Nanotechnology Industries Association

NIA Report

Closing the Gap: The Impact of Nanotechnologies on the global Divide

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The NIA, Nanotechnology Industries Association, is the sector-independent, responsible voice for the industrial nanotechnologies supply chains; it proactively supports the ongoing innovation and commercialisation of nanotechnologies and promotes their safe and reliable advancement.

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NIA Report

Closing the Gap: The Impact of Nanotechnologies on the global Divide

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Executive Summary

Nanotechnologies are capable of introducing promising applications that could impact upon our daily lives; it is through the visualisation and control of matter at the scale of a billionth of a metre that allows nanotechnologies to modify and enhance the properties of products across all industry sectors. Even though nanotechnologies have immense potential, they are only in their infancy and have yet to reach full maturity. When considering the changes they could bring, it must be asked: are nanotechnologies going to reduce the rich-poor divide, or will they have the opposite effect?

In light of debates that make nanotechnologies responsible for a further widening of the aforementioned divide, this report analyses this Nano-Gap, or Nano-Divide, by examining the pros and cons of nanotechnologies and their impact global development and the on-going fight against poverty.

In order to analyse this topic objectively, this report looks at how nanotechnology-based inventions and their potential applications could be implemented in developing counties, and whether they could benefit the most underprivileged populations. Obstacles and problematic issues that could arise are also scrutinised, with the following more fully addressed:

- Will nanotechnologies reach the populations they wish to assist?
- What impact could they have on world trade and already weak economies?
- What of the unprecedented nature and uncertainties surrounding the risks of nanotechnology?
- Will inventors from the developing world have to circumvent challenging intellectual property rules in order to make full use of the technology?

This subsequently leads the report into looking at the possible ways forward for the fair development of nanotechnologies. Finally, the report looks at the possibilities for scientists and entrepreneurs from low- and middle-income countries to scale-up the benefits for their countries with the help of international cooperation and global dialogue.

Glossary

ACP – African Caribbean and Pacific Group of States
BRICS – The acronym for the association of Brazil, Russia, India, China and South Africa
CBEN - Center for Biological and Environmental Nanotechnology of the Rice University
CEST - Commission de l'Éthique en Science et en Technologie (Commission on the Ethics of Science and Technology)
CGIAR - Consultative Group on International Agricultural Research
EPFL – École Polytechnique Fédérale de Lausanne
EPO – European Patent Office
ETC Group – Group on Erosion Technology and Concentration
FAO – Food and Agriculture Organization of the United Nations
GDP – Gross Domestic Product
GNI – Gross National Income
GRET - Groupe de Recherches et d'Echanges Technologiques
HDI – Human Development Index
IAEA - International Atomic Energy Agency
IBSA – India, Brazil, South Africa trilateral initiative for nanotechnologies
ICS-UNIDO - International Centre for Science and High Technology of the United Nations Industrial Development Organization
ICTP - International Centre for Theoretical Physics
IFPRI - International Food Policy Research Institute
ILO – International Labour Organization
IPEN – International POPs Elimination Network
ISN – Institute for Soldier Nanotechnologies
MDG – Millennium Development Goal
MIT –Massachusetts institute of technology
NGO – Non-Governmental Organisation
NTNOIC - Nano Technology Network of the Organization of the Islamic Conference
OECD – Organisation for Economic Co-operation and Development
OIC – Organization of Islamic Cooperation
OIC-COMSTECH - Organisation of Islamic Cooperation's Standing Committee on Scientific and Technological Cooperation
SAICM - Strategic Approach to International Chemicals Management
STM – Scanning Tunnelling Microscope
TWAS – The World Academy of Sciences, formerly known as the Third World Academy of Sciences
UN DESA - United Nations Department of Economic and Social Affairs
UNDP - United Nations Development Programme
UNEP – United Nations Environment Programme
UNESCO - United Nations Educational, Scientific and Cultural Organization
UNIDO - United Nations Industrial Development Organization
UNITAR - United Nations Institute for Training and Research
UNOSSC - United Nations Office for South-South Cooperation

US EPA – United States Environmental Protection Agency
US PTO - United States Patent and Trademark Office
WHO – World Health Organization
WIPO - World Intellectual Property Organization

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Chapter 1. Setting the Scene

What is Nanotechnology?

Inspired by nature's crafts and operating at the smallest scale of matter, nanotechnology has achieved major breakthroughs in its short history. The possibility of utilising nanoscale features in a dedicated technology was first mentioned by Professor Richard Feynman in his speech, *'There is plenty of room at the bottom'*[1]. It was not until the invention of the scanning tunnelling microscope (STM) in 1981, however, that nanosciences and its applications to various and disparate fields of technologies, commonly called nanotechnologies, became established disciplines of scientific investigation and engineering. Aided by the device's introduction, researchers now had the power to both visualise and manipulate atoms at the scale that dictates the functionality of matter: the nanoscale. Since then significant progress in microscopy and probe technologies has supported an increasing sophistication of the research and development of nanotechnologies. Today nanotechnologies are applied in almost all industrial sectors and are championed as instrumental in creating entirely new industries based on the wide range of properties that can be realised through the technology. At the nanoscale matter behaves according to the laws of quantum physics, and the understanding of these enables the effective visualisation, design and control of matter at this scale. The results of such work are manifold: one example is the straight-forward improvement of resource efficiency allowed by the larger surface area of nanomaterials, which allows for small quantities of nanoscale materials to achieve the same efficiency as larger quantities of non-nano ones; another example is that applications of nanotechnology enable common manufacturing methods be more environmentally safe, as the use of nanomaterials enables processes, which previously required the use of solvents, to be conducted in water-based dispersions, and furthermore it also means that energy-intensive processes can be conducted at lower temperatures; finally, through the limitation of grain sizes to below 30 nm, common materials obtain new properties[i].

Most importantly nanotechnologies find applications in almost every domain of industrial activity and as a result, even though they are still in their infancy, their impact on the economies of the world is expected to be profound. In this respect industrialised countries are leading the global race for nanotechnologies, but developing countries could also find interesting applications that would aid them in bringing their populations out of poverty and propelling them to economic growth.

A divided World

In 2008 1.28 billion people were living on less than USD 1.25 a day[2]; with current estimates indicating that approximately 15% of the world's population are undernourished[3], fighting inequity remains one of the main challenges of the 21st century.

In spite of regular international initiatives aiming to reduce global imbalances and the differences between and within nations, the world remains acutely affected by deep disparities; natural and man-made scourges, such as hunger, poverty, disease, war, dictatorship, slavery and corruption, all contribute toward widening this divide. This results in a minority of the world's population living in industrialised, developed countries that have robust societal structures and are abundant with goods, while the majority live in much poorer conditions.

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[i] A much-quoted example is gold, which is widely used for jewellery and high-performance electronics due to its chemical stability; when its grain size is limited to below 10 nm it becomes a highly reactive chemical catalyst.

Several indicators developed at the international level allow one to grasp the extent of global inequality. Some, such as Gross Domestic Product (GDP) and Gross National Income (GNI), focus upon economic wealth. Others, such as the United Nations Development Programme's (UNDP) Human Development Index (HDI), include more variables and base their results upon parameters such as life expectancy, education and GNI, thereby offering a fuller picture of the scale of development within a given country. A glance at a HDI world map[i] not only illustrates the divide between wealthy developed countries and the developing world, but also shows multiple complexities that do not allow the world to be split into two so easily.

In 2012[ii] Norway had the world's highest HDI (0.955). The average of countries within the Organisation for Economic Co-operation and Development[iii] (OECD) was 0.888, and the world's average was 0.694. Comparatively the least developed country in the world was a sub-Saharan African state, Niger (0.304) (the average HDI of the sub-Saharan area, meanwhile, was 0.475).

Additionally the gap in economic wealth is just as wide: developed countries, or high-income economies, are defined by the World Bank as being countries with a GNI (ppp)[iv] per capita, of $12,276 or more. The least developed countries, or low-income economies, have a GNI (ppp) per capita of $1,005 or less[4]. In between these extremes are emerging, or middle-income economies, such as the BRICS countries (Brazil, Russia, India, China and South Africa); these act as regional driving forces actively bridging the divide.

In the context of this global divide, nanotechnologies are forecast to have an important influence on the global repartition of wealth and wellbeing. The 'nano-divide', or 'nano-gap', describes a phenomenon by which the surge of nano-enabled products would widen the existing divide; this theory is however counter-balanced by the features and promises offered by nanotechnologies, and by the solutions it bears for issues faced by the developing world.

Closing the Divide, a global Concern

Numerous international and charitable organisations around the world have long been fighting to narrow this divide. In 2000 world leaders held the multilateral United Nations Millennium Summit, which addressed the issues of poverty and hunger. With mankind entering the 21st century, heads of states across the globe agreed that they would follow eight distinct guidelines to improve the living conditions of the most deprived: these were named the Millennium Development Goals (MDGs). Set to be reached in 2015, the MDGs are the latest in international mobilisation efforts targeting global inequalities, and though reviewed since, the MDGs remain:

I. Eradicating extreme poverty and hunger
II. Achieving universal primary education
III. Promoting gender equality and empowering women
IV. Reducing child mortality rates
V. Improving maternal health
VI. Combating HIV/AIDS, malaria, and other diseases
VII. Ensuring environmental sustainability

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[i] United Nations Development Programme. *Human Development Indices World Map*. Available at: http://hdr.undp.org/en/statistics/data/hd_map/

[ii] United Nations Development Programme. *International Human Development Indicators*. Available at: http://hdr.undp.org/en/statistics/

[iii] 34 member states of the OECD (http://www.oecd.org/general/listofoecdmembercountries-ratificationoftheconventionontheoecd.htm)

[iv] The Growth National Income is calculated with purchasing power parity (ppp).

VIII. Developing a global partnership for development

With two years left to go until 2015 and colossal challenges still prevalent, it looks increasingly unlikely that all these objectives will be reached. Although the World Bank and the UNDP acknowledge that there have been great improvements, and even the achievement of some of the goals, poverty still blights the world on a dramatic scale. Furthermore the advancements of the last decades are fragile; the economic crisis of 2008, and the spread of austerity policies that have arisen from it, have strongly hit development aid budgets, and a dramatic food crisis has affected Africa. As such the United Nations still considers world development to be at the heart of the world's political agenda.

Science and Technology, Engines for Development

Increasingly some low- and middle-income economies see innovation as a way to not only attain these MDGs, but also as a way to close the gap between themselves and developed countries. Although there are numerous factors involved in development, and many of them are difficult to act upon, the last few centuries' advances, at least with regard to quality of life and life expectancy, may be attributed to developments made by science and technology: major technological breakthroughs such as the steam-engine, modern telecommunications and modern medicine, have all had a lasting positive influence on humanity.

While developed economies invest substantially in science, technology and innovation in order to foster economic growth and maintain their global competitiveness, developing nations lack the political and economic latitude to do the same, and consequently lag behind in research and development[i].

Nevertheless some countries have been strategically investing in new technologies so as to improve their economic results. In the last 30 years, several Asian economies have rapidly achieved successful economic growth; South Korea and Taiwan have, in particular, looked to high-tech manufacturing to achieve this[5]. Both nations have since achieved a high level of human development and have become world leaders in this field; Samsung, from South Korea, is now the world's leading technology company[6], whilst Foxconn International Holdings, from Taiwan, is the world's premier electronics manufacturer[7].

Similarly, developing economies could benefit from technological change and from the progresses made in scientific research with targeted 'technological leapfrogging' strategies that would relate to some of the key issues that developing countries face. This is already evident in developing markets where mobile phone usage and infrastructure outpaces the installation of landlines[8]. From this wider telecommunications access, greater access to new markets has been enabled, and along with it improved knowledge, which has acted as a further catalyst for economic growth. Solar cell developments have created cheap, portable solar lamps that bring electricity to even the most rural areas of the planet without the need for an expensive electrical grid[9]. Recent applications of modern technologies are now, therefore, capable of helping fight global inequality.

