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Strategic foresight for the post-2015 development agenda

Report of the Secretary-General

Executive summary

This report identifies, analyses and presents for discussion key issues concerning the role of strategic foresight for policymakers, particularly in developing countries. Chapter II provides an introduction to strategic foresight and its use around the world. Chapter III presents key trends related to science, technology and innovation (STI) that are likely to be relevant for development in the post-2015 period, based on the findings of the meta-analysis of recent foresight reports and inputs from international foresight experts, together with a critical assessment of their potential socioeconomic and development impacts. Chapter IV highlights key policy lessons. Chapter V presents findings and suggestions for consideration by national Governments and other relevant stakeholders.

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Introduction

1. The Commission on Science and Technology for Development (CSTD), at its seventeenth session in May 2014, selected strategic foresight for the post-2015 development agenda as one of two priority themes for the 2014–2015 intersessional period.

2. To contribute to a better understanding of this priority theme and to assist the Commission in its deliberations at its eighteenth session, the CSTD secretariat convened a panel meeting in Geneva, Switzerland, from 26 to 28 November 2014. This report is based on the findings of the intersessional panel, including the expert discussions held during the strategic foresight café organized within the framework of the panel, national reports contributed by members of the Commission and inputs from experts in different regions.

I. Strategic foresight in theory and practice[1]

3. Strategic foresight (also referred to as technology foresight or future-oriented technology analysis) is the systematic assessment of STI in the long term and their potential impacts on society, with a view to identifying areas of scientific research and technological development likely to influence change and produce the greatest societal benefits.

4. As the most upstream element of the technology development process, foresight provides input to technology strategies, policies and plans by proposing pathways to reach a defined vision. Foresight thereby guides the development of technological infrastructure, supports innovation and provides incentives and assistance to enterprises in the domain of technology management and transfer, leading to enhanced competitiveness and growth.

5. Strategic foresight exercises are prepared based on a participatory process that involves structured debate among policymakers, experts, industry and civil society representatives and other stakeholders, leading to a shared understanding of long-term issues. Assessments can be conducted using one or a combination of several methodologies to systematically gather anticipatory intelligence from a wide range of knowledge sources.

A. Common foresight methodologies

6. Various foresight methodologies are used in different countries around the world. The sharing of foresight experiences is part of a research process called mapping, which involves the systematic monitoring and analysis of foresight practices, players and outcomes. Recent foresight mapping work suggests rising interest in strategic foresight, mainly because forward-looking activities have become more than merely tools to support policy or strategy development in STI. The constantly expanding scope of foresight involves a wider range of objectives, including analysing the future potential of STI, promoting network-building, setting priorities for STI, supporting methodology and capacity-building and generating shared visions. In addition, mapping efforts show that multi-scope or multipurpose foresight is now a common phenomenon.

7. The mapping of foresight practices has helped to identify methods that are widely used globally. An examination of close to 1,000 exercises from around the world shows

[1] L Georghiou, JC Harper, M Keenan, I Miles and R Popper, 2008, *The Handbook of Technology Foresight: Concepts and Practice* (Cheltenham, Edward Elgar Publishing).

that the top ten most widely used foresight methods are the following, in order of occurrence: expert panels, scenarios, trend extrapolation, futures workshops, brainstorming, Delphi,[2] interviews, key technologies,[3] questionnaires and/or surveys and strengths, weaknesses, opportunities and threats analyses.[4] Two of the most important factors influencing the selection of methods are their nature (qualitative, quantitative or semi-quantitative) and mix (dependence or influence on other foresight methods). Qualitative approaches are favoured, while some methods are more suited to being used together, such as the frequent use of brainstorming as an input for the Delphi method.

8. Information and communications technologies are increasingly applied to most foresight approaches, especially interaction and evidence-based activities. Many applications are available to support modelling, data mining, scanning, participatory processes and visualization, such as online surveys, big-data analysis, web-based horizon scanning and creativity platforms.

B. Strategic foresight around the world

9. A mapping analysis of the top ten foresight methods per region has revealed regional features, such as the frequent use of the key technologies methodology in Southern Europe and North America.[5] Other regional practices are noted in this section.

Europe

10. Foresight exercises in Europe emphasize both anticipating and collaboratively shaping the future through coordinated governance and decision-making. Foresight is increasingly practised in an institutionalized form and there is growing interest in sharing foresight experiences, for example through the European Foresight Platform and the International Foresight Academy.

11. Some countries, such as France, have a rich history of futures work that stretches back several decades and still influences current practice. Others, for example Ireland and the United Kingdom of Great Britain and Northern Ireland, have a shorter history influenced by technology foresight and sustainable futures traditions. In Eastern Europe, little legacy remains of the communist era tradition of futures thinking in the context of State central planning. Recent work has been heavily influenced by technology foresight practices in Northern and Western Europe. The European Commission and the United Nations Industrial Development Organization have played important roles in this policy tool transfer. Activities in Southern Europe began relatively recently, with over half represented by technology foresight exercises in Spain.

[2] The Delphi method "entails a group of experts who anonymously reply to questionnaires and subsequently receive feedback in the form of a statistical representation of the group response, after which the process repeats itself. The goal is to reduce the range of responses and arrive at something closer to expert consensus" (Rand Corporation, 2015, Topics: Delphi method, available at http://www.rand.org/topics/delphi-method.html (accessed 13 February 2015)).

[3] This method identifies the most influential technologies over a specific time period, to set research and development priorities.

