GLOBAL SUSTAINABLE DEVELOPMENT REPORT

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CHAPTER

3

PERSPECTIVES OF SCIENTISTS ON TECHNOLOGY AND THE SDGs

3.1 Technology and the SDGs

In view of its ambition and the complexity of the challenges it addresses, implementing Agenda 2030 is a daunting task. Scientists and many people see technology as a major factor that can help to meet the Sustainable Development Goals. Technology can help build on synergies among the goals, realize possible multiple benefits as well as avoid barriers and conflicts on the challenging road toward SDGs. Against this background, the present chapter presents a range of perspectives of scientists on the most promising actions or policy elements for optimal leveraging of technology for the SDGs and "leaving no-one behind", as well as on which technologies will be most crucial until 2030 (see Box 3-1). It aims to inform policy makers in this early phase of implementation.

Box 3-1: Methodology

The present chapter is a synthesis by UN staff of inputs from 61 scientists and experts in April and May 2016 to two specific questions: *There are many technology challenges for achieving the SDGs and lots of expectations for technology solutions. Against this background: (1) What are the most promising actions or policy elements for optimal leveraging of technology for the SDGs and "leaving no-one behind"? (2) Which technologies and what level of their performance and deployment will be most crucial until 2030?* It is important to note that present chapter does not present a consensus view of contributing scientists, but presents the range of views submitted.

The two questions were addressed at several hundred eminent scientists and experts from a wide range of disciplines. The request for inputs was also sent to scientific members of the Technology Facilitation Mechanism's 10-Member Group, UNFCCC TEC members, previous contributors to the Global Sustainable Development Report, especially those who had submitted science-policy briefs, as well as participants in the UN expert group meeting on emerging issues which was held in April 2016. Requests were also sent to expert staff in UN entities and major scientific organizations and programmes, such as the International Council for Science (ICSU), Future Earth, and the Sustainable Development Solutions Network. Recipients were encouraged to further share the call with relevant colleagues. Notably, one of the responses was from an interdisciplinary team of seven academics active in the Harvard Project on Innovation and Access to Technology for Sustainable Development which conducted 18 original case studies in the water, energy, health, agriculture and manufacturing sectors and synthesized literatures across a range of fields including innovation systems, economics, science and technology studies, law, engineering, international relations and complex systems.[1, 2]

The contributing scientists have affiliations with research institutions in 20 countries: Australia, Austria, Brazil, Canada, Chile, China, Ethiopia, France, Germany, India, Ireland, Japan, Jordan, Mali, Mauritius, the Netherlands, Norway, South Africa, the United Kingdom, and the United States of America (see acknowledgments). They represent a wide range of sustainability science disciplines.

In addition, the following data sources were considered: 58 technology-related science-policy briefs[3] prepared by 97 scientists in support of the GSDR and the HLPF that had been submitted by individual scientists since 2014; an online survey in early 2016, whereby scientists could simply list what they considered the most important emerging technologies; and a follow-up UN expert group meeting on emerging issues that was organised in New York from 5 to 6 April 2016 (see also chapter 5).

Source: Authors.

3.1.1 Technology – a solution and a problem

Technology has greatly shaped society, economy and environment. Indeed, technology is a double edged tool[4, 5] – while technology progress has been a solution to many ills and problems, it has also added ever new challenges.[6, 7]

Socio-economic development is inextricably linked to technology change, as technology, society and institutions co-evolve. Technology change can be a source of conflict, as well as a tool for social inclusion and greater cooperation. For example, ICTs have allowed huge advances in this respect, e.g., in health, education, transport and communications, but they have led to security and privacy challenges. To varying degrees, all technologies consume resources, use land and pollute air, water and the atmosphere. While increasing eco-efficiency of technology use has reduced the amounts of resources consumed and pollution produced per unit of output over the long run, absolute amounts of consumption and pollution have continued to increase unsustainably. Against this background, governments have long called for concerted actions to accelerate change towards more sustainable technology. Many technology optimists believe such acceleration is essential and call it the technology innovation imperative.[8]

It should also be noted that technology change itself is often not neutral. Instead, it is often biased toward capital and skilled labour and hence has significant distributional effects leading to increased inequality.[9] Technologies invented or adapted in developing countries are likely to be more suitable for use in other developing countries.[10, 11]