Commonly major technological breakthroughs have served as magic bullets to developmental problems; nevertheless they often face many barriers. An example of this is the digital revolution; although 63% of all internet users are now located in the developing world[10], it took a substantial amount of time to reach this figure, and indeed, disparities remain: several developing countries are

[i] The World Bank. *Research and development expenditure (as % of GDP)*. Available at: http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS

still lagging behind in terms of connection speed, and the percentage of internet users in them is still low compared to ones in the developed world.

New technologies have the potential to change living conditions but their promises must not be overestimated. Due to the multi-faceted nature of global interactions, trade and cultural specificities, different countries will not react in the same way to technological breakthroughs. While the outcomes of any given technology can be seen as positive, technology alone does not have the potential to redress the aforementioned inequalities. Social, economic, ethical and political hurdles ought to be considered just as important to development, if not more so, than technological ones. In addition cultural barriers may significantly affect the spreading of technological achievements: poor countries, and especially the least developed ones, are sometimes facing situations where their primary concern is the securing of basic needs.

Charity and aid can have significant positive effects in helping alleviate acute problematic situations, both as long-term and permanent tools of support; however they are often criticised for missing sustainability models. While charitable organisations have a track-record of stimulating local industries in the developing world, such as in African countries where they have been producing bed-nets and malaria treatments[11], they can also have unwanted effects: for example, a reported case of distribution of anti-mosquito nets to a malaria-ridden population in Africa resulted in dramatic failure, as the local net factory experienced severe competition as these nets were reportedly being used for fishing instead[12].

In order to incentivise the uptake and use of technology, legal systems could be used as tools to eliminate barriers and achieve the successful implementation of new solutions; for example, the creation of an SME-friendly environment would facilitate the cooperation between such enterprises and universities.

Global challenges are, however, multi-faceted in nature; technology can be seen as a successful means for improving solutions, but these solutions also need to be multi-dimensional.

Nanotechnologies and developing Countries: the 'Nano-divide' Debate

Aware of the reported benefits nanotechnologies could have for their populations, some countries in the developing world have considered that this technological development could allow them to avoid the implementation of outdated technologies, thus engaging them in 'economic leapfrogging'; as such they are increasingly investing in it.

> "Nanotechnology, unlike other technologies, offers a unique chance to bridge the technological gap between the industrialized and developing countries."
>
> Graziano Bertogli
>
> *Bridging the gap*, Third International Dialogue on Responsible Research and Development of Nanotechnology, 2011

Nanotechnology has potential applications in every industrial sector, from medicine to solar panels, and thus promises immense opportunities for enabling radical changes in the lifestyles of populations around the globe. It is often seen as one of the most promising, cutting-edge, and disruptive technological breakthroughs of the last few decades. Relatively low production costs are envisaged, which could amplify the potential positive outcomes of nano-enabled products by making them very cost-effective to create. Additionally nanomaterials can allow for the special characteristics of rare raw materials to be recreated in more commonplace ones.

Rich economies have identified the characteristics and potential of nanotechnologies and have thus been investing in them; with crucial market benefits foreseen, nanotechnologies have become involved in the global competition between developed countries.

Nanotechnologies are nonetheless in their infancy and must not be seen as a miracle cure. Furthermore this technology is sometimes considered 'disruptive' and subsequently accompanied by emotionally-driven interventions that have no scientific basis[i]. Alongside these debates, environmental and human safety issues have also been raised.

Linking the question of nanotechnologies to global development, the United Kingdom's Royal Society of Engineering provided a reminder in their 2004 report that every technological breakthrough has ''winners' and 'losers''. The report refers to the notion of a 'nano-divide', which is seen as 'the potential for nanotechnologies to intensify the gap between rich and poor countries because of their different capacities to develop and exploit nanotechnologies'. This concept was then split between the 'nano-innovation divide', which covers the leading actors within nanotechnology shaping its innovation, and the 'nano-orientation divide', which conceptualises the market, rather than the social, orientation of nano-products[13].

The non-governmental organisation (NGO) Action Group on Erosion, Technology and Concentration (ETC Group) has previously claimed that nanotechnologies are a tool used by industrialised nations to maintain their dominance over developing ones. In its 2003 report on 'Atomtech'[ii], the NGO asked if 'like in the industrial revolutions that have preceded it, will we see a decline in the well-being of poor people and increased disparity between rich and poor?'[14] A study by Salamanca-Buentello[15], on the other hand, aimed to show how nanotechnology has the potential to help populations in need increase their living conditions and reach the MDGs.

Such a debate is not unique to nanotechnology, as other technological breakthroughs, such as the multitude of developments based on biotechnology, fostered similar opposition. In order to be a constructive addition to the current debate, this report attempts to present the ongoing situation of nanotechnologies as well as its potential future outcomes.

In order to achieve an improvement in living conditions around the world, a number of social and political pre-requisites that do not depend on science and technology have to be fulfilled: social, economic and ethical questions ought to be understood and not excluded from the equation when considering how nanotechnologies are spreading their benefits to all sectors of the global economy.

This report wishes to look at the impact nanotechnologies may have on developing countries because they, due to their disruptive scientific, technological and economic potential, cannot be considered as an evolution of any previously existing technologies. The potential applications of nanotechnologies are plentiful and could address most of the chronic challenges faced by poor developing countries, such as pandemics, and natural and human disasters.

The complex nature of the global divide, and the diverse realities faced by developing countries, also ought to be considered. Although relatively poor, the countries from the BRICS bloc, and some other emerging economies such as Indonesia, have been enjoying stable economic growth and steady enrichment recently. Those countries now have the economic means with which to invest in nanotechnology and play an increasingly important role in its research, while poorer countries, are

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[i] With the 1986 novel 'Engines of Creation', Eric Drexler invented the 'grey-goo', a fictional scenario in which self-replicating robots consume the Earth. This 'self-replicative grey goo' was mentioned in 2003 by Charles, Prince of Wales when he asked the Royal Society to consider the risks of nanotechnology.

[ii] '"Atomtech" better describes the technologies that aim to manipulate the fundamental building blocks of matter.' ETC Group. 2003. *The Big Down* Available at: http://www.etcgroup.org/content/big-down-0, p.6

still lagging behind (even though some have managed to start financing activities in the area). The extreme poverty affecting such developing countries could be balanced in a practical way, with appliances adapted to the needs and practices of the local populations. Nanotechnologies are today believed to be able to offer the specific solutions needed by developing countries to face some of their recurrent challenges. More importantly nanotechnologies have a different role to play for all such countries. For some, nanotechnologies and their foreseen market benefits open the door to economic development, while for others they offer bespoke tools that would help in pulling them out of extreme poverty; both are different, but valid, ways of closing the gap.

In addressing the debate around the concept of a nano-divide, this report wishes to look closely at the options offered by nanotechnologies for developing countries, and questions how these countries could get the best out of them.

From this perspective, the report will first cover the potential applications of nanotechnologies for developing countries (Chapter 1); it will then identify the obstacles to the fair development of nanotechnologies (Chapter 2), and finally question how to scale the benefits of these applications (Chapter 4).

Chapter 2. Beneficial Applications of Nanotechnologies for developing Countries

This chapter provides examples of how nanotechnologies are benefiting developing countries. The earliest collection of nanotechnology applications for the poor was documented in a 2005 study by Fabio Salamanca-Buentello *et al*., which is covered in the first part of this chapter; the second part gives specific attention to a couple of key sectors, selected for their relevance to the needs of the poor, in which nanotechnologies are already helping improve living conditions in developing countries as well as increasing their wealth.

Nanotechnology-based Solutions for the Millennium Development Goals (MDGs)

In 2005 nanotechnology research and its potential benefits for the developing world were analysed in terms of the completion of the MDGs; *Nanotechnology and the Developing World*, the Salamanca-Buentello study[16], is one of the milestones in the nano-divide debate.

In the developing world nanoscience and nanotechnologies can potentially contribute to diverse improvements in areas such as water treatment, energy, agriculture, and medicine; this cross-sectoral aspect is indicative of nanotechnologies significant potential to contribute to the reduction of poverty. So as to address the variety of applications, and to identify the areas in which nanotechnologies were closest in bringing their promises to fruition in the emerging and developing markets, the Salamanca-Buentello study questioned a panel of 85 nanotechnology experts and concluded that nanotechnologies could benefit a total of five different MDGs (out of eight):

- The findings identified applications of nanotechnologies in the section 'energy storage, production and conversion' as an area in which improvements in the living conditions of the most disadvantaged regions of the world could be made. According to the panel, developments in hydrogen storage, based on carbon nanotubes and nano-enhanced photovoltaic cells (among others), could enable the achieving of MDG VII, 'Ensure Environmental Sustainability'.
- Nanotechnology was also forecast by this study to potentially impact the eradication of extreme poverty and hunger (MDG I) with applications in the field of agriculture in particular: for example, 'nanosensors for soil quality monitoring', 'nanocapsules for herbicide delivery' and 'nanoporous zeolites for slow release and efficient dosage of water and fertilisers for plants and of nutrients and drugs for livestock' could all have a positive impact on productivity.
- 'Combat HIV/AIDS, malaria and other diseases' (MDG VI) was also identified as an area in which nano-enabled test kits, medicines and other nano-products could bring a helpful contribution.
- MDGs V (improve maternal health) and IV (reduce child mortality) were considered to be areas in could most be affected by nanotechnologies; the realisation of these two MDGs could benefit from the input of nanotechnologies in agricultural productivity enhancement, water treatment and remediation, disease diagnosis and screening, drug delivery systems, food processing and storage, air pollution and remediation, health monitoring, and vector and pest detection and control.

Researchers and scientists also listed examples of the possible innovative nanotechnologies that could help reach specific MDGs. The 2013 MDG Report by the UNDP[17] estimates that the target of halving the rate of extreme poverty had supposedly been achieved in 2010, and other targets had seen significant improvements in the past years. However, nine years after the publication of the Salamanca-Buentello study, the use of nanotechnology-based innovations to improve living conditions in the poorest countries is not widespread, and poverty and inequalities are still dramatically high in the least privileged areas of our planet.

> 'Perhaps most importantly, our results can provide guidance to the developing countries themselves to help target their growing initiatives in nanotechnology. The goal is to use nanotechnology responsibly to generate real benefits for the 5 billion people in the developing world.'
>
> Fabio Salamanca-Buentello *et al.*
> *Nanotechnology and the Developing World*
> PLoS Med 2(5), 2005

Since 2005 the use of nanotechnologies has been growing rapidly in both developed and developing countries[18]; it is, however, impossible to assess their role in the progresses made relative to the MDGs. The Salamanca-Buentello study did not provide solutions for developing countries: it only identified sectors that could deliver the intended solutions, and suggested that nanotechnologies could have poverty reduction-oriented applications that would significantly improve the living conditions of their inhabitants.

The Diversity of Nanotechnology Applications

Nine years after the publication of *Nanotechnology and the Developing World*, nanotechnologies offer even more opportunities for developing countries. Many of the technology's achievements are getting closer to commercialisation and could bring their benefits to places where their input would be immensely beneficial to both the local populations and to the economy. The innovative solutions supported by the use of nanotechnologies mainly target the areas of:

1. Access to clean water
2. Medical solutions, diagnosis and treatment
3. Agricultural crop optimisation
4. Energy production and storage

The following sections provide examples of the potentially beneficial applications that are at different stages of development but could help bridge the global divide.

1. Water

Poor countries see their development hampered by health and sanitation issues, and one of the most problematic areas is access to clean drinking water. Often contaminated by toxic pollutants or bacteria-causing diseases, such as cholera, water is addressed by the MDGs through a target to 'halve the proportion of the population without sustainable access to drinking water' (MDG VII.C)[19]; this goal was achieved in 2010. Unsafe drinking water carrying diarrhoea-causing pathogens, however, still kills thousands of children per day in developing countries[20], and access to clean water, a central and strategic resource, remains decisive in areas of the globe where water management systems would require costly and challenging improvements.

During the past few years, water treatment has been a focus for nanotechnology research and some milestones have been achieved: from overly-efficient filters to the production of cheap solutions to counter arsenic pollution.