[4] Analysis undertaken by R Popper on data of the European Foresight Monitoring Network (2005–2009), iKnow (2008–2011) and European Foresight Platform (2009–2012). See http://www.foresight-platform.eu/ and R Popper, 2008, How are foresight methods selected? *Foresight*, 10(6): 62–89.

[5] S Bitar, 2013, *Why and How Latin America Should Think About the Future* (Washington, D.C., Inter-American Dialogue) and M Keenan and R Popper, 2008, Comparing foresight style in six world regions, *Foresight*, 10(6): 16–38.

Latin America

12. Foresight in Latin America has evolved slowly but progressively. Many countries have launched national programmes and projects incorporating concepts and techniques from a wide range of international foresight exercises, mainly from Europe. However, the region has also achieved its own foresight style due to the creative use of limited resources, which has at times resulted in effective innovations in practices and tools, from new management systems and online support tools to new ways of achieving stakeholder commitment. International organizations, such as the Organization of the Andrés Bello Agreement on Educational, Scientific and Cultural Integration, United Nations Economic Commission for Latin America and the Caribbean, United Nations Industrial Development Organization and, more recently, the European Commission, have also played a key role in supporting foresight programmes and capacity-building activities in the region.

North America

13. Many of the most popular foresight methods were developed in the United States of America in the 1950s and 1960s and used extensively in both the public and private sectors. Much foresight activity is conducted at State and federal levels in Canada and the United States. The National Intelligence Council of the United States produces a global trends report to shape strategic conversations within and beyond Government. Sectoral technology road map exercises are particularly popular among United States firms.

Asia

14. Japan pioneered the development of national technology foresight and, since 1970, has used the Delphi method to forecast and shape future technological trajectories. Besides having an influence in Europe, experiences in Japan inspired similar exercises in China and the Republic of Korea and in South-East Asia. In the context of the Asia-Pacific Economic Cooperation forum, the Centre for Technology Foresight was set up in 1998 to conduct region-wide studies and develop capabilities in member countries, work largely influenced by practices in Australia, Japan, North America and Northern and Western Europe.

Africa

15. Most foresight exercises in Africa are sponsored or conducted by international organizations, such as the African Development Bank, European Union, Food and Agriculture Organization of the United Nations, International Food Policy Research Institute, Joint United Nations Programme on HIV/AIDS and United Nations Development Programme. The majority of exercises consider Africa as whole and only a few focus on individual countries.

II. Key trends in science, technology and innovation in relation to the post-2015 development agenda

16. The post-2015 development agenda will embody a universal vision to end poverty and transform the world to better meet human needs and the necessities of economic transformation, while protecting the environment, ensuring peace and realizing human rights. The CSTD has noted that in the global quest to shape this agenda, the important role of STI in realizing development aspirations needs to be strongly articulated.[6]

[6] E/CN.16/2014/2.

17. The CSTD, as the torch-bearer of STI issues in the United Nations system, has stressed the importance of creating STI capabilities, promoting entrepreneurship and strengthening innovation capacities as relevant to fostering inclusive and sustainable development. In the context of its priority theme on strategic foresight, the CSTD secretariat organized a horizon-scanning exercise with input from international foresight experts to identify key STI trends that have the potential to contribute to the post-2015 development agenda and sustainable development goals.[7] These trends were discussed at the 2014–2015 intersessional panel, including expert discussions held during the strategic foresight café, and are encapsulated under the following five areas addressed in this chapter: natural resources, energy, climate change, convergence and urbanization.

A. Technologies related to natural resources

18. Industrial and technological developments, as well as changing consumption patterns associated with growing economies and prosperity, contribute to the increasing demand for both renewable biological resources and non-renewable stocks of minerals, metals and fossil fuels. The world is a closed material system, with finite limits on the amount of resources available. Resources are not scarce in absolute terms, yet they may be unevenly distributed globally, making access uncertain and potentially fostering conflict.

19. Innovation plays a complex role in shaping the demand for and supply of resources. Groundbreaking technologies can create new uses for resources and new ways to locate and exploit deposits, potentially increasing the burden on the environment. But innovation can also enable societies to reduce their use of finite and polluting resources and shift towards more sustainable alternatives. The impact of intensifying global competition for resources will therefore depend greatly on whether technological development can be steered towards establishing more resource-efficient ways of meeting the needs of societies. The following sections consider potential technologies that may be useful in managing food and water resources more efficiently.

1. Food

20. Changing demands and uses for agricultural products are driving subsequent changes in food production. As diets shift from cereals-based towards more protein, fat and sugar-based diets and plant-based energy production increases, a nexus forms between differing interests with regard to quality and quantity increases of food, environmental capacity for agriculture, climate change adaptation, economic accessibility of food and increased vulnerability. The following four key technology trends are considered in the context of ending hunger, achieving food security and increasing agricultural productivity: nanofood; cultured meat and efficient animal production; information and communications technology used in agricultural production; and functional foods.

21. Nanofood applications cover the entire food chain process and can result in decreased inputs and waste, increased productivity in agricultural processes and improved

[7] In coordination with V Carabias-Huetter, Lecturer of Technology Foresight at the Institute of Sustainable Development, Zurich University of Applied Sciences, with input from experts from the International Foresight Academy and the European Commission, including Y Blumer, M Hoppe, H Spiess, D Wemyss and C Zipper from the Zurich University of Applied Sciences, K Haegeman from the Joint Research Centre of the European Commission, R Johnston from the University of Sydney, I Mariani, B Park from the Science and Technology Policy Institute of the Republic of Korea and R Popper from the University of Manchester.

quality and safety of food and water supplies, culminating in higher efficiency in food processing.