3.1.2 Technology dimension of the SDGs

The 2030 Agenda recognizes the importance of technology for the achievement of the SDGs. Technology is not only captured in SDG17 as a key "means of implementation". Among the 169 targets, 14 targets explicitly refer to "technology" and another 34 targets relate to issues that are most often largely discussed in technology terms (Table 3-1). There are also certain technology dimensions to the other remaining 121 targets, in which case, however, technology is only one of many means for their implementation. Table 1 categorizes those 48 targets that are most closely related to technology along three targets: (a) significant overall technology performance improvement; (b) universal access to sustainable technology; and (c) global effective innovation system for sustainable development. Table 3-1 is based on interdisciplinary expert assessment. Individual views as to which targets are technology-related necessarily differ. For example, energy engineers tended to see large technological components in the target to provide universal access to affordable, reliable and modern energy services, whereas political scientists or anthropologists tended to emphasize the non-technological elements.[12]

Table 3-1 thus translates the complex list of SDG targets into a form that can readily be related to existing scientific literature and assessments (see also their coverage in the Global Sustainable Development Reports 2014 and 2015). Technology-related targets have also been proposed in the scientific literature. They are usually much more quantitative than the agreed SDG targets.

The remaining 121 targets – which are not included in Table 3-1 – fall primarily into the equity and institutional categories. Hence, while the creators of the SDGs overwhelmingly focused on the objective to "leave no-one behind" in all its dimensions, when it came to technology, they included a significant number of overall technology performance targets. This is very much in line with scientific findings that point to a need for making simultaneous progress in equity, overall technology performance and institutions, as well as in both radical and incremental technology change.

Table 3-1: Selected SDG targets that most closely relate to technology

Principle & overall goals	Technology-related SDG targets (48 of 169 targets)
Significant overall technology performance improvement 19 targets	**General technology performance targets for 2030:** 8.4 Improve progressively… global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation… 8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation…. 9.4 …upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes…. **Issue-specific, quantitative technology performance targets for 2030:** 2.3 …double the agricultural productivity …. of small-scale food producers…. 3.3 …end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases 3.6 …halve the number of global deaths and injuries from road traffic accidents 6.3 …halving the proportion of untreated wastewater 7.3 …double the global rate of improvement in energy efficiency 12.3 …halve per capita global food waste at the retail and consumer levels… **Issue-specific, qualitative technology performance targets for 2030:** 3.9 …substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination 6.3 …improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials…. and substantially increasing recycling and safe reuse globally 6.4 …substantially increase water-use efficiency across all sectors… 7.2 …increase substantially the share of renewable energy in the global energy mix 7.b …expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries… 12.3 …reduce food losses along production and supply chains, including post-harvest losses 12.5 …substantially reduce waste generation through prevention, reduction, recycling and reuse 14.1 …prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution (by 2025) 14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels 2.5. …maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species (by 2020)
Universal access to sustainable technology 12 targets	**Access to basic services by 2030:** 1.4. …ensure that all men and women …. have… access to basic services…and…appropriate new technology… 6.1 …achieve universal and equitable access to safe and affordable drinking water for all 6.2 …achieve access to adequate and equitable sanitation and hygiene for all and end open defecation….. 7.1 …ensure universal access to affordable, reliable and modern energy services 11.1 …ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums 11.2 …provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety… **Access to technology:** 3.b ….provide access to affordable essential medicines and vaccines…. 9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, ….., with a focus on affordable and equitable access for all 9.c Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020 16.10 Ensure public access to information and protect fundamental freedoms… **Technology use:** 5.b Enhance the use of enabling technology, in particular ICT, to promote the empowerment of women 11.2 …expanding public transport

Table 3-1: (continued)

Principle & overall goals	Technology-related SDG targets (48 of 169 targets)
Global effective innovation system for sustainable development 17 targets	**Research, development and demonstration:** 3.b Support the research and development of vaccines and medicines for the communicable and non-communicable diseases that primarily affect developing countries.... 9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending 9.b Support domestic technology development, research and innovation in developing countries… 14.a Increase scientific knowledge, develop research capacity and transfer marine technology… **Technology transfer and diffusion:** 17.7 Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms, including on concessional and preferential terms, as mutually agreed 17.8 Fully operationalize the technology bank and science, technology and innovation capacity-building mechanism for least developed countries by 2017 and enhance the use of enabling technology, in particular information and communications technology **Higher education and STI capacity building:** 4.b By 2020, substantially expand globally the number of scholarships available to developing countries.... for enrolment in higher education, including....information and communications technology, technical, engineering and scientific programmes… 13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning **STI policy environment and market incentives:** 8.3 Promote development-oriented policies that support … entrepreneurship, creativity and innovation… 9.b …ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities 12.c Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts… **International cooperation on STI capacity, technology access and transfer:** 2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks… 6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies. 7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology 9.a Facilitate sustainable and resilient infrastructure development in developing countries through enhanced.... technological.... support to African countries, least developed countries, landlocked developing countries and small island developing States 12.a Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production 17.6 Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism

Source: Authors, based on interdisciplinary expert assessment.

