The filters also remove bacteria from water. With nanotubes, smart sensors could be incorporated into the filter as several nanotube-based sensors are known already. Nanoparticles have been shown to degrade pesticides and pollutants[21]. Several nanomaterials are known to be antibacterial and they can be incorporated on various kinds of substrates[22]. It may be mentioned that we have not listed numerous other discoveries in the area related to this application.

(c) Improving food security: Nutrient deficiency is a widespread phenomenon throughout the developing world, which challenges the physical and mental health of over one billion people. Food starvation can, but not always is related to crop failure. Novel techniques using nanotechnology can be applied in agriculture for breeding crops with higher levels of micronutrients, enhance pest detection and control and improve food processing. The lack of adequate storage facilities besides crop failure is one of the major reasons causing food shortage in the developing world, and in particular in remote areas. In India alone, huge quantity of wheat and rice are rotting in the open. Especially in the tropical belt, food gets spoiled easily because increased temperatures favour the growth of microorganisms, which reduce its quality or render it even inedible. Oxygen accelerates the degeneration process because it enables growth of microorganisms. It is known that carbon dioxide inhibits the growth of microbes. Carbon nanotubes could be used in food processing and preservation as an oxygen scavenger and can prevent packed food from deteriorating[23]. Another application of one of the recent nano-scale innovations involves atomically modified food and this marks the beginning of a radically new paradigm for food production. It has the potential to sidestep the controversial genetically modified food and increase the yield of agricultural produce. In Thailand, researchers at Chiang Mai University have modified local rice varieties to develop a variant that grows throughout the year by applying nanotechnology[24]. This particular nanotechnology technique involves the perforation of the wall and membrane of a rice cell through a particle beam for introducing one nitrogen atom into the cell, which triggers the rearrangement of DNA of rice. Novel techniques applying nanotechnology could contribute to improving the current situation, which in several parts of the globe is alarming.

(d) Health diagnosis, monitoring and screening: Nanoscale techniques have the potential to revolutionize the health sector, in particular in the fields of diagnosis, screening and monitoring of diseases and health conditions[25]. A large spectrum of novel applications using nanoscale techniques in health care is possible as the beginning of a new paradigm for health care. Lack of accurate, affordable and accessible diagnostic tests impedes global health efforts, especially in remote and in accessible regions and poor settings. Widespread communicable diseases like HIV/AIDS, malaria, tuberculosis, etc. could be diagnosed with screening devices using nanotechnology. Standard diagnostic tests for widespread diseases in the developing world are costly, complex and poorly suited to resource-limited settings. A radically new approach to health diagnosis has been developed in India by the Central Scientific Instruments Organization (CSIO). Theoretical simulation and design parameters for a micro-diagnostic kit using nanosized biosensors were completed in 2004 and it is ready for clinical trials[26]. The techniques are based on highly selective and specific biosensors and receptors like antibodies, antigens and DNA, which enable early and precise diagnosis of various diseases. The diagnostic kit 'Bio-MEMS' (micro-electro-mechanical-system) has the size of about 1 cm^2, costs around Rs 30 per piece and is easy to apply. Testing time is rapid and only requires a tiny amount of blood. This novel diagnostic tool could also find application in the detection of other diseases and pollutants in the environment, including water and food[27]. To develop therapeutics to combat malaria caused by the parasite *Plasmodium falciparum*, a common disease in many parts of the developing world, Subra Suresh and his team at MIT are using nanotechnology to systematically measure mechanical properties of biological systems in response to the onset and progression of the disease[28]. Innovative drug delivery systems using nanotechnology are another area where nanotechnology can find application. Cancer in the developing world as widely diffused as elsewhere, is a big challenge to human health. Latest results obtained in cancer detection and treatment with nano-scale techniques provide hope that nanotechnology could be heading for a breakthrough in defeating this disease. A way to detect cancer safely and economically is by the injection of 'molecular beacons' into the body. Britton Chance and his colleagues at the University of Pennsylvania developed tiny capsules that use the specific biochemical activity associated to a tumour to detect breast cancer[29]. As far as cancer treatment is concerned, Jennifer West and her team at Rice University, Houston, developed gold 'nano bullets' that can destroy inoperable human cancers. The nanoshells consist of tiny silica particles plated with gold and when these are heated with infrared light, the cancer cells die[30]. Carbon nanotubes have been transported into the cell nucleus and continuous near infra-red radiation absorption of nanotubes causes cell death. This methodology has been used for cancer cell destruction[31].

(e) Environmental pollution: Environmental degradation due to unsustainable ways of production and other human activities exposes the entire world population to increased risks. Innovative techniques using nanoengineered materials and devices can be deployed for the removal of polluting molecules in air, water and soil. Cleaner manufacturing processes and methods, applying nano-scale techniques, could also contribute to lesser environmental pollution, especially in the developing world where international standards are often not safeguarded. Arsenic in soil and water for instance, is a widely diffused problem in several regions of the developing world. A simple, cheap but effective nano-scale technique to remove arsenic involves TiO_2 nanoparticles[32]. Nanomaterials have been shown to be effective in removing metal ion contamination. A wider application of such technologies harnessing discoveries in nanoscience could have a positive and wider impact on the health conditions and natural habitat of millions of people.