22. The increasing demand for meat in developing countries can be met through intensification of production, among other solutions. Intensification includes growth-enhancing technologies that have led to improved efficiency and lower environmental impacts. Vaccines are available for livestock, to protect people and animals from harmful pathogens, but cost-effective production and distribution systems are lacking. Meat alternatives such as in vitro manufacturing of meat products through tissue-engineering technology are also available.

23. Sensors are increasingly used for the real-time tracking of animals, crops and machines. Automation of specific tasks by robots or microrobots improves harvesting, picking, weeding and irrigation. The use of mobile telephones and tablet computers provides farmers, as well as suppliers, retailers and policymakers, access to markets, fertilizer sources and weather reports. The use of mobile technology and other information and communications technology applications can also make a difference in farmers' incomes. Currently available services include market (price) information, local weather forecasts and disease diagnostics. The further penetration of mobile networks (second-generation and also, increasingly, third and fourth-generation technologies) is expected to open new opportunities for supporting rural areas.

24. Functional foods have optimized nutritional aims to supply dietary requirements for improving bodily health, decreasing health risks and even curing diseases. Such foods were first developed in Japan in 1991 for specified health uses and to combat increasing health care costs. They can contribute to improving the quality of life of ageing populations.

25. Food security remains a problem in developing countries, particularly in terms of nutritional quality. Developing countries have high agricultural potential that can only be realized through improvements in efficiency. Step-change improvements in productivity help ensure food security and continuous technological inputs help maintain increases in yields. Nanotechnology applications can also contribute significantly to food security by increasing the competitiveness of food producers and improving their market access. Process improvements in meat production may be efficient enough to cover global demand and may have financial, health, animal welfare and environmental advantages over traditional meat. However, it may take time for societies to become accustomed to alternative meats, particularly due to the perception that the production process is unnatural.

2. Water

26. Some of the most challenging water-related problems that may be addressed by technology are water scarcity, particularly due to groundwater depletion, water quality in developing countries, access to water and sanitation in rural and urban settings and the recycling of materials.[8] Deployment of water supply and sanitation infrastructure in developing countries must be accelerated through innovative options that consume less water, energy or capital. Current technological trends focusing on decentralizing sanitation and wastewater filtration to recover energy and nutrients can help increase access to water and sanitation and also improve water quality. The following are three promising technological developments aimed at improving the management of water resources:

[8] For an in-depth discussion on agricultural water management, see United Nations Conference on Trade and Development (UNCTAD), 2011, *Water for Food: Innovative Water Management Technologies for Food Security and Poverty Alleviation* (New York and Geneva, United Nations publication).

decentralized and sustainable sanitation; energy and nutrient recovery from wastewater; and drinking water and wastewater treatment via membranes and advanced water filtration.

27. New sanitation systems in developing countries address the costs and institutional problems associated with infrastructure expansion and connection to a centralized piped wastewater treatment plant. Sustainable sanitation systems consider the entire service chain, as well as end products, and eliminate pathogens. They often incorporate hand washing or flushing and use new treatment materials and methods such as sand, soil and urine separation, incorporating energy recovery, nutrient reuse and ecological sanitation.

28. The energy and nutrient content of wastewater may be captured and recovered for reuse. Anaerobic digestion processes for wastewater and solids can be used to produce energy, such as a methanol-based biogas. Microbial fuel cells have begun to be used to produce electricity, through the metabolism of microorganisms that treat wastewater. Phosphorus and nitrogen are found in appreciable concentrations in biosolids and urine. Therefore, end products may be composted or phosphorus may be directly recovered, via chemical precipitation, pyrolysis or other means.

29. Separation processes that remove pollution, salts or solids from fresh water or wastewater allow for the safer reuse of water and have the potential to be economically productive, while employing previously unusable sources. Nanotechnology for filtration, membrane filtration and seawater desalination are advancing in technical and economic feasibility. New designs include forward osmosis and high-efficiency energy recovery and the integration of renewable energies such as solar.

30. Long-term durability is expected to be achieved in sanitation by minimizing health risks and environmental impacts, with low upfront costs. Decentralized energy and fertilizer sources can contribute to economic development. However, infrastructure constraints on implementation may arise when new technologies involve the renovation of current sanitation systems. Cheaper, smaller and energy-efficient treatment devices allow access to clean drinking water by a greater population, which improves economic productivity, overall health and environmental quality. Nanofilters are likely to be employed in developing regions of the world to provide potable water by 2020.[9]

B. Sustainable energy systems

31. The energy system consists of three interlinked components. On the demand side there is a need for energy services and specific energy carriers, such as for fuels or electricity. On the supply side there are a variety of potential energy sources, whether fossil fuel-based or renewable. The interface of supply and demand is a complex system of local and global markets, transport infrastructures (including the electricity grid) and institutions (such as transmission system operators), which ensures that energy production matches demand. The energy system therefore requires infrastructure that entails high upfront costs and long life cycles, usually decades, involves a variety of actors and is affected by several non-technical factors such as regulatory constraints and consumer lifestyles.

32. According to the International Energy Agency, global energy demand will grow significantly in the coming decades, mainly in developing countries. Energy demand in developed countries is expected to stabilize in the medium term. A number of technological trends are expected to contribute to cheaper, more sustainable, resilient and integrated energy systems in the next few decades. The overview of technology trends in this section

[9] R Silberglitt, PS Antón, DR Howell and A Wong, 2006, *The Global Technology Revolution 2020, In-depth Analyses* (Santa Monica, Arlington and Pittsburgh, Rand Corporation).

is structured according to the three components of an energy system and highlights the challenge for policymakers, which is to address the growth in global energy demands while simultaneously moving to more sustainable energy systems.