The remarkable efficiency of nanotechnology-based filtration systems has sometimes become problematic: in South Africa, for example, a study examined the filtration of brackish groundwater with polymeric nano-filtration and reverse osmosis membranes: it transpired that this was technique was too efficient, however, and produced water not considered drinkable by the standards of the World Health Organisation (WHO) due to the lack of nutrients[21]. While some nanotechnologies still require improvement, there is a plurality of applications that are promising for water treatment; thanks to nanotechnologies, small-scale portable filters can be manufactured; the portability of such filters, which are also more efficient at cleaning water than conventional filters, makes them better adapted to the needs of local populations. Furthermore they can be produced inexpensively: as an example, PureMadi, a non-profit organisation from the University of Virginia[i], manufactures low-priced water filtration systems out of ceramics that are already on the market - these filters use nanoscale copper or silver with biocidal properties to safely purify water in remote areas of South Africa[22]. Even better, the water filters are produced locally in rural South Africa, thus benefiting the local population with both employment and drinkable water.

There are many filtration techniques that benefit from nanotechnologies: a scientific article written by Iranian researchers[23] proposed the use of graphene-based nano-composites to absorb water pollutants[24]. Another example is of a mobile and autonomous system of water preparation developed by researchers from the University of Kassel in Germany in 2010; about the size of a backpack, this device allows for villages to purify water in case of emergency as it uses a membrane with nanometric holes to filter water. It is also lightweight (20kg) and can filter up to 1,200 litres per day. This device was also considered to be significantly cheaper than other large-scale filtration appliances as it would cost less than EUR 1000[25].

Arsenic contamination is another type of water pollution: it mainly affects wells in countries with poor water management systems and bears high health risks. In 2006 nanotechnologists from the Center for Biological and Environmental Nanotechnology (CBEN) of Rice University (Texas, USA) used rust nanoparticles to magnetically trap the arsenic and purify water[26]. The International Food Policy Research Institute (IFPRI)[27] also identified iron oxide nanoparticle filters, nano-enabled synthetic clays, and zinc oxide as applications of nanotechnology that could cleanse arsenic from water. Finally carbon nanotubes and nanoporous zeolites[28] can also be used to clean dirty water.

In the field of water purification nanotechnologies have the potential to detect pollutants too: for example, the Northwestern University, Illinois, USA, together with the École Polytechnique Fédérale de Lausanne (EPFL), developed a so-called ‘nano-velcro’ trap for mercury particles. The nano-velcro detects the presence of mercury in water, and alerts populations if there is a sanitary crisis. The cost of producing this device is estimated to be USD 10[29].

2. Medicine

Another area in which nanotechnologies can bring formidable gains is medicine, where nano-enabled devices and medicines allow for significant progress. The field of nano-enabled medicine covers a lot of new applications for healthcare in which nanomaterials and nano-electronics are being used for targeted drug-delivery, or for the early detection of diseases (a combination of therapeutic treatments and early diagnosis of illnesses, known as ‘theranostics’); nanotechnologies also allow for the development of cost-effective and simple diagnosis devices for patients, and efficient treatments for diseases affecting developing countries.

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[i] PureMadi. Available at: http://www.puremadi.org/PureMadi/Welcome.html

The so called ‘big three’ diseases (HIV/AIDS, malaria and tuberculosis) are responsible for millions of deaths in developing countries, while their impact on the developed world is significantly less due to the social and medical apparatus in these countries offering better living conditions to those who fall ill. With the help of nanotechnologies, this dramatic issue could be efficiently addressed.

In 2010 34 million people were affected by the Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome (HIV/AIDS)[30]; it is an epidemic that has been spreading since the last century. Most of the carriers of the disease live in poor countries (see **Figure 1**) and have no access to medical information or treatment; the UNDP estimates that in 2010, 6.5 million people were receiving classic antiretroviral therapy in developing countries, while the MDG target aims to provide this treatment to 15 million people[31].

Nanotechnologies appear to be of great help in fighting the HIV/AIDS epidemic: for example, researchers from Columbia University have developed a diagnosis device called the mChip[i]. The mChip uses nanoscale gold to react with contaminated blood[32]., and the strengths of this device are:

- its cost, estimated to USD 1
- its portability. as the mChip is the size of a credit card
- its ease of use, since the device only needs a few droplets of blood, and the result can easily be read
- its quick formulation of results, for the mChip rapidly provides the results to the user

This decisive tool in the struggle to halt the progression of the epidemic was successfully tested in Rwanda; in addition it also detects syphilis and other infectious diseases.

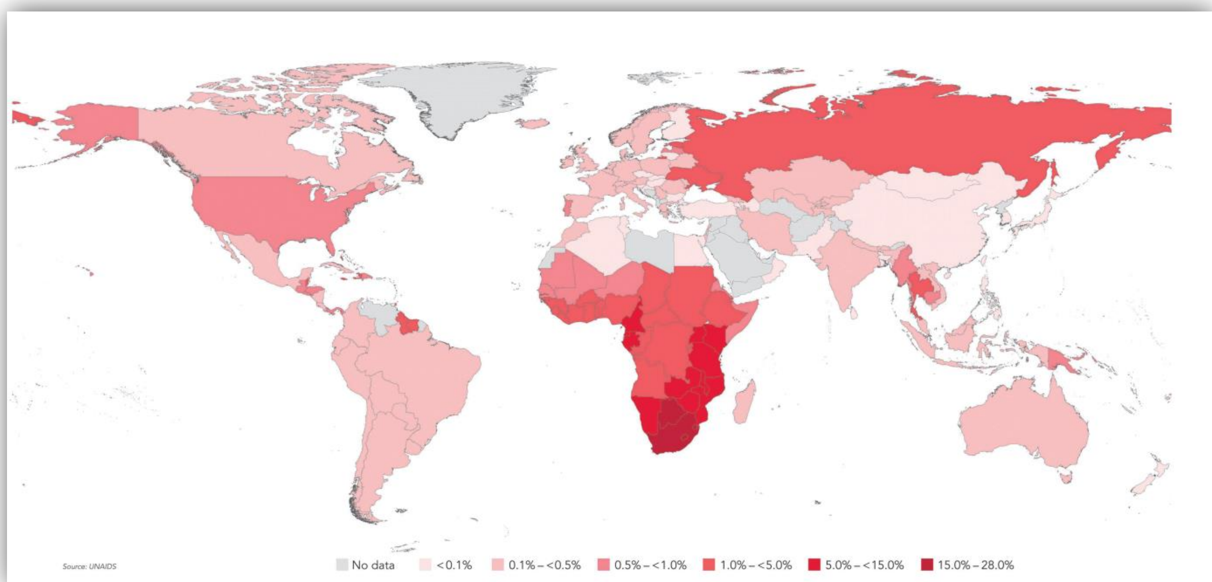

Figure 1 HIV prevalence map. (source: UNAIDS, 2011) [ii]

Many developing countries are also afflicted with malaria; according to estimates in the 2012 UNDP MDG Report, of the 655,000 deaths caused by this disease, 91% occurred on the African continent and 86% of the victims were under the age of 5[33]. Combating this disease is part of the sixth MDG, and

[i] mChip info available at: http://www.mchip.info/

[ii] HIV prevalence map. (source: UNAIDS, 2011) Available at: http://www.unaids.org/globalreport/HIV_prevalence_map.htm

international funding has focused on providing African children with non-nano-enabled solutions such as insecticide-treated nets and artemisinin treatments. In their 2012 report, however, the United Nations explained that the disease had been adapting to the classical treatment over time. In addition insecticide-treated nets lose their effectiveness as the insecticide wears off with washing. To counter these problems, Thai researchers have created bed nets with an increased life span of five years. The product uses a 'nanoscale formulation of pyrethroid, the common insecticide used for bed nets, with particles so small that washing does not dislodge them'[34].

Nano-enabled medicine does not only have promises in terms of treatment, but also in terms of disease diagnosis: for example, a 'nanowire based biosensor'[i], developed by a company called 'QuantuMDx' located in Newcastle, United Kingdom, detects the presence of malaria parasites in less than 20 minutes. Produced under the auspices of the Nanomal project[ii], the sensor also identifies any drug resistance, thus allowing for targeted treatments. This portable device was estimated to be able to reach markets within three years[35]; QuantuMDx's devices can also diagnose tuberculosis and other diseases afflicting the developing world[iii].

Aside from the nano-enabled medical devices that are reaching markets in Western and industrialised countries, nanotechnologies offer cheap and easy-to-use theranostic solutions that may benefit developing and emerging countries. In addition to the previous examples, the use of cheap nano-gold-based appliances is rapidly becoming a solution for the diagnosis of cancers[36].

3. Agriculture

A lack of access to drinking water, along with worldwide food epidemics, means that world hunger is a scourge that international organisations have been struggling against for decades. 850 million people, representing 15% of the world's population, are estimated by the Food and Agriculture Organisation (FAO) to be undernourished[37]; data from the FAO shows that the main afflicted areas are, once again, countries within the developing world (see **Figure 2**).

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[i] NanoMal. *The NanoMal Technology*.Available at: http://www.nanomal.org/technology.html

[ii] NanoMal. *The NanoMal Project*.Available at: http://www.nanomal.org/index.html

[iii] QuantumDX. Devices – QPOC (TM). Available at: http://www.quantumdx.com/devices-QPOC.html

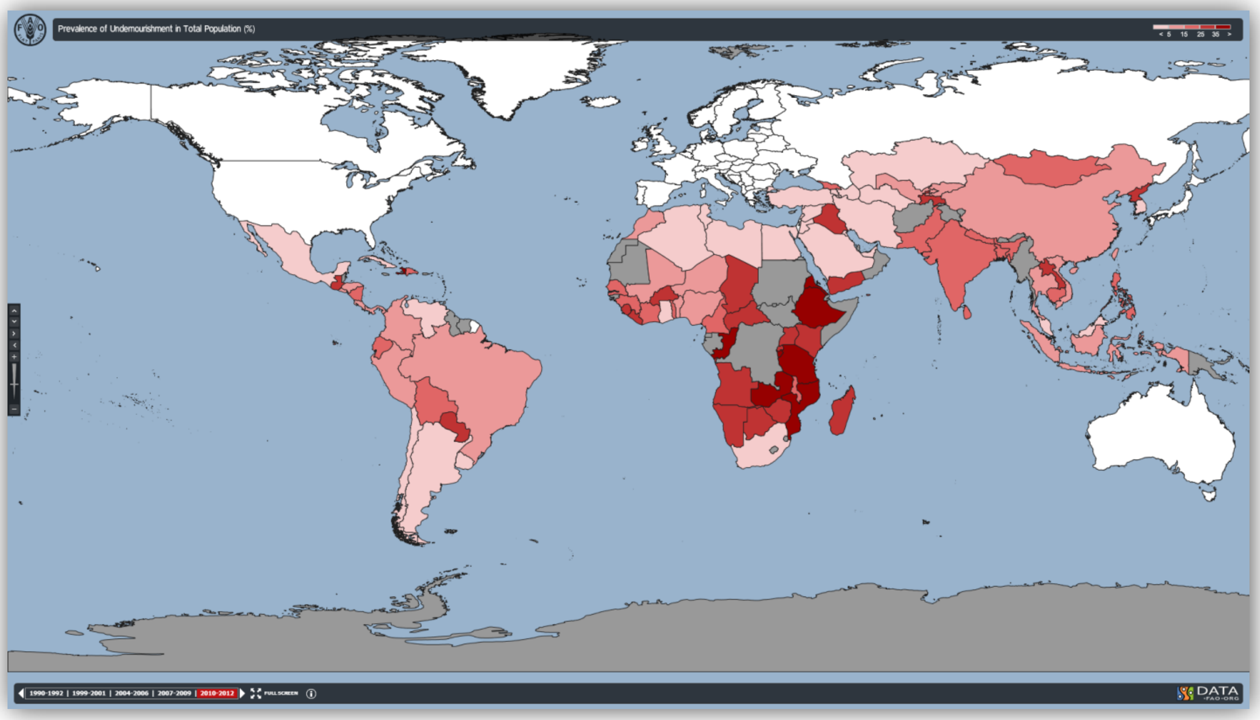

Figure 2 Prevalence of undernourishment in total population (%). (source: FAO, 2013)[i]

The role of agriculture in improving the living conditions of the populations from poor countries has been emphasised by the FAO; according to the international institution, 'agricultural growth is particularly effective in reducing hunger and malnutrition'[38]. In a 2008 article Dr Kofi Anane-Fenin[39] of Ghana stated that nanotechnology 'may offer a range of solutions to a number of poverty-related problems'; specifically addressing the needs of the ACP countries[ii], where agriculture is believed to provide a living for 60-70% of the population, the scientist identified the potential benefits of nanotechnologies for them. Furthermore, in the words of the IFPRI, who wrote a policy brief on the topic in 2011, nanotechnologies could 'make agriculture more efficient, increase yields and product quality, and thereby increase nutritional benefits'[40].