3.2 Scientists' perspectives on policy and actions for leveraging technology for the SDGs

Against this backdrop, much can be learnt from a synthesis of the most important current perspectives of scientists.[13,14,15] In the survey conducted for this report, scientists were asked to identify the *"the most promising actions or policy elements for optimal leveraging of technology for the SDGs and 'leaving no-one behind'"*. (see Box 3-1).

In the following, the selected proposals of these scientists are summarized. (Table 3-2) They do not necessarily present a consensus of the contributors, but illustrate the range of views and perspectives. More detailed results are reported in a background paper for this chapter on *"Perspectives of scientists on technology and the SDGs"*[16] in which scientists' responses are presented along disciplinary lines.

Table 3-2: Selected proposals by contributing scientists for optimal leveraging of technology for the SDGs and leaving no-one behind

Theme	Summary proposals	Action level
Strengthening national systems of innovation to accelerate technology progress	• Systematically strengthen national systems of innovation, especially in developing countries. • Incremental and radical technology and infrastructure performance improvements – all are needed. • Barriers to technology deployment and diffusion in developing countries to be removed and R&D investments to be increased. • Coherent and comprehensive techno-economic policies are needed. • Science, technology, and innovation (STI) literacy need to be strengthened in every country to create knowledge-based, innovative societies that utilize scientific evidence to help inform policy. • Learning across spheres of practice and implementing lessons from existing technology-related initiatives and from "experiments" of new SDG-related technologies in specific communities.	National
Plans, roadmaps and integrated assessment	• National and international action plans and technology roadmaps for achieving the SDGs individually and together. • Science roadmaps, technology roadmaps and R&D roadmaps to agree on priority actions of the science and engineering communities. • Technology investments need to be significantly increased. • Share information and advice among countries on policies, actions, and partnerships. • Communication, education and public awareness raising are essential, especially among consumers. • Systems thinking and technologies for a circular economy. • Integrated assessment models can be useful to design sustainable development policies. • Countries to explore their own desired paths of economic diversification based on identification of promising technological trajectories and new industries. Industrial policies.	National and global
Putting technology at the service of inclusion	• Access to affordable, modern technology for everyone, especially in developing countries. • Inclusive innovation policies to promote equity. • Technology assessment and foresight to understand potential implications of new technologies and guide policy. • Ecosystem approach to policy, in order to address technology gaps continually arising with new technologies. • Taking into account the interests of underserved populations throughout the innovation process. • Promote access to and use of assistive technology for people with disabilities. • On-the-ground solutions and technological innovations to be considered a core component of livelihood strategies. • Leverage the social technology of sharing in urban slums. • Intervention research drawing on cognitive science, psychology, behavioural economics, and anthropology. • Explicitly consider informal cultural norms and the nexus to formal rules when assessing technology needs/gaps.	Global, national and local
Building institutions that support sustainable technology progress	• Institutions need to be reformed to re-orient innovation systems towards sustainable development. • Support for R&D and incentives for deployment of cheaper technologies with systemic benefits, including off-grid electricity systems, e-mobility and novel antimicrobial medicines. • Promote urban innovation units, living labs, open science, and science parks, to harness localised, inclusive innovations. • Re-defining megacities' functions through legislation and balanced distribution of public resources. • Institutions to promote development of low cost local technology solutions based on community knowledge. • Better data need to be collected, openly shared and analysed. • Partnerships at the city and national levels could bring together and share disaggregated data. • New tools and scientific innovations for data collection and analysis. Big data to monitor and promote the SDGs.	Global, national and city

Source: Authors, based on contributing scientists' proposals.

Responding scientists typically proposed policies and actions that encompassed several themes and types of actions, not just one or two. They tended to highlight also policies and actions that go far beyond their disciplinary special expertise, which illustrates their integrated systems views. This runs counter to the high level of specialization that exists in modern science. This result may not be representative of science as a whole, but is likely due to a selection bias arising from inviting scientists interested in aspects of sustainability science (see Box 3-1 on methodology).

3.2.1 Strengthening national systems of innovation to accelerate technology progress

National systems of innovation need to be strengthened, especially in developing countries. National innovation systems comprise many institutions and the cooperative actions of financiers, law makers, business people, institutional checks and balances, and researchers developing new technologies.[17] These 'systems of innovation' play a key role in enabling the