1. Demand for energy

33. Energy efficiency, mainly of industry and transport, is expected to increase gradually, driven by technological developments and cost considerations. Annual incremental energy efficiency investments in transport, buildings and industry is projected to increase by about $336 billion up to 2029, frequently involving the modernization of existing equipment.[10] Such measures might bring a return on investment once the respective amount of energy has been saved. Bioenergy can play a critical role in climate change mitigation, but there are challenges such as the sustainability of practices and the efficiency of bioenergy systems. Energy efficiency improvements are expected to be economically viable in the long term due to budget relief from fossil fuel costs and a reduced need for generation capacities. Meanwhile, in developing countries, population and economic growth may diminish the impact of efficiency improvements and there may be fewer resources available to invest in energy efficiency.

34. In developed countries, where a reliable supply of electricity is widely guaranteed, future increases in demand may be due to the widespread implementation of electric cars (e-mobility) or heat pumps. In developing countries, demand is expected to be driven mainly by more widespread use of information and communications technology, which will enable broader access to markets, communications and information exchanges and new economic potential through service provision, towards increased quality of life. Increased electrification in developing countries and the spread of the use of clean fuels for cooking and heating is expected to yield large health benefits. The transition from the traditional use of biomass and a more efficient combustion of solid fuels will reduce air pollutant emissions such as sulphur dioxide, nitrogen oxide, carbon monoxide and black carbon.

35. Construction standards for buildings in growing urban areas considerably impact energy demand, such as for heating and cooling, and the development of energy infrastructure, such as an electricity grid. Adoption of very low-energy building codes and appliance standards for new buildings is expected to lead to energy cost savings, emission reductions and considerable and diverse side benefits. Residential consumers account for a large share of global energy demand, representing up to 40 per cent of consumption in developing countries.[11] In the next 30 years, urban migration in developing countries is expected to demand high levels of new housing infrastructure, with the associated energy infrastructure. In some developed countries, applied standards have already contributed to a stabilization of, or reduction in, total energy demand for buildings. The European Union has set a target that all new buildings should be nearly zero-energy by 31 December 2020.[12]

2. Supply of energy

36. Extraction of unconventional fossil fuel sources, such as shale gas, oil sands and coal-based natural gas, has dramatically expanded in the past decade. This considerably

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[10] Intergovernmental Panel on Climate Change, 2014, *Climate Change 2014: Mitigation of Climate Change* (Cambridge and New York, Cambridge University Press).

[11] L Pérez-Lombard, J Ortiz and C Pout, 2008, A review on buildings energy consumption information, *Energy and Buildings*, 40(3): 394–398.

[12] European Parliament and the Council of the European Union, 2010, Directive 2010/31 on the energy performance of buildings, 19 May, available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF (accessed 13 February 2015).

extends the static lifetime of fossil fuels, i.e. the reserve volume divided by current annual consumption. Unconventional sources became economically interesting as a result of both technological developments (such as horizontal drills, hydraulic fracturing, multilateral wells and microseismic monitors) and higher energy prices. While unconventional source reserves function as a buffer for price increases in fossil fuels, they do so only in the medium to long term, due to the time lag between exploration and production.

37. Renewable energy sources such as the sun and wind are generally carbon neutral and can be implemented in a decentralized manner, rapidly brought online and used to connect regions. However, the impact of such sources in different regions depends on local availability, a key determinant of the costs of generation. Large subsidization efforts have been made to bring renewable energies up to scale, such as direct government subsidies for technology, feed-in-tariffs and external financing, for instance for climate change mitigation. Relatively established renewable energy technologies, such as in biogas, wind and solar energy, are expected to mature further, which will bring down their costs and reduce their implementation risks. Production from these sources is expected to increase considerably in the next decades from the status quo of almost 20 per cent to up to 65 per cent by 2050.[13]

38. Many renewable energy technologies, such as wave, tidal and geothermal energy, biomass and nuclear fusion, have not yet reached widespread industrial commercialization. As subsidies, advantageous economic conditions, consumer acceptance, incremental innovation or technology scaling develop, these technologies may also expand. Energy intensity reductions of about 20 per cent may potentially be realized through innovation.

3. Interface of energy demand and supply

39. New challenges from renewable energy arise where the supply and demand sides of energy meet – i.e. in transport, delivery, storage and consumer services – for instance in large-scale intermittent power generation, which will either require additional reserve capacities or demand-side management measures to ensure adequacy of supply. In addition, new technologies such as affordable solar power panels or (bio)gas-fired microturbines may empower consumers to become prosumers, leading traditional supply chains to resemble networks. One of the biggest challenges in electricity supply, therefore, is managing the grid to accommodate intermittent and decentralized production along with centralized production, as well as flexible prosumers and consumers and storage capacities. The following three technological trends enhance this interface: smart energy systems; the development of energy transport infrastructure; and energy storage.