Nanotechnology has many applications in the field of agriculture that may positively impact upon the livelihoods of developing countries' farmers. In the brief, *Agriculture, Food, and Water Nanotechnologies for the Poor* [41], the IFPRI identified innovations brought about by nanotechnologies that have great potential: firstly, developing countries' agricultures could benefit immensely from the aforementioned benefits of nanotechnology-enabled solutions for water purification, making polluted water available as safe for both human consumption and food production, and permitting the removal of pesticides from water that might have been used to protect and grow crops in arduous conditions. Finally, nanoporous zeolites can be used to improve soils, thereby increasing soil water retention or porosity.

In the area of pesticides and herbicides, nanotechnologies, or more precisely nano-encapsulations of crop protection formulations, allow for a time-release mechanism and also reduce the amount of product used, thereby minimising the products' environmental and health impact whilst still

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[i] Food and Agriculture Organization. FAOSTAT. *FAO World Hunger Map. Prevalence of Undernourishment in Total Population*. Available at: http://faostat.fao.org/site/563/default.aspx

[ii] Africa Caribbean and Pacific (ACP) is a group of states that are signatories of the Cotonou Agreement with the European Union (except Cuba).

protecting crops. The biocidal properties of nanoscale silver are a further area of development of nano-enabled pesticides, and it has seen tremendous progress: in December 2011 a nano-silver-based pesticide was granted conditional approval for use by the United States Environmental Protection Agency (EPA). The use of this pesticide, produced by the Swiss company HeiQ, was considered 'in [the] public interest'[42] by the Agency.

Fertilisers also stand to benefit from nanotechnology[43]; encapsulated in nanomaterials, plant nutrients such as nitrogen can be used with increased efficiency: the nanocapsules release nitrogen only when it is 'directly internalized by the plant' and thus significantly improve crop yield. In a similar fashion nanoscale titanium dioxide could be used as a bactericidal additive to fertilisers, and nano-silica particles could be used to improve the resistance of the plants to stress.

'Potential nanotechnology applications currently in the R&D pipeline have the potential to make agriculture more efficient, increase yields and product quality, and thereby increase nutritional benefits'

International Food Policy Research Institute (IFPRI)
Agriculture, Food, and Water Nanotechnologies for the Poor
2011

One of the most promising uses of nanotechnologies in agriculture was identified by the IFPRI as being crop-monitoring: thanks to nano-enabled sensors farmers may have access to up-to-date information on their produce (*i.e.* presence of plant viruses, lack of nutrients...). This allows them to use the appropriate products to optimise the benefits of their yield, and reduce spillage and wastage. Additionally nano-enabled sensors could improve the agricultural production of developing countries by detecting contaminants in food.

To summarise, in the words of John Whitehead from the Consultative Group on International Agricultural Research (CGIAR), due to their characteristics, 'nanotechnologies could increase agricultural productivity, enhance food and water safety, boost farmers' competitiveness, and improve access to markets'[44].

4. Energy

In many developing countries access to energy is a problem; even though these countries' soils are resource rich, and even often rich in hydrocarbons, local populations rarely benefit from this wealth as they lack a viable energy distribution infrastructure. The absence of satisfactory energy distribution grids and efficient power plants, as well as the massive exportation of fossil fuels, leaves the populations of developing parts of the planet in drastic situations. On top of the issue of unstable electricity supplies, developing countries' populations use dangerous appliances, such as poorly ventilated cookstoves running on the combustion of solid fuels. Widely used in developing countries, such cookstoves are considered to be responsible for both diseases and deaths: according to the WHO the indoor air pollution caused by the combustion of solid fuel use is believed to be the origin of nearly 2 million premature deaths, while chronic obstructive respiratory disease caused by exposure to such pollution kills more than a million people a year[i]. Access to clean energy could resolve this phenomenon and should be a priority for developing and developed countries alike. Aside from the

[i] World Health Organization. 2011. *Indoor air pollution and health*. Fact Sheet N292. Available at: http://www.who.int/mediacentre/factsheets/fs292/en/

issue of pollution, electricity ought to be seen as an element of well-being. In the absence of access to electricity and light, the education of young inhabitants of developing countries is significantly hampered as they cannot study or work after sunset (which occurs early in tropical and equatorial countries).

Nanotechnology has already achieved a lot in the area of energy production, from which the developing world could significantly benefit; in the area of clean energy nanotechnologies have helped to produce cheaper and more efficient solar panels. The specific benefits of this technological development are that solar panels do not require an electricity grid for their energy to be delivered to homes, and their use is particularly well-suited to the addressing the needs of countries that are located in areas of the planet with large numbers of sun hours.

Significantly propelled by the desire of developed countries to undergo an 'energy transition' (shifting from fossil fuels to renewable energies), the achievements of nanotechnology in photovoltaic energy have been plentiful: most recently nanowire array-based solar cells delivered outstanding results in terms of efficiency[45] that were acknowledged in the internationally-recognised magazine Nature[46].

Nanotechnology has also allowed for the emergence of graphene, a one-atom thick sheet of carbon with promising applications in the field of energy production, as it features highly conductive characteristics. Carbon nanotube films have also been used by Yale University[47] to build more efficient solar panels. Silicon nanocrystals[48] are yet another technical breakthrough that might mean the creation of better solar panels. Finally, a 30 nanometre thick gold mesh has been used to significantly increase the efficiency of solar panels; the 'Plasmonic Cavity with Subwavelength Hole array', or PlaCSH, reflects less sunlight and captures more of it on cloudy days, with an estimated increased efficiency of 175% as compared to conventional cells[49]. All these nano-enabled solar cells hold the promise of cheap and efficient solar energy.

Coupled with LEDs, these efficient panels become decentralized light sources for rural areas of the developing world and contribute to the development of these regions. Locally produced energy has the potential to bring about significant improvements in living conditions to here; however, to support this system, energy storage has to be considered a key element.

Nanotechnologies are responsible for the recent developments in batteries and fuel cells: once again the research is driven by developed countries going green, but, coupled with efficient nano-enabled batteries, cheap solar panels could benefit the developing world a great deal. In this field the traditional components of a battery benefit from the improvements made by nanostructured materials: many examples are available, and researchers keep on improving battery performance with new techniques. The deposition of nanoscale aluminium oxide (Al_2O_3) on battery electrodes can significantly improve Lithium ion (Li-Ion) charge-discharge performance and lifespan[50], while silicon nanocrystals, used in solar panels, can also improve the quality of batteries[51]; meanwhile nano-enabled ceramic separators[i] improve these devices' heat-resistance and lifespan.

In addition nanotechnologies can indirectly impact the consumption of energy in developing countries: according to Dr Mohamed Abdel Mottaleb, director of the Nano Materials Masters Program at the Nile University, Egypt is subjected to energy shortages in the summer because of a lack of insulation in houses and the overuse of air conditioners. The Director of the Centre for Nanotechnology of the Nile University praised the use of nano-enabled paintings that would 'insulate the house from at least 10% of the heat coming in'; such a technological fix could reduce electricity consumption by 50%[52].

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[i] Evonik, *Scientific breakthrough: SEPARION® opens up new markets for lithium ion batteries*, Available at: http://corporate.evonik.com/en/content/product-news/lithium-ion-batteries/Pages/separion.aspx

5. Other societally and environmentally beneficial Applications of Nanotechnologies

The broad range of applications of nanotechnologies can bring tangible benefits to several other societally and environmentally beneficial areas; aside from water treatment, medical solutions, agricultural benefits and energy access, nanotechnologies have the potential to deliver positive results through the remediation of air pollution, construction materials, and more.

The problem of air pollution has become a key issue for large cities within the developing world, especially in China and India. Filtering appliances using nanotechnology can help get rid of extremely harmful particles: unlike most classic filtration systems[53], nanofiber membranes are able to filter out gaseous pollutants as much as they do volatile organic compounds (VOCs), microorganisms, and allergens[54] under the size of a micron. Applications of nanotechnology are also increasingly being used in catalysts, where they reduce the emission of harmful particles.

Nanotechnologies also allow for the improving of construction materials: the use of some nanomaterials in concrete can increase its stability; carbon nanotubes[55] and silicon dioxide nanoparticles[56] are expected to increase its mechanical durability, while iron oxide nanoparticles[57] are expected to multiply its compressive strength. The addition of nanomaterials often also enhances the thermal properties of building materials and thus can play an energy-saving role, which could impact on the energy consumption of poor countries. The use of such construction materials could especially benefit developing countries that are particularly vulnerable to natural disasters. Unconventional constructions and a lack of anti-seismic buildings exacerbated the effects of the quake and although nanotechnologies would not have completely mitigated the damage, the use of nano-enabled materials in future constructions could help to avoid such large-scale disasters.

Conclusion

Nanotechnologies offer a range of options for addressing the needs resulting from the hardships faced by developing regions; and whilst most of the nano-innovations discussed above have non-nano counterparts (*i.e.* cheap solutions exist for water treatment, alternative models of agriculture and energy production), nanotechnologies have some unique features that make their impact much greater. Chief among them is that they are cross-sectorial, rendering the options that can be offered by their breakthroughs tangible in every sector of interest for the populations of developing countries. More specifically the example of nano-enabled medicines and theranostics already shows some positive outputs for world health development because they leave the door open to converging innovation that will enable diagnosis and treatment of the diseases affecting underprivileged populations.

It has been demonstrated that nanotechnologies often enable cheap and mobile solutions that can be adapted to the needs of populations who lack the infrastructure required.

Finally, thanks to the rapid growth and evolution of nanotechnologies, the applications of nano-enabled devices and formulations presented above serve to be both impressive examples of the current improvements enabled by nanotechnologies, and to be illustrations of future innovations and improvements in making the new technological developments available to broader populations, especially those in difficult situations.

Chapter 3. Obstacles to the fair Development of Nanotechnologies

In order to bring about the positive impacts described in the previous chapter nanotechnology, like any emerging technology, needs to be both available to all and developed fairly; spreading the benefits of technological change throughout the world is a challenge that involves actors from both the public and private sectors. While the notion of a so-called 'nano-divide' is based on the belief that nanotechnologies could widen the existing gap between the developing and developed world, there are nevertheless many other factors, common to all emerging technologies, that ought to be taken into account; as a result nanotechnologies may have to overcome several hurdles in order to reach those in need and deliver their aforementioned benefits.

This chapter addresses the barriers that could prevent the fair development of nanotechnologies, as well as the potential ways to break them down. Several of these barriers are due to the nature of the nanotechnologies themselves, but some are not; rather they are linked to wider debates.

The Issue of Access

There are numerous options involving nanotechnologies that could improve living conditions in developing countries, but there are questions about how they can adequately reach the countries' populations; a number of issues may hamper citizens from gaining access to the technology, such as the fact that some nanotechnologies are developed for, and subsequently restricted to, the militaries, or simply because it is difficult for any technology to reach rural populations within developing countries and be adequately maintained.