(f) Energy storage, production and conversion: The chronic power shortage and increased need for energy resources of the rapidly growing population and economies of the developing world are challenging the energy market. Since almost all sources of energy are not renewable, soon the world will face a global energy supply problem. Solar energy is an interesting and valid alternative, especially in the sun-rich South. Scientific studies have demonstrated that nano-scale techniques involving nanotubes and nanoparticles lead to increased conversion efficiencies. Semiconducting particles of titanium dioxide coated with light-absorbing dyes bathed in an electrolyte and embedded in plastic films are cheap and easy to manufacture and offer an alternative to conventional energy production and storage. Because of their low cost-structure, photovoltaics using nanotechnology are a valid alternative to overcome the problem of power shortage, especially in the developing world. Researchers at Nanosolar, a venture capital start-up based in Palo Alto, California are developing cheaper methods for producing photovoltaic solar cells using nanotechnology[33]. The idea is to boost the power output of nano solar cells and make them easier to deploy by spraying them directly on the surfaces. The approach is simple and could be easily replicated in the developing world. These highly efficient solar cells can be made with a mix of alcohol surfactants and titanium compounds sprayed on a metal foil. Within 30 s, a block of titanium oxide perforated with holes of nanometre size rises from the foil. Solar cells are formed when the holes are filled with conductive polymer and electrodes are added and then covered with a transparent plastic. These are concrete examples that nanotechnology is suited for energy storage, production and conversion in the developing world.

(g) Global partnerships: The inclusion of the South in the nano-dialogue creates new platforms and alliances between the North and South and strengthens their ties. Allocation of some of the large public scientific fundings of nanoscience and technology could be directed to developing countries in order to foster development, diffusion and dissemination of nanoscience, engineering and technology in the developing world. Global research networks of excellence enhance the value of the international scientific community. Encouraging international partnerships between the North and South, similar to the first North–South expert group meeting of nanoscientists and nanotechnologists in Trieste, Italy in February 2005 are certainly important, but also scientific exchange and alliances between countries of the developing world are becoming a necessity in view of the ongoing regionalization trends in politics and economics[34]. Global research networks, including scientific cooperation and collaboration are needed to find joint solutions for the most pressing problems of the world community but partnerships at the regional level will, in the long term, gain importance and therefore South–South nano-networks need to be envisaged.

Unexplored biodiversity of the South – opportunities for bio-nanotechnology

The development of nanocomponents that imitate or emulate natural processes can find many applications in a myriad of sectors. Protection and preservation of species in the tropical belt have become a new dimension because of bio-nanotechnology and its potential applications. The scientific exploration of the nano–bio interface becomes interesting in view of developing synthetic life-forms, manufactured organs and bio-nanodevices. Availability of the necessary research infrastructure provides the developing countries with a strategic advantage vis-à-vis the industrialized world, since the biodiversity is much larger in the tropical and subtropical belt as in other geographical and climatic zones. It lies in the hands of the developing countries to make use of this distinctive asset and to discover the secrets of its yet unexplored biodiversity and the particular physical properties of its living organisms. The Lotus effect, discovered by Wilhelm Barthlott and his student Christoph Neinhuis at the University of Bonn, illustrates how knowledge of what happens at the bio–nano interface can be made fruitful. Lotusan, a dirt-repellent paint is the commercialized form of the scientific discovery of the Lotus effect. Discovering the richness of the flora and fauna present in the developing world by the developing world itself with regard to bio-nanotechnology is of crucial importance. The rich cultural heritage, including the millennia old traditional knowledge in homeopathic, ayurvedic and herbal medicine together with the large biodiversity provide developing countries with a strategic advantage which the North lacks. It lies in the hands of these countries, especially those that have already adopted nanotechnology initiatives within the bounds of their national technology development policies, to make use of the unique assets for a better positioning in the emerging global nano world.

Conclusion

The potential societal implications of the scientific and technological innovation process in the realm of nano and the diffusion of the future applications of the discoveries at the frontiers of science are only partially understood and therefore need to be further explored. The uniqueness of nanoscience and nanotechnology, especially with regard to its pervasiveness into virtually all spheres of human life, explains why the magnitude of the potential impacts will exceed that of all other conventional yester-year technologies. The convergence of the newly emerging technologies of the 21st century has the potential to revolutionize social and economic development and may offer innovative and viable solutions for the most pressing problems of the world community and its habitat. However, a better understanding of the potential benefits and hazards of nano-scale science and technology is essential because it will provide policymakers with better tools to take responsible choices. Nanoscience and its deriving technologies have the potential to improve the state of the developing world, if the applications are designed and tailored to best fit the needs of the people. Nanotechnology, unlike other technologies, offers a unique chance to bridge or bypass the technological gap between the industrialized and developing world; however, a favourable terrain for their growth needs to be prepared. Therefore, joint and concerted efforts by all concerned are needed to rule out future factions and new divides.

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