40. The advancement of information technology services and the mining of big data have led to the personalization of energy use for end customers. Intelligent devices that measure energy use, provide instant feedback, adapt to individual lifestyles and respond to changes in the energy grid all result in demand that is more adaptable to current energy situations and more responsive to energy use. Smart energy systems help consumers become more energy efficient through better information transfers. In addition, the integration of decentralized renewable energy into the grid is possible with relevant grid codes, i.e. operational practices that account for interruptions from generators of renewable energy. Many countries are adapting transmission grids to be able to integrate higher shares of variable renewable power.[14]

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[13] International Energy Agency, 2014, *Energy Technology Perspectives 2014: Harnessing Electricity's Potential* (Paris).

[14] International Renewable Energy Agency, 2014, *REmap 2030: A Renewable Energy Roadmap* (Abu Dhabi).

41. The development of energy transport infrastructure entails high upfront costs and requires long-term financial viability. It is a crucial factor in the integration of renewable sources. In Europe, for example, it requires building a high-voltage electricity grid that is capable of connecting large-scale renewable electricity production sites in the North Sea (offshore wind power) and North Africa (solar thermal power) with demand hotspots (mainly large European cities) in a robust way. In developing countries, the use of decentralized off-grid electricity systems is promising, although they require storage or high flexibility in demand in order to avoid the need for costly transmission systems and to minimize grid power losses over long distances.

42. New energy storage technologies will greatly facilitate renewable energy integration, which may be a necessary flexibility for rural energy provision. In contrast to oil products and natural gas, storage systems will become ever more important for electricity in particular, as it is difficult to stockpile and its production and consumption need to be balanced at all times since there is no buffer in the grid. Storage systems include traditional approaches such as pumped hydropower, but also technological options that are not yet available on a large scale mostly due to cost constraints, such as batteries, supercapacitors or fuel cells that can be powered by hydrogen.

C. Technology for climate change mitigation, adaptation and carbon offset

43. Technology plays an important role in combating climate change and its impacts, as assessed by the Intergovernmental Panel on Climate Change and the Organization for Economic Cooperation and Development, among others.[15] The policy scenarios investigated by the Organization for Economic Cooperation and Development model different technology pathways to reduce emissions and achieve a 450 parts per million emission pathway with the same timing of emission reductions but assuming different patterns of technological development, as follows:

- 450 accelerated action: All technologies available for keeping mitigation costs as low as possible, within boundaries set by capacity constraints
- Low efficiency and renewable sources: Assumes lower efficiency improvements in energy use compared to default assumptions under 450 accelerated action scenario, through lower level of improvement of energy inputs in production and slower increases in production from renewable sources
- Progressive nuclear phase-out: Assumes nuclear capacity currently under construction and planned until 2020 will be built and connected to the grid and that after 2020, no new nuclear units will be built, in order that world total capacity by 2050 will be reduced due to natural retirement of existing plants
- No carbon capture and storage: Assumes no greater use of carbon capture and storage technologies beyond levels projected under 450 accelerated action scenario [16]

44. In the short term, until 2020, altering the set of climate change mitigation technologies results is expected to result in only limited changes in the mix and level of electricity generation. In the longer term, to 2050, the role of renewable energy technologies is expected to be more pronounced, and renewable electricity is projected to supply about half the needs in member countries of the Organization for Economic

[15] Intergovernmental Panel on Climate Change, 2014, and Organization for Economic Cooperation and Development, 2012, *Environmental Outlook to 2050* (Paris).
[16] Organization for Economic Cooperation and Development, 2012.

Cooperation and Development and in China, Brazil, India, Indonesia, the Russian Federation and South Africa, which will also rely on capital-intensive nuclear and fossil-fuel plants with carbon capture and storage. The Organization for Economic Cooperation and Development states that the "results reveal strong complementarities between nuclear and fossil fuels (with or without carbon capture and storage) in most regions".[17] Under the progressive nuclear phase-out scenario, China, Brazil, India, Indonesia, the Russian Federation and South Africa in particular may face a gap in electricity generation.

45. Decarbonizing (i.e. reducing the carbon intensity of) electricity generation is a key component of cost-effective mitigation strategies to achieve low stabilization levels. Mitigation scenarios with policies that stabilize atmospheric concentrations in the range of 430 to 530 parts per million carbon dioxide equivalent by 2100 lead to substantial shifts in annual investment flows during the period 2010–2029 compared to baseline scenarios. During this period, annual investment in conventional fossil-fuel technologies associated with the electricity supply sector is projected to decline by about $30 billion, while annual investment in low-carbon electricity supply (i.e. from renewable sources, nuclear and electricity generation with carbon capture and storage) is projected to rise by about $147 billion.[18]

46. Greenhouse gas emissions from energy supply can be reduced significantly by replacing current coal-fired power plants with modern, highly efficient natural gas combined-cycle power plants or combined heat and power plants, provided that natural gas is available and fugitive emissions associated with extraction and supply are low or mitigated. In mitigation scenarios reaching atmospheric concentrations of about 450 parts per million carbon dioxide equivalent by 2100, power generation from natural gas without carbon capture and storage acts as a bridge technology, with deployment expected to increase before peaking, then falling to below-current levels by 2050 and declining further in the second half of the century.

47. Power plants with carbon capture and storage are expected to become competitive around 2030 and increasingly so by 2050 in member countries of the Organization for Economic Cooperation and Development and in China, Brazil, India, Indonesia, the Russian Federation and South Africa. Under the no carbon capture and storage scenario, switching to alternative technologies, including renewable energy sources, would likely increase electricity prices and alter consumption patterns. Under each scenario, technological and productivity improvements will have a strong impact on the climate change mitigation potential of the energy mix.