> 'A significant divide is likely to open in regard to access to military nanotechnologies simply because those who develop them are likely to wish to keep them to themselves.'
>
> Dr Robert Sparrow
> *Negotiating the Nanodivides*
> 2007

The interest military research has paid to nanoscience has long been controversial; Quebec's Commission on the Ethics of Science and Technology (Commission de l'Éthique en Science et en Technologie, CEST), for example, has expressed concern regarding the ethical issues raised by the military's development and use of nanotechnologies[58]. This concern was echoed by the ETC group, which considers military nanotechnology to be a thriving business sector[59]. In addition the Australian ethicist and specialist in nanotechnologies Dr Robert Sparrow considers that 'those who develop [military nanotechnologies] are likely to wish to keep them to themselves'; as it stands developing countries are not likely to gain access to the benefits of military nanotechnologies developed in industrialised economies [60].

Nonetheless military research is a driver for scientific research[61] and may yet have a positive outcome for the general population as far as nanotechnologies are concerned. Five strategic research areas for improving the performance of soldiers on the battlefield were identified by the Institute for Soldier Nanotechnologies (ISN) at the Massachusetts Institute of Technology (MIT)[i] - these areas are: 'lightweight materials'; 'soldier medicine'; 'ballistic protection'; 'hazardous substance detection'; and 'protection and integrated nano-systems'. Research for garments that provide protection against chemical or biological weapons has applications in fighting air pollution, and the military could also develop water purifiers to allow deployed squads to drink clean water on the field.

[i]Institute for Soldier Nanotechnologies (ISN) of the Massachusetts Institute of Technology (MIT). *Research.* Available at: http://web.mit.edu/isn/research/index.html

In many developing countries even low-priced technologies are not available to the majority of the population[62]; new technologies sometimes cannot reach these populations due to the malfunctioning of local markets, especially in isolated areas[63], and the difficulty in gaining access to consumers often causes the failure of businesses in the developing world[64].

Furthermore, due to the difficulty in accessing otherwise basic commodities, nano-enabled devices may be considered by these populations to be 'gadgets': unnecessary and superfluous high-tech tools that would replace goods they already do not have access to. Some also see these types of devices as luxury investments[65], and its applications are therefore not considered indispensable. Nanotechnology, however, has the potential to improve every product and as such ought to be seen as a disruptive technological change rather than as just a gadget; its multiple applications comprise new and cheap solutions to some of the issues facing the developing world. In the field of medicine, for example, nanotechnologies are the origin of a number of diagnostic and therapeutic solutions that otherwise have no counterpart, and some of these come at very low prices; These kinds of applications could significantly participate in improving the living conditions of the poor. In this scope NGOs could play a role in incentivising research into pro-poor technologies that will reach the targeted populations and bring to them the benefits that could improve their living conditions.

Another barrier that could prevent access to nano-products is that, due to the existing gap in technological advancement between industrialised and poorer countries, nano-enabled products are engineered and produced in the richest areas of the globe. The development of nanotechnologies often requires clean-rooms, and such environments are seldom available in the developing world. According to supporters of the 'nano-divide', the nano-products produced by industrialised countries may not fit into the lifestyles and cultural needs of the populations in the developing world[66]; promoters of this argument claim that cultural barriers must be understood and overcome 'with the tools, resources and expertise of the social sciences and ethics'[67]. Commercial nanotechnologies are primarily developed by corporations from industrialised countries leading the global race for nanotechnology, and for this reason, the ETC Group worries that its developments will not address the needs of poorer populations. In support of this argument, the Project on Emerging Nanotechnologies[68] report, *Nanotechnology: the Social and Ethical Issues*, stated that there was a lack of incentive for developed countries' researchers to work on pro-poor nanotechnologies. The demonstration of a need for a given technology or innovation in the developing world can be put forward as an argument against this, and should strengthen the drive for companies from developing countries, who are familiar with their domestic markets, to get involved with nanotechnologies; also, it is through not-for-profit organisations that some nanotechnology applications have been brought to the developing world.

Some organisations from civil society relate the issues of the market orientation of nano-products to the distribution of fundamental research and development. According to a report by Lux Research[69], the private sector is steering research in the field of nanotechnology and, as a result, some argue that products are geared more towards maximising returns rather than benefiting the societal good[70]. Moreover blame is centred on the American university system, which has increasingly focused on technology transfer as a means of getting a return on the investments they have made in research and development[71].

As with any other type of new technology, factors related to time must not be neglected. At the current stage nanotechnologies are still in their infancy, and the first generation of nanotechnology-based products are currently reaching the markets. Nevertheless the characteristic attributes of nanotechnologies means that the market penetration of such products will be fast, and so developing countries are expected to rapidly benefit from them.

In the views of Prof. Mohammed A. Hassan from The World Academy of Sciences (TWAS), it is probable that in the short term nanotechnologies will benefit developed countries as they will have been adapted for use in culturally-relevant consumer goods[72]; in the longer term, however, nanotechnologies could nevertheless use their full potential and reach developing countries' populations. The expanding markets of low- and middle-income economies experiencing rapid economic growth[73] will soon be very attractive to industries in both the business-to business and the business-to-consumer areas, because the demand for nano-enabled products will rise.

Therefore when it comes to the issue of gaining access to nanotechnologies, it seems that developing countries and their local businesses should get involved while the technologies are still in their infancy, so that they can direct the research and products towards their needs.

A global Intellectual Property Divide

Patents are often used as an indicator for the development and maturing of a technology: by protecting and registering inventions and their inventors, patents not only promote innovation but also allow for the measuring of the development of technologies. Furthermore patents allow for the mapping of both research progress and strength of individual countries in a given technology, including nanotechnologies, and statistics from these can give a picture of which areas of the globe are active in a particular field.

A 2012 study analysed the origin of inventors in patent literature using data from the United States Patent and Trademark Office (US PTO) and on international patents applications from the World Intellectual Property Organization (WIPO)[74]. This study showed that American inventors dominated the field, representing 53% of all nanotechnology patent literature; they were followed by industrialised Asian and European countries. Emerging countries such as China and India were also present in the ranking, although the proportion of patentees that they represent is minimal. Even though this study is centred on the United States of America, the supremacy of developed countries was also demonstrated by a 2007 OECD study[75] on nanotechnology patents, based on data provided by the European Patent Office (EPO). Applicants for the period 1978-2005 were mainly from the United States (34.6%), European Union Member States (28.4%) and Japan (29.2%). In this ranking, neither China nor India were mentioned. Nanotechnology intellectual property claims, therefore, appear to be centred on a few actors only.

The intellectual property system could however be problematic when looking at specific questions about access to nanotechnologies. Difficulties faced by developing countries in gaining access to them are undermined by the defects of the intellectual property system, and some stakeholders blame the inadaptability of nanotechnology to the patenting system: the increasing patenting of nanomaterials that are simply nanoscale versions of natural elements presents ethical questions, as patenting rules supposedly forbid the patenting of naturally occurring materials[76]. The complexity of the nanotechnology patent landscape has been condemned by the scientific journal *Nature*, which stated in 2012 that the 'thicket of [nanotechnology] patents'[77] was resulting in both overlapping patent claims as well as a critical lack of visibility for patents. The authors of the article called for open-source research in nanotechnology as basic nanotechnological principles are being patented: for example, more than 1,600 US patents had mentioned single-walled carbon nanotubes at the time of the publication of the *Nature* article. The Bayh-Dole act, a 1980 law that granted universities in the United States control over their own creations, played a role in the thickening of an American patent thicket as universities would use patenting to cover their costs. This nanotechnology patent thicket is considered by the French NGO Groupe de Recherches et d'Echanges Technologiques (GRET) to be an obstacle to innovation, as the multiplicity of patents may increase the cost of access to the technology[78]. Such defects were also underlined by Dr Indrani Barpujari, according to whom patents are not an appropriate tool for measuring the development of nanotechnologies 'owing to their multi-disciplinary character, cross-sectoral applications, broad claims as well as difficulties in fulfilling the patentability criteria of novelty, non-obviousness and industrial application'[79].

The multiplication of patents is believed to 'limit the number and types of products that may become public goods', according to the Meridian Institute, which has also stated that the observed thicket could limit 'access to developing country researchers or those who would like to conduct research to benefit the poor'[80]. This criticism of the patenting system was shared by the ETC Group, which added that 'patent tollbooths' would require researchers from poorer countries to 'pay royalties and licensing fees to gain access'[81], thus blocking them from developing nanotechnologies. The UK Royal Society's and UK Royal Academy of Engineering's 2004 report on nanotechnology stated that 'there is a concern that broad patents could be granted on nanotechnologies, for example on processes for manipulating or creating materials, which would stifle innovation and hinder access to information, not least by those in the developing world.'[82] At the United Nations level, the United Nations Educational, Scientific and Cultural Organization (UNESCO) added in 2006 that excessive patenting of nanoparticles could make the creation of a useful nano-enabled product a very complex undertaking as its inventor could face 'nearly unnavigable complexity in terms of competing and overlapping patent claims'[83].

Patents can be used as indicators for the global development of nanotechnologies. They have, however, been facing issues with the appearance of a nanotechnology patents thicket. Nevertheless patents have to be renewed regularly as the lifespan of a patent decreases as innovation in the field speeds up. Nanotechnology, as a cutting-edge technology, is a quickly expanding area of science that may soon reach the public domain.

Potential Risks for developing Economies?

Problems related to access and patenting issues are significant obstacles to the dissemination of new technologies in the developing world. Furthermore it needs to be taken into account that the influence of a disruptive technology, such as nanotechnology, may impact upon several aspects of countries' economies; in a globalised world, technological breakthroughs may affect markets and induce changes that may result in potential harm for developing economies. As an example, rare earth materials, which are used in modern electronics, are massively mined in developing countries[i] whose soils are found to be rich in them, thus providing the countries with significant income; nanotechnologies, however, may change this as better materials may be manufactured and hence used as substitutes for these raw materials. This would affect one of the engines of growth in developing countries, thereby significantly impacting on their trade balance[84]. To elaborate further, carbon nanotubes and other organic semiconductors could replace the rare earth elements that are currently being used in microelectronics. A shift such as this would impact upon – for example - the trade balance of China, which is the main supplier of rare earth metals for semiconductors. Moreover carbon nanotubes could replace copper wiring[85], which is another important source of income for developing countries. Similarly nano-silicon carbide can improve tyres and could consequently diminish the demand for rubber[86].

Such concerns about the potential impact of nanotechnology on these poorer markets were first raised by scientists from the developing world in 2005, at the inaugural United Nations Industrial

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[i] US Department of Energy. *Map of the estimated rare earth reserves and deposits*. Available at: http://energy.gov/maps/estimated-rare-earth-reserves-and-deposits

Development Organization (UNIDO) Expert Group Meeting on North-South Dialogue on Nanotechnology[87]. Another oft-quoted potential risk for developing economies is that, while raw materials markets might be disturbed, the impact on the environment could be positive as nanotechnology could potentially slow down the environmental damage caused by the deforestation and mining that are often required for the extraction of raw materials. Nanotechnologies could replace them with alternative manufactured solutions that are much more efficient, requiring less of both energy and materials. To illustrate, nano forms of carbon have been identified as being more efficient semiconductors than the rare earth materials that are currently being extracted in developing countries.

The development of new technologies may also have an impact on the structure of a country's workforce. In the view of the ETC Group, nanotechnologies may impact traditional sectors in developing economies and job markets by affecting mining, factory work and farming[88]; these are three sectors that have traditionally offered work to the poor. This approach is based on the theory of 'technological unemployment' that was popularised by John Maynard Keynes[89]; the term implies that workers are made redundant due to the improved performances resulting from technological development. This theory was however criticised for its predominant focus on mechanisation, and thus the impact of mechanisation on employment was minimised[90]. As such the validity of this theory in the case of nanotechnologies is difficult to ascertain.

Importantly many of the potential risks mentioned above are not nano-specific. Rather, as with all emerging technologies, the challenges that can arise from new technologies that can disrupt the global economy are often much more than just technological; they involve the areas of education and culture as well.

Nano-specific Issues

Though new technologies face many obstacles on their path to the developing world, nanotechnologies have some of their own specific challenges to overcome. Uncertainties surround nanotechnologies and this often leads to the invocation of fantasised applications, such as human enhancement techniques that could have unforeseen repercussions on privacy and human freedom leading to worldwide eugenics and totalitarianism[91]. While nano-specific ethical problems ought to be considered, the debate is marred by fictional and non-scientifically funded theories such as that of grey goo[i].