D. Converging technologies

48. The history of technological progress provides compelling evidence that change is often not linear but exponential. Dynamics increasingly come from the convergence of technologies.[19] Acceleration in technological change may also lead to breakthroughs that could affect economic sectors that have been slower to change in the past, notably energy and transport. The following sections consider the three convergence areas – biotechnology, nanotechnology and advanced materials and manufacturing – identified by the horizon-scanning exercise organized by the CSTD secretariat as potential game changers in the context of sustainable development goals.

[17] Ibid.
[18] Intergovernmental Panel on Climate Change, 2014.
[19] R Silberglitt, et al., 2006.

1. Biotechnology trends and applications

49. Recent advances in the ability to manipulate and modify living systems have enabled improvements in health monitoring, disease control and therapeutic and prosthetic options and have even given rise to the possibility of designed organisms. Reaction to these developments varies widely throughout the world, with some countries and regions opting for slower development due to ethical issues and concerns about environmental risks and others embarking on a faster development path. By 2020, "the following applications of biotechnology will be technically feasible:

- Performance of many different bioassays on a sample at once, which will enable rapid analyte identification from very small amounts of material, for both medical diagnoses and forensic evaluations
- Personalized medicine, based on large databases of patient information and disease states, as well as the ability for rapid and parallel gene sequencing
- Development of genetically modified insects, such as pests that produce sterile offspring or that do not carry or transmit disease vectors
- Widely available capability for genetically modified staple food crops, with especially strong impact in the developing world
- Ability to design and test new drugs using computer simulations (in silico), as well as new capabilities to test for harmful side effects on model systems assembled on computer chips (lab-on-a-chip)
- Targeted drug delivery to organs or tumours using molecular recognition
- Implants and prostheses that mimic biological functions, restore critical functions to existing organs or tissues, or even augment those functions"[20]

50. Such technological trends are expected to make health care more personalized, predictable, cost-effective and easy to access, including in remote places. While some new technologies may make treatments more complex and expensive, other technologies will make treatments cheaper, more efficient and available for many. Examples of such applications include targeted drug therapies and increasingly accurate diagnostic and surgical methods using biological materials and processes.

51. Funding frameworks based on citizen science, crowdfunding and angel philanthropy are designed to provide for personalized, predictive, preventive and participatory medicine in the developing world. Development aid may focus on supporting such novel frameworks, to help developing countries take full advantage of technological opportunities such as health informatics and to strengthen their biotechnology innovation ecosystems.

2. Nanotechnology trends and applications

52. Nanotechnology, specifically research and development in nanometre-scale science and related technologies, is a burgeoning field worldwide and this "worldwide interest is based on the belief that the ability to understand and affect atomic and molecular interactions at the nanoscale is both a prerequisite and an enabler for a host of technological capabilities, from smart, multifunctional materials to designer drugs and new generations of information and communications systems".[21] The following "applications of nanotechnologies will be feasible by 2020:

[20] Ibid.

[21] Ibid.

- New families of miniaturized, highly sensitive and selective chemical and biological sensors
- Improvements in battery power management and capacity
- Individually worn sensors, especially for military and emergency personnel
- Computational devices embedded in commercial goods (already done today and likely to become more widespread)
- Wearable personal medical monitoring devices with data recording and communications capability
- Functional nanostructures for controlled drug delivery and for improved performance of implants and prosthetic devices
- Capability for widespread human and environmental surveillance and monitoring”[22]

53. Nanotechnology is especially relevant because, given that the properties of materials change with decreasing size, the ability to design and manufacture materials and increasingly complex structures and devices at the atomic or molecular scale offers many approaches and tools that can vastly enhance the ability to detect and remedy environmental deterioration. Examples include nanotechnology for energy conversion and storage, such as dye-sensitized solar power cells. Nanomaterials are also likely to enable the development of functional building materials such as self-healing and self-cleaning concrete.

3. Advanced materials and manufacturing trends and applications

54. The multidisciplinary field of advanced materials has grown over the past few decades through the integration of physics, chemistry, metallurgy, ceramics, polymer science and, most recently, biology, to become a rich source of technological advancement. Advanced materials are enablers of many of the applications of biotechnology and nanotechnology. Based on continued developments in materials science and engineering and manufacturing, the “following may be feasible by 2020:

- Fabrics that incorporate power sources, electronics, and optical fibres
- Clothes that respond to external stimuli, such as temperature changes or the presence of specific substances
- On-demand manufacturing of components and small products to individual personal or corporate specifications (initially limited to low-complexity items)
- Widespread adoption of green manufacturing methods that substantially reduce the introduction of hazardous materials into commerce and the volume of hazardous waste streams
- Nanostructured coatings and composite materials with greatly enhanced strength, toughness, wear resistance and corrosion resistance
- Organic electronics for increased brightness of lighting systems and displays
- Mass-producible solar cells using composite materials based in part on nanostructured, organic or biomimetic materials
- Water purification and decontamination systems based on nanostructured, activated membranes and filters

[22] Ibid.

- Designed catalysts for chemical processes based on combined rapid computation and materials screening
- Engineered multifunctional tissues grown in vivo from biodegradable scaffolds (likely limited initially to selected tissue and organ types)"[23]

55. Advances in materials science are often followed by product innovations. In the coming years, disruptive technologies are expected in the area of nanomaterials (such as graphene, carbon nanotubes and nanoparticles), photonics and three-dimensional circuits, universal memory and multicore, which are the foundations for running information and communications technology products and processes.