In the context of this debate on the 'nano-divide', the uncertainties surrounding nanotechnologies may have been seen as additional reasons to hamper its development. Environmental health and safety (EHS) and occupational health and safety (OHS) issues are closely linked to nanotechnology and the toxicity of some nanomaterials is still being debated, well ahead of their commercialisation. The issues surrounding the technology and its suspected impact on human health and on the environment are, however, not specific to the developing world and efforts have to be made by both developing and developed countries, as well as by researchers and by industry, in order to produce safe-by-design nano-products that minimise risks[92].

Concerns on handling such products are present all along their lifecycles. Another issue is that some developing countries benefit economically from low standards and insufficient regulations on waste reprocessing. Along with poor recycling rates, substandard waste management could potentially cause harm to the environment[93]. Whilst environmental concerns have arisen around nanotechnologies,

[i] With the 1986 novel 'Engines of Creation', Eric Drexler invented the 'grey-goo', a fictional scenario in which self-replicating robots eat up Earth.

there is also a green component to nanotechnologies that offers waste remediation solutions and promises to optimise energy production and consumption.

Another issue has been raised in a report by the NGO International POPs Elimination Network (IPEN)[94]: the report underlines the fact that the EU has set regulations on cosmetic products and biocides to protect its populations against the adverse effects of nanotechnologies, while no African country has done the same. International corporations active in the field of nanotechnologies would therefore avoid restrictive regulations set in place by developed countries[95], thereby exposing local communities to the risks resulting from the production of nanomaterials[96]. The European Union can, however, be seen as a trend-setter and a global normative power[97], and with the largest market worldwide, the EU can impose its regulations on all exporters and thus influence the regulation of nanotechnology globally. In addition the restrictive European regulatory approaches mainly aim at informing consumers and policy-makers about this new technology with detailed notification, registration and labelling provisions. The regulatory activity of the European Union is not promoting environmentally harmful delocalisation for, in such a case, hosting the manufacture of nanomaterials could benefit developing countries as employment, skills and revenue would go along with the settling of manufacturing activities[98].

Like any other emerging technology, nanotechnology has to overcome a number of obstacles so that its development is fair. Several of the points raised by its opponents, and by supporters of the 'nano-divide' notion, ought to be closely examined. Efforts have to be made to ease up the conditions of access to innovations and its patents. The risks for developing economies are only to be related to an evolution of global economics, and the nano-specific issues that arise are often imagined; when such issues are proved, however, they have been taken very seriously by decision-makers in both the developed and developing world.

Chapter 4. Scaling the Benefits of Nanotechnology to the developing World

The most important barrier that the fair development of nanotechnologies faces lies in the access and appropriation of the technology by the poorest populations. Since 2005 nanotechnologies have been looked at by developing countries as a means to respond to a number of their local social and economic challenges[99].

Once the potential obstacles to the fair development of nanotechnologies have been identified, the route to scaling up the benefits of nanotechnologies in the most efficient way must be discussed. Technology alone cannot take up the challenge of solving the hardships of the poor; nevertheless this report has demonstrated that there are clear applications for nanotechnologies that could respond to the needs of underprivileged populations. Nanotechnologies hence ought to be seen as a viable path for improving the living conditions of the poor, and its benefits can be understood through two main perspectives:

- Nanotechnologies can be seen as a tool for improving aid and better addressing the needs of populations, or
- Developing countries could develop a local nanotechnology market and use nanotechnologies as economic tools that will close the divide and increase both the wealth and the living conditions of their populations.

Additionally globalisation allows technologies that are introduced in rich regions to reach poorer ones as they become inexpensive; this phenomenon, however, can take a long time. Furthermore it implies that developing countries will not be able to close the gap as they are left with a passive role.

This chapter questions ways in which the benefits of nanotechnologies can be scaled-up to the developing world, and how advantage can be taken of new technologies trickling-down in such a way that companies from developing countries could use them to increase the living conditions of their populations. To answer these questions this chapter first addresses the new elements that nanotechnology brings to aid; it then justifies the need for an appropriation of the technology by developing countries. Finally this chapter closes by addressing the initiatives that have been undertaken to help scale the benefits of nanotechnologies for the developing world.

How can Nanotechnologies improve Aid?

The applications of nanotechnologies presented in Chapter 2 have the potential to tackle the issues that developing countries are facing. If brought to these countries' populations they can improve their daily lives, and the aid system shall benefit from these efficient devices and appliances. There are a few reasons why nanotechnology can improve the efficiency of aid.

Nanoscience touches upon all layers of industry by bringing changes to matter itself, and can potentially improve all products currently being used by aid providers. Areas such as water purification, medicine, agriculture and energy all stand to benefit from the blossoming of nanotechnologies, and it is these sectors that ought to be considered as cornerstones for the economic and social development of poorer countries, because it is in them that they are facing important obstacles; solving issues such as access to clean water would significantly improve the living conditions of any given population. With the help of nanotechnologies, aid can provide better filters, medical devices, and solar panels.

Furthermore some of the specificities of nanotechnology make its products different from the traditional options to solving world poverty; existing non-nano-enabled appliances can be improved with nanotechnology and as such have better performance, be more sustainable and become portable. Mobile devices, for example, can be directly used by populations that are economically distant from the entire array of modern technologies; nanotechnologies could have a similar impact by allowing many more technologies to become portable. In the field of medical devices nanotechnologies open the possibility of self-testing: portable, self-assessing HIV tests that are built for a few dollars (as in the example of the aforementioned mChip[i]) perfectly illustrate how nano-products can bring their benefits to the developing world.

Similarly easy-to-use devices such as solar lamps can have an impact on the populations of developing countries; for example, thanks to solar lamps, whose efficiency is often amplified with the help of nanotechnologies, children are able to study at night. Indirectly therefore the scientific progresses in photovoltaic energy, as well as in LEDs, leads to an improved education that will most likely be accompanied by better economic results in the long term[100].

Portable water filtration devices can also significantly improve the quality of life of inhabitants of developing countries, where access to drinking water is not equally spread. As opposed to classically expensive water filtration systems, nano-enabled ones offer improved efficiency at a low cost. The improvement of access to clean water increases the health of a given population, and economic benefits can be expected to follow. Moreover access to water is an identified cause of conflicts[ii]; efficient, easily accessible filtering devices that nanotechnology enables could help in pacifying these conflicts.

Aid and charity organisations have identified the potential of nanotechnologies and some have already used them to improve the quality of their work. For example since 2009 the Bill and Melinda Gates Foundation has focused on using nanotechnologies for agriculture and in the fight against malaria[101]. Likewise it is in an aid perspective that the mChip has been successfully used in the field to detect diseases, such as HIV in Rwanda[102]. Finally, in the example of water purifiers, PureMadi is a non-profit organisation which involves local people at an early stage of the development of the technology in South Africa; in addition to bringing clean water to rural populations, the production of this water purification device has helped to stimulate the local community as the devices are produced locally[103].

Lastly, contrary to the infrastructures that have been implemented in industrialised countries for energy or water distribution, the production cost of individual water filters, solar lamps and other forms of the aforementioned innovations using nanotechnologies is believed to be low. Additionally, once spread in rural areas, these devices do not need as heavy a maintenance commitment as traditional infrastructures and networks require. The benefits of nanotechnologies are hereby twofold: devices distributed through the channel of aid could impact individual lives; and they could act as a substitute for large national networks.

Technology can improve the quality of the aid that is provided to developing countries and consequently could allow for the closing of the gap existing between developing and developed countries.

Building Nanotechnology's Capacity in developing Countries

While the poorest countries need aid to deal with the most precarious situations and natural disasters, other countries in the developing world need to foster economic growth so as to catch up with

[i] See page 10.

[ii] Pacific Institute. *Water Conflict Chronology: maps, list, chronology, sources*. Available at: http://www.worldwater.org/conflict/index.html

industrialised countries. Nanotechnologies can bring their promises to these populations via aid, but it is through the economic expansion of nanotechnologies (foreseen to reach a market size of EUR 2.6 trillion worldwide in 2014[104]) that developing countries could 'leapfrog' some stage of gradual economic and technological advancement and significantly reduce the gap that exists between them and the industrialised world. In the scenario where the developing world fails to develop its own nanotechnology, it will only be able to rely upon pro-poor businesses benefiting from its applications; it is therefore imperative to scale the benefits of nanotechnologies to the developing world so as to ensure the balanced development of nanotechnologies across the globe.

As demonstrated earlier[i] some nano-enabled devices that are invented and created in developed countries can be locally assembled in developing ones and therefore involve the local community; the scientific knowledge required is, however, still located in the countries of origin, and so for local populations to get the full benefits of nanotechnologies there is a need for the appropriation of nanoscience and nanotechnology by local scientists. The emergence of a nanotechnology market in developing countries could help strengthen these countries' economic growth and also improve the living conditions of the local populations. In order to be able to nurture such a capacity in developing countries, the following elements have to be merged:

- a favourable policy environment,
- a scientific capacity,
- an industrial capacity, and
- a reliable market.

1. Building scientific and industrial Nanotechnology Capacity in the developing World

With a market and an environment receptive to the creation of nanotechnology companies, the developing world could close the gap on the richest countries; however there would still be a need for scientific and industrial capacities in developing countries to be developed as they have been suffering from a so-called 'brain drain' (see below), along with poor education and infrastructure.

Industrialised countries have been targeting nanotechnologies with significant subsidies[105]; to the contrary, and due to their limited resources, developing countries often do not have the means to set in motion such large-scale financing, thus putting them at a disadvantage. The gap in public investment may result in developing countries seldom having the necessary facilities and infrastructure to practice this cutting-edge science; it constitutes the first barrier to the development of technology.

Crippled by the 'brain drain' phenomenon that characterises the migration of skilled workers to developed countries, where they will be able to earn more[106], developing countries do not have enough skilled workers. According to Graziano Bertogli, from the International Centre for Science and High Technology of the United Nations Industrial Development Organization (ICS-UNIDO), developing countries face high developing costs in training skilled workers in new procedures and devices developed by the industrialised countries, consequently putting the developing world at a 'definitive disadvantage'[107].

To bridge this global scientific capacity divide, people need to be trained in order to mitigate the 'brain drain'. Education in nanotechnology must be achieved locally and from the earliest age, as it is believed that this is when an impact can really be achieved[108].

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[i] Such as the PureMadi water filter mentioned page 9.

Furthermore trained nanotechnologists need local opportunities to practice: well-trained and skilled individuals often move to industrialised countries as they are offered better wages, better working conditions and better living conditions. It is in the interest of developing countries for the 'brain drain' to be reversed, and there has to be an incentive for researchers in strategic fields, such as nanotechnology, to apply their skills in these countries. The loss of skilled workers must be put into perspective by the experience and skill obtained by the scientists that have worked abroad[109]; such skilled workers must be seen as assets who can spur on the development of nanotechnologies in these countries.

Additionally, with the help of the internet, a 'brain drain' can matter less. The digital era allows for the reinforcing of capacities in developing countries through internet-based platforms and educational projects; information can be made easily accessible to scientists and technicians in developing countries, thus improving the quality of research, reducing the duplication of research, and enhancing scientific effort worldwide[110]. There are a few examples of websites dedicated to the diffusion of scientific knowledge; projects such as Research4Life[i], which offers free access to over 8,100 scientific publications, are contributing to achieving MDGs through the dissemination of science to reduce 'the scientific knowledge gap'. Such knowledge-sharing initiatives allow people in developing countries to access data from other parts of the globe. Another organisation, the Global Research Alliance[ii], is actively involved in the creation of an international network of scientists and researchers. Platforms dedicated to nanotechnologies can also be found on the internet. For example the nanoHUB[iii] contains information and tools for nanotechnology research and development. In 2010 the nanoHUB platform had been used by over 100,000 people from 150 countries[111]. Another web-based tool for nanotechnology-capacity building in developing countries is Open Source Nano[iv], which gives DIY (do it yourself) instructions for nanotechnology-based items such as water filtration devices. Finally the Meridian Institute[v] and Scidev.net[vi] provide information on nanotechnology for developing countries and contribute to the efforts in bridging the gap. It is through such initiatives that developing countries can gain access to nanoscience and its applications, and therefore develop nano-enabled products that contain solutions to the issues that they face.