56. Constant adaptability is expected to pervade all aspects of manufacturing, from research and development to innovation, production processes, supplier and customer interdependencies and lifetime product maintenance and repair. Products and processes will be sustainable, with built-in reuse, remanufacturing and recycling for products reaching the ends of their useful lives. Closed-loop systems will be used to eliminate energy and water waste and to recycle physical waste. Advances in materials science, microelectronics and information technology, biotechnology and nanotechnology will profoundly affect manufacturing and help manufacturers address the challenges to come.

57. By 2020, green manufacturing techniques are likely to provide a variety of more environmentally friendly alternatives to manufacturing processes that currently use or produce hazardous materials. Using such techniques, manufacturers are expected to be able to sustain levels of production in stricter regulatory environments while consuming fewer non-renewable resources, creating less hazardous waste streams and reducing their impacts on the environment. Additive manufacturing (three-dimensional printing) will help reduce the time-consuming long-distance transport of products or components that are currently mass produced and may shift industrial production from peri-urban areas to city centres.

58. It is important to note that advanced materials and manufacturing technologies are in the early stages. Their long-term impact, particularly in terms of value chains, represents a research area that has yet to be explored.

E. Urbanization and habitat[24]

59. Cities are places of markets and innovation. They are at the forefront of economic wealth creation, as most innovation and paid employment tends to be located in urban areas. Urbanization is therefore a driver of economic development not only for cities but for their surrounding regions or countries. Economic growth in cities and improvements in infrastructure have been shown to intensify urban migration. In addition, cities are a prime example of sociotechnical systems where technical and socioeconomic developments co-evolve. For example, urbanization is strongly interlinked with mobility, the use of natural resources and energy. This section provides insights as to how emerging technologies interact with such developments.

60. According to the United Nations Department of Economic and Social Affairs, by the year 2050, the global share of people living in urban areas will increase to approximately 66 per cent, led by cities in Asia, Latin America and, particularly, Africa.[25] In many regions, medium-sized cities are expected to grow faster than megacities with over

[23] Ibid.

[24] For an in-depth discussion on this topic, see E/CN.16/2013/2.

[25] United Nations Department of Economic and Social Affairs, 2014, *World Urbanization Prospects* (New York, United Nations publication).

10 million inhabitants. One strong trend is the extension of city areas; efforts to promote a reurbanization of the city core, also known as densification or compact cities, are unlikely to compensate for the trend towards sub and peri-urbanization, although large-scale effects may be achieved by building infrastructure in compact urban areas for various services such as housing, sanitation, health care or access to electricity.

61. Supplying urban areas with goods and resources is becoming ever more complex. While previously, most food and other consumer goods for a city were produced in its urban hinterland, large cities today are embedded in international trade networks. While the dependence of urban areas on surrounding rural areas is therefore decreasing, their dependence on global markets is increasing.

62. Urbanization can benefit from technological trends in the following three areas: information and communications technology; vehicle and engine technologies, materials, infrastructure and operating technologies; and technologies for self-sufficiency.

63. City authorities are expected to have access to ever more sophisticated information and communications technology tools (such as geographical information systems) to manage and visualize large amounts of real-time or near-real-time data relevant to city development, collected with the help of sensors, satellites and mobile crowdsourcing, among others. Such technology will also optimize transportation systems through mass-mobility applications, including traffic-flow control and fleet management, and its use in intelligent vehicle technologies. In public transportation, electronic ticketing and payment will improve services, leading to a higher degree of capacity utilization. Finally, smart travel cards, services and applications are expected to combine different public and private services, such as private car-sharing initiatives, leading to seamless mobility.

64. Vehicle and engine technologies are expected to lead to improvements in transportation and mobility, including high-speed trains and autonomous vehicles, electric, hybrid and fuel-efficient vehicles, lightweight material technologies, nanosolutions for batteries or engines and technologies enabling the reduction of physical mobility, such as for communications or virtualization, or even three-dimensional printing.

65. Urban agriculture, partly based on biotechnology or organized in multi-storey platforms through the use of construction and building technologies, can reduce the inflow of food from rural areas and increase the self-sufficiency of urban populations. Emerging technologies such as for solar or wind energy may reduce the dependence of cities on surrounding rural areas for energy supply by enabling energy production inside urban areas. In addition, improved thermal insulation of buildings reduces the need for fossil fuels.

III. Policy lessons learned from horizon-scanning exercise and foresight research

66. The horizon-scanning exercise organized by the CSTD secretariat and foresight research conducted for this report identified a range of technology trends that may have the potential to contribute to development, particularly in the context of the post-2015 development agenda. Four policy lessons can be identified, and are detailed in this chapter.

1. The selection of technological paths depends on the context of countries

67. Not all countries are faced with identical challenges; each is at a different stage of development, with different technological capabilities, cultures and priorities. In addition, it is necessary to consider that wide differences exist between implementation capacity, investment costs and the long-term impact of each technology. Policymakers are confronted with questions of context and relevance when evaluating technologies, and selection should

be based on the specific socioeconomic needs and cultural context of countries, especially given that some technologies could facilitate progress towards multiple sustainable development goals.

2. Technology trends cannot produce positive development outcomes on their own

68. Technological development does not ensure development outcomes. For example, convergence spurred by information and communications technology and electrification has the potential to provide solutions in the areas of agriculture, health care and good governance. However, such technological solutions do not necessarily imply that social inequalities have been overcome and in some cases may result in higher inequality. Policy intervention is therefore needed to prevent the creation of new inequalities or the amplification of existing ones.