Alongside their lack of scientists, developing countries lack the required infrastructure: with their R&D capacity inhibited by a lack, or shortage, of high-tech R&D equipment such as clean-rooms and analytical equipment, poor countries are not able to become active players in nanotechnology and to effectively close the gap. There are, however, a number of examples assessing the implication of developing countries installing nanotechnology facilities within their borders, and, as has been shown by the IBM-led public-private partnership (PPP) for a nanotechnology centre in Egypt[112] this lack of infrastructure can be addressed.

To assist developing countries in closing the gap industrialised countries have to foster a dialogue with local communities. According to the NGO IPEN several nanotechnology facilities are being set up in Morocco, Egypt and Kenya, while Ghana and Senegal are benefiting from the assistance of the United Nations Department of Economic and Social Affairs (UN DESA) in setting up such projects[113]. Moreover a partnership between the American State University of New York and the Zimbabwean Science and Technology Development Ministry resulted in the African country launching its

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[i] Research4life. *About*. Available at:http://www.research4life.org/about/

[ii] The Global Research Alliance. Available at: http://www.theglobalresearchalliance.org/

[iii] NanoHUB. Available at: https://nanohub.org/

[iv]Open Source Nanotechnology. Available at: http://opensourcenano.net/

[v] The Meridian Institute. Available at: http://www.merid.org/

[vi] SciDevNet. Available at: http://www.scidev.net/global/

International Nanotechnology Centre in Harare in March 2013[114]. Thanks to such international mobilisation efforts developing countries are now getting nanotechnology R&D facilities; a first step towards the emergence of a nanotechnology industry.

The issues related to the industrial and scientific capacities of developing countries in nanotechnologies should be considered as major roadblocks for nanotechnologies; yet the current dynamic for promoting better access to knowledge via the internet, and initiatives for the establishment of nanotechnology centres in developing countries, are helping to overcome these obstacles.

2. Unveiling the Potential for Nanotechnology Industries in developing Countries

Alongside the necessity for scientific and industrial capacities, developing countries could become active players in nanotechnology if they developed a local market based on the applications that their populations need (see Chapter 1). The development of such a local market would have positive consequences and could act as an engine for the economic blossoming of these countries.

Developing countries should consider themselves as markets for nanotechnologies as many applications already have a target audience there. In discussing the potential routes to reducing the development gap that divides the world, the role of the private sector must not be underestimated. Recently the phenomenon of the rapid spread of mobile telephony in the developing world was said to have been 'private sector-led but demand-driven'[115]. Likewise nanotechnology applications ought to adapt to the specificities of the markets in developing countries so as to bring their anticipated economic and social impact. In order to achieve such an objective, entrepreneurs from the developing world must take proactive action. Research and development in nanotechnology, and regional nanotechnology companies, would benefit immensely from local markets.

Developing countries have their strengths, like, for example, entrepreneurship: when markets malfunction in developing countries, people have high entrepreneurial intentions and potential. The 2012 edition of The Global Entrepreneurship Monitor Global Report states that sub-Saharan Africa has the most intense entrepreneurial spirit worldwide, and that the people there have 'positive perceptions about opportunities and capabilities'[116].

Entrepreneurs from the developing world, however, have difficulties in accessing funding. Some alternative funding methods, such as microfinance, have flourished in such countries, even though they came to a halt in 2011 according to the Microcredit Summit Campaign[117]. International funding and public-private partnerships also help companies from the developing world thrive. In addition, as some of the aforementioned nano-products have low production costs, if developing countries appropriate nanotechnologies they could have the financial prerequisite to orientate the research and the products towards their needs.

Industry clusters are also believed to be a key ingredient of entrepreneurship success[118]. For example, clusters have been organised around the software industry in India[119]. Around modern infrastructures developing world entrepreneurs could create clusters of nanotechnology companies and achieve a successful nanotechnology industry sector.

The ability of developing countries to overcome the gap could also be viewed from a legal and regulatory point of view; states have the tools to create a legal environment that allows for the creation of a sustainable and economically viable high-tech sector. Developing countries have however rarely had the financial resources necessary to set aside public subsidies for fields of technology, as has been done in the industrialised world. Nevertheless governments have legislative power and should use this tool to help local economies thrive. The legal structure of support to SMEs could, along with funding, be a levee for developing countries to open to allow nanotechnology companies to emerge; it is therefore within the capabilities of developing countries to create receptive environments for the economic development of nanotechnology.

With its disruptive characteristics, nanotechnology has the potential to improve all products: such characteristics have to be taken into account by developing countries that base their activity on large-scale manufacturing. As an example China, which has been known as the 'workshop of the world'[120], has also identified the potential of nanotechnologies and has subsequently become a globally significant actor in this field[121].

Local private sectors can improve access to useful nanotechnologies, but it is only through adapted investments in infrastructure and research[122] that nanotechnology companies will be able to bring improvements to populations in the developing world.

International Mobilisation for Dialogue and Technology Transfer

In addition to the setting-up of local markets in developing countries, international mobilisation for technology transfer contributes to the scaling-up of the benefits of nanotechnology in developing countries. Cooperation and dialogue at every level, and the involvement of many actors, are important tools in allowing developing countries to build their own science.

In order to allow for the successful and global implementation of nanotechnologies, several initiatives have been launched to foster stronger international cooperation between people from the developed and the developing world. Likewise developing countries have been organising nanotechnology cooperation amongst themselves.

1. Nanotechnology Dialogues

Cooperation starts with dialogue; in the previous decade, international *fora* tried to foster stronger communication on the theme of nanoscience between scientists from developing and developed countries. It has, however, been difficult to involve developing countries. As the French NGO GRET underlined, the lack of participation of these countries in discussing the global governance of nanotechnologies has been problematic[123]. Nevertheless numerous initiatives have been run, promoting nanotechnology for the poorest; for example Cientifica has been involved in opening the dialogue on the funding and development of nanotechnologies in developing countries - in 2009 the organisation published a white paper on *Global Funding of Nanotechnology Research and Development*[124].

Another example is the Global Dialogue on Nanotechnology and the Poor, which was launched in 2005 and it aims at achieving the non-discriminatory development of nanotechnologies across the planet; this international dialogue is supported by the International Development Research Centre (Canada), the UK Department for International Development, and the Rockefeller Foundation (US)[125]. It involves organisations and states in a dialogue to circulate scientific fixes to global issues.

On another level the series of International Dialogues on Responsible Development of Nanosciences and Nanotechnologies, also known as the 'Alexandria Process', started in Alexandria[126], Virginia, United States in 2004. These conferences aimed to initiate an international approach to the challenges raised by nanotechnology. The 2008 edition was held by the European Union and focused on discussing the regulatory issues[127] related to nanotechnology; a key issue for the fair development of the field.

Industrialised countries have been assisting developing ones in implementing regulations to protect both the environment and their workers, and in ensuring that industries in developing countries follow rules for proper and efficient production. To achieve this objective the Strategic Approach to

International Chemicals Management (SAICM), a joint initiative by the UN Environment Programme (UNEP) and the WHO, provides an arena for global dialogue on chemicals. Since 2009 it has taken the issue of nanomaterials into account. In this forum developing countries are represented and active; SAICM has held a number of conferences in developing countries in the past (Jamaica, Ivory Coast, Senegal, and Kenya).

Alongside these examples, a number of international conferences have brought the discussions on the challenges of nanotechnologies forward and involved stakeholders and decision makers from developing countries:

- The XIX World Congress of the International Labour Organization (ILO)[i], Istanbul, 2011, addressed nanotechnologies and safety and health at work to a mixed audience from developed and developing countries.
- In 2006 Zimbabwe hosted the event 'Nanodialogues'[ii]. Organised by the NGOs Practical Action and Demos, and with the participation of Lancaster University, 'Nanodialogues' aimed to find bottom-up approaches that engage local communities from both poor and rich countries.
- Other international organisations have had a close look at the potential benefits of nanoscience for the poor. The FAO and the WHO co-organised expert meetings on this topic[128].

The lively international dialogue on nanotechnology is an important element in the diffusion of knowledge and in international cooperation on the fair and safe development of nanotechnologies. Through this tool the industrialised world is involved in assisting developing countries in closing the gap responsibly as they share knowledge of the technology's benefits and drawbacks.

2. Nanotechnology Transfer

Apart from fostering dialogue, countries and organisations from the industrialised world have been actively assisting poorer countries in developing nanotechnologies. Several organisations have been taking an interest in the benefits of nanoscience for the poorest regions; the French NGO GRET emphasised the need for North-South scientific partnerships to adapt nanotechnology to local uses, and to contribute to ownership and technology transfer towards developing countries[129]. Similarly Quebec's CEST called for collaboration between Canadian universities and developing countries, for the formation of researchers, and for the support of localised research and development in developing countries.

Alongside the EU and some other states, international organisations facilitate technology transfer with developing countries; a decisive tool for the empowerment of developing countries in the area of nanotechnologies. In the EU several projects within the 7th Framework Programme for Research and Technological Development (FP7) incentivise such international collaboration[130]; it is a feature that shall keep playing an important role in the next science programme framework, Horizon 2020, which covers the period 2014-2020. Horizon 2020 is expected to focus its international cooperation targets on three major country groupings, among which are developing countries[131].

There are some examples of international cooperation in nanotechnology involving European funding. Within the Nanotechnology for Development (NANO-DEV) research project[iii], people from

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[i] XIX World Congress on Safety and Health at Work. Available at : http://www.ilo.org/global/meetings-and-events/events/world-congress-on-safety-and-health-at-work/lang--en/index.htm

[ii] Nanodialogues. Available at : http://practicalaction.org/nanodialogues-1

[iii] Nanotechnology for Development. *About the Program*. Available at: http://www.nano-dev.org/

Kenya, India and the Netherlands have sought to understand 'how nanotechnology can contribute to development'; the cooperation was partly done through ICPC Nanonet, an EU funded project in which the NANO-DEV team also participated. ICPC Nanonet's goal was, specifically, 'to provide wider access to published nanoscience research, and opportunities for collaboration between scientists in the EU and International Cooperation Partner Countries (ICPC).'[i] Likewise the projects INCONTACT[ii] and CAAST-Net had a focus on nanotechnology capacity building for developing countries[132]. European funding has also been used for infrastructure in Tunisia, where a water purification plan using nanotechnology[133] was launched in collaboration with the University of Liege and the European Commission.

With a larger scope the United Nations is able to assist developing countries through its agencies. The United Nations Institute for Training and Research (UNITAR) has helped Nigeria develop its nanotechnology research facilities together with the government of Switzerland[iii]. Similarly, under the United Nations Industrial Development Organization (UNIDO), the International Centre for Science and High Technology (ICS) works to promote the transfer of knowledge to developing countries; it is an institution which has been paying a great deal of attention to nanotechnologies since 2004 and sees 'enormous potentiality' for developing countries and their growth[134].

Finally there is a role to play for NGOs that are key actors in the promotion of pro-poor solutions of nanotechnologies. The French NGO GRET believes that financing pro-poor nanotechnologies would be an incentive for developed countries to open themselves up to the markets of developing countries and find nano-enabled solutions that address the problems facing inhabitants form the poorer areas of the world[135].

3. South-South Cooperation - Regional Engines in Nanotechnology

Whilst dialogue and technology transfer often originate from within developed countries from the so-called 'global North', countries from the 'global South', mostly comprising developing countries, are also active. In 1978 the Plan of Action for Promoting and Implementing Technical Cooperation among developing countries was launched in Buenos Aires[iv]; it followed the establishment, in 1974, of the United Nations Office for South-South Cooperation (UNOSSC) under the authority of UNDP. Since then UNOSSC has been dedicated to improving cooperation among countries within the developing world[v], and these countries have been organising themselves through South-South cooperation to reduce their dependency on the developed world. This phenomenon can also be witnessed in the field of nanotechnologies; it involves stakeholders from emerging and developing countries that are actively contributing to developing nanotechnologies so as to bridge the gap between the north and south.