69. Policies need to address infrastructure gaps, particularly in the underlying requirements of new technologies such as access to electricity and information and communications technology, and encourage transdisciplinary and interdisciplinary research based on the findings of technology foresight studies. Special attention should also be paid to the creation of capabilities, as countries need to have the capabilities to identify and derive the benefits of advances in science and technological applications. In addition, technologies need to be complemented by behavioural changes and incentives, in order to have a significant impact. Monetary and non-monetary incentives, as well as information measures, may facilitate behavioural changes. For example, emissions can be substantially lowered through changes in consumption patterns, dietary changes and reductions of food wastes.

3. The role of converging technologies is increasing

70. Analysis of technology trends provides evidence of the increasing role of converging technologies, as discussed in chapter II. Information and communications technologies are key drivers of such convergence and are increasingly present in various socioeconomic areas, including food production, mobility, urbanization, energy supply and health. A more widespread use of information and communications technology may be applied to a variety of issues, ranging from farming to energy supply and urbanization. This is an area that deserves policy attention.

4. Collaboration can contribute to advancing technology foresight in developing countries

71. Regional and international collaboration plays an important role in advancing technology foresight in developing countries. It is beneficial for countries in the same region to use existing regional institutional platforms, pool available resources and maximize impact through joint foresight exercises to address common challenges. Countries that are not in the same region but face similar development challenges, for example, landlocked developing countries, least developed countries and small island developing States, may also consider joint foresight initiatives. It is important to foster the exchange of experiences among developing countries and countries that have been successful in overcoming similar challenges in the past.

IV. Findings and suggestions

72. This chapter proposes a set of key issues for consideration by the Commission, drawing on the findings of the 2014–2015 intersessional panel, including the expert discussions held during the strategic foresight café, and the horizon-scanning exercise.

1. Findings

73. The findings of the panel were as follows:

(a) Strategic foresight has evolved in the last decades into a participatory process that is increasingly employed by countries and regions to gather intelligence on future trends so as to allocate resources in a way that prepares societies for such trends. Various methodologies and institutional arrangements are used, depending on the specific objectives of a foresight exercise.

(b) Several emerging technology trends have been identified as having a major impact on the post-2015 development agenda, including in the areas of natural resources, sustainable energy, climate change mitigation, adaptation and carbon offset, converging technologies, health and disaster resilience, urbanization and habitat and sustainable transportation and mobility. These trends do not automatically produce societal benefits and policy intervention is needed to prevent the creation of new inequalities.

(c) Technology convergence, which is predominantly driven and facilitated by information and communications technology, necessitates transdisciplinary and interdisciplinary approaches, when responding to complex societal challenges by using STI.

(d) Technology foresight can help policymakers better understand unsustainable trends and contribute to the implementation of the post-2015 development agenda by informing it on a regular basis. Technology trends should be analysed in the context of wider socioeconomic trends, to identify their societal impact.

(e) Technology foresight can help anticipate future innovation policy and private sector investment needs, particularly with regard to critical infrastructure needed for sustainable development and attaining sustainable development goals. Foresight generates insights on the dynamics of change, future challenges and options and new ideas, to transmit them to policymakers as inputs for policy design.

(f) Foresight is increasingly becoming an essential multi-stakeholder tool to make sense of and create strategic options to deal with today's complex global challenges, which are difficult to define, require new ways of thinking, lack clear accountability, transcend national boundaries and require a long-term approach.

(g) Vocational training can provide a major boost in terms of preparing the workforce for disruptive technologies. Appropriate strategies may be devised for both preemployment and on-the-job vocational training. Partnerships between universities, non-governmental organizations and the private sector are indispensable for the success of vocational training on a significant scale.

2. Suggestions

74. The CSTD may wish to consider the following:

(a) Sharing findings on STI and information and communications technology trends and their implications in the High-level Political Forum on Sustainable Development, the Global Sustainable Development Report and in sustainable development goals implementation processes.

(b) Establishing a knowledge portal to share peer-reviewed foresight practices conducted at national and regional levels, thereby assisting member States in identifying future trends and potential strategic partnerships.

(c) Contributing to capacity-building, awareness creation and impact assessment for foresight initiatives in member States.

(d) Encouraging the Science, Technology and Innovation Policy Reviews of UNCTAD to focus more on strategic foresight, possibly by including a dedicated chapter on this theme.

75. Member States may wish to consider the following:

(a) Fully integrating STI into national socioeconomic development plans and ensuring that STI objectives are driven by societal needs, as opposed to analysing STI trends in an isolated way.

(b) Using strategic foresight to identify potential gaps in education for the medium and long term and addressing such gaps with a policy mix including, among others, vocational training, counselling, open access provision and quotas and targets to encourage enrolment in science, technology, engineering and mathematics.

(c) Strengthening vocational education to prepare societies for disruptive technologies by establishing dedicated national vocational training institutions, increasing cooperation between vocational training institutions and industry and funding training facilities, student exchange programmes and equipment.

(d) Using foresight as a process to encourage structured debate among all stakeholders, including representatives of Government, science, industry and civil society and the private sector (particularly small and medium-sized enterprises), towards a shared understanding of long-term issues and building consensus on future policies.

(e) Undertaking strategic foresight initiatives on global and regional challenges at regular intervals.

(f) Using existing regional mechanisms to kick-start cooperation on foresight studies, particularly to learn from countries that have overcome development challenges by using STI and information and communications technology, and to jointly tackle common challenges.

(g) Cooperating towards the establishment of a mapping system to share technology foresight outcomes with other member States of the CSTD.