Within the developing world there are several regional driving forces actively pushing poorer countries towards nanotechnology. Thanks to the ICPC Nanonet project, which recorded the number of scientific publications in the field of nanotechnology in the developing world, it is possible to have another resource for understanding the reality of the divide in the level of development of

[i] ICPCNanoNet. *About ICPCNanoNet*. Available at: http://www.icpc-nanonet.org/content/section/5/39/

[ii] Inco Wiki. *INCONTACT– One World (2010-2013)*. Available at: http://www.ncp-incontact.eu/nkswiki/index.php?title=INCONTACT

[iii] United Nations Institute for Training and Research. *Nano Pilot Project: Africa Region*. Avaiable at: http://www.unitar.org/cwm/nano/pilot-projects/AfricaRegion

[iv] United Nations, 1978. Plan of Action for Promoting and Implementing Technical Cooperation. Available at: http://ssc.undp.org/content/dam/ssc/documents/Key%20Policy%20Documents/BAPA.pdf

[v] United Nations Office for South-South Cooperation. Available at:http://ssc.undp.org/content/ssc.html

nanotechnologies (see **Figure 3**). Whilst developing countries generally have a very low number of scientific publications published, the most advanced of these are very active in the field and could act as regional drivers. Through South-South cooperation the emerging countries can deliver appropriate assistance to the least developed ones and so help them gain access to nanotechnologies.

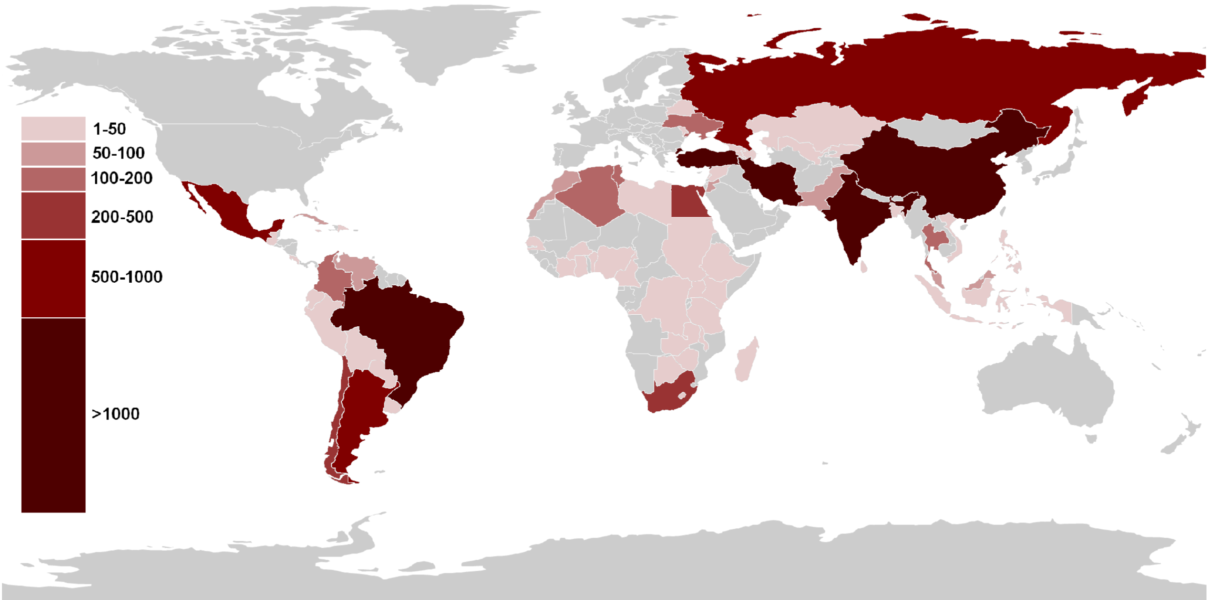

Figure 3 Publications in nanotechnology in 2009, ICPC NanoNet (source: NANO-DEV, 2012[i])

The rising awareness of nanotechnologies in emerging and developing countries reveals the potential that this science represents for their economic growth. China is already a major player in the field of nanotechnology[136], while Thailand has been reported to have invested USD 10 million in nanotechnologies in 2010. At that time, according to Dr Donald MacLurcan[ii], the country was already producing and exporting nano-enabled products in food packaging, water purification and herbal medicine[137].

Brazil has been playing a leading role in Latin America since it initiated a National Strategy for Nanotechnology in 2000. In 2010 the Brazilian Ministry of Science, Technology and Innovation estimated that Brazil had over 3,000 nanotechnology researchers, including professors and students[138]; it is via the collaboration with universities that Brazilian industries are expected to reach the forefront of nanotechnology innovation[139]. Brazil has been playing an influential role, together with South Africa and India, in the India, Brazil, and South Africa Nanotechnology Initiative (IBSA)[140] that aims to foster collaboration between these emerging countries. The initiative focuses on health, water treatment and agriculture; these are three areas of nanotechnology where the applications could directly bring benefits to the populations and economies of the developing world.

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[i] Beumer, K. 2012. Policy Brief, Nanotechnologies for Development. Available at: http://www.maastrichtsts.nl/wp-content/uploads/2012/04/Beumer-NANO-DEV-Policy-Brief-April-2012-Nanotechnologies-for-development.pdf

[ii] Dr McLurcan is the co-founder of the Post Growth Institute; he worked on the impact of nanotechnology on the global inequity.

In the Middle East the regional leader in nanotechnology is Iran. In order to be influential amongst Islamic developing countries, the country founded the Organisation of Islamic Cooperation's Standing Committee on Scientific and Technological Cooperation (OIC-COMSTECH). With the help of the World Academy of Science (TWAS) and the Joint Research Grants Programme, Iran pushes forward the dialogue on nanotechnology[i]. The country also plays an important role in the Nano Technology Network of the Organization of the Islamic Conference (NTNOIC), a global discussion area for nanotechnologies[141].

In Africa research and development has been led by an emerging South Africa, which in 2002 launched its support for nanotechnologies with its South African Nanotechnology initiative; this was only two years after the massive investment plan initiated by the US' National Nanotechnology Initiative in 2000. The South African strategy focuses on health, water and energy as a first pillar, while the second one supports the chemical and mining industry[142]. Facilities built under this plan have provided the country with state-of-the art instruments, and the country now hosts the top African universities in the field of nanotechnology[143]; South Africa therefore acts as the driving force of nanotechnologies in Africa. The potential of nanotechnologies has also been identified by Nigeria; Nigerian academia believes that 'nanoscience and advanced manufacturing technology will provide the nation with new frontiers [with which] to bridge the technological divide in Nigeria'[144], and the country is showing increased interest in the issue. Further African countries have also launched their own nanotechnology initiatives, like Zimbabwe or Kenya[145].

At the regional level Africa currently hosts a couple of initiatives to foster the development of nanotechnologies, and even though they are African initiatives they often involve actors from the industrialised world. For example NANOAFNET, the Nanosciences African Network, is the African continent's voice in the emerging field of nanosciences and nanotechnology'[ii]; this initiative was created in 2005 in Trieste, Italy, under the joint patronage of the Abdus Salam International Centre for Theoretical Physics (ICTP), UNESCO, the International Atomic Energy Agency (IAEA), TWAS and the ICS-UNIDO, it is supported by several international agencies. Likewise the African organisation Focus Nanotechnology Africa Inc.[iii] (FONAI) has ambitiously decided 'to combat the 'brain drain' from Africa and all forms of poverty including science and technological poverty'. It has managed to gather actors from across the globe so that it can establish 'a first-of-a-kind nanosciencetech-academy', as well as a nanotechnology journal. In order to actively close the gap, it also claims to have managed to mobilise large sums of money from industrialised countries and international organisations projects. Another initiative is the African Network for Solar Energy (ANSOLE)[iv], in which Austrian authorities are involved.

Several developing countries are at the forefront of nanotechnology and are trying to act as regional drivers. Nevertheless the situation is very different from any given country to another; regional dynamics may help with the inclusion of the least developed countries in the global diffusion of nanotechnologies. Moreover the large variety of actors involved in the development of this technology underlines the interest that it generates all over the planet.

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[i] The World Academy of Sciences. *TWAS-COMSTECH Joint Research Grants*. Available at: http://twas.ictp.it/prog/grants/twas-comstech-joint-research-grants

[ii] Nanoscience African Network Mission. Available at: http://www.nanoafnet.tlabs.ac.za/

[iii] Fonai. Available at: http://fonai.org/Home_Page.php

[iv] Ansole. Available at: http://www.ansole.org/

Benefits of nanotechnologies could be brought to developing countries via the traditional channels of aid; however, in order to truly achieve the goal of improving the living and socio-economic conditions of populations from such countries, it is imperative that they seize the opportunity and appropriate nanotechnology. Such an appropriation requires scientific and industrial capacities as well as favourable market conditions. To therefore achieve the objective of the developing world independently building nanotechnology for its own purposes, countries should engage in international mobilisation that can initiate dialogues, technology transfer and South-South cooperation.

Chapter 5. Conclusion

The global issue of poverty and difficult living conditions is a complex challenge that countries and organisations worldwide have been tackling for decades. This challenge, however, is multi-faceted, and responding to it requires a similar solution. Nanotechnologies offer several options for developing countries and their populations; however, a response to the global divide shall not be limited to nanotechnologies. Whilst nanotechnologies will not widen an existing gap, they bear the potential to significantly improve the living conditions of the poorest.

The beginnings of a disruptive new technology, such as nanotechnology, are set to affect the distribution of global wealth; nanotechnologies have applications that can improve every product, some of which could represent appropriate responses to the needs of underprivileged populations in the developing world. Nanotechnologies are thus foreseen to deliver a positive impact on the reduction of global poverty and poor living conditions through new applications and devices that directly influence the lives of the populations; low-priced, such devices are set to improve water quality, to facilitate the diagnosis and treatment of diseases, to increase the efficiency of agriculture, and to optimise energy consumption and production. Additionally the economic weight of nanotechnology is forecast to be major; companies as well as populations could immensely benefit from it in terms of economic prosperity and employment. Even though the technology requires advanced tools and well-trained people to research, develop and commercialise it, developing countries have already been showing interest and progress in nanotechnology as a means to responding to their societal challenges and also improving their economic performance.

Technology alone can nevertheless not be held accountable for the widening or closing of the gap that separates the richest countries from the poorest as several political and socio-cultural factors act independently from technology. In order to make the best out of nanotechnologies for the developing world, a number of obstacles require attention. In the complex setting of globalisation, the advent of nanotechnologies may not benefit the poorest if some issues are not addressed and, most importantly, if the developing world is not able to seize the opportunity of appropriating nanotechnology for its own uses. In addition uncertainties concerning the environmental repercussions of those new products must be addressed.

The impact of nanotechnologies shall not be the same for the emerging countries that are actively closing the gap and already investing in them, and the poorest countries that only receive the benefits of nano-products through the channels of international aid. Nevertheless the growing influence of emerging countries, such as those who make up the BRICS block, gives them the ability to drive nanotechnology developments in the developing world, and, via South-South cooperation, emancipate themselves from the industrialised world.

Developing countries also benefit from the expansion of the internet, which has made access to information, and especially scientific information, almost universal. In addition authorities have been willing to discuss and to share perceptions and experiences through international dialogues, which is to the benefit of all.

Nanotechnology is still in its infancy and will take time to deliver on its promises. The developing world will also need time to appropriate the technology so as to make the most out of it and to boost its economies. Global inequality shall not be widened by nanotechnology in and of itself; nevertheless nanotechnology offers a positive influence in reducing the divide between the rich and the poor by providing new approaches to tackle the challenges faced by the developing world, and as such its impact will vary according to how it is implemented.

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Nanotechnology
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The NIA, Nanotechnology Industries Association, is the sector-independent, responsible voice for the industrial nanotechnologies supply chains; it proactively supports the ongoing innovation and commercialisation of nanotechnologies and promotes their safe and reliable advancement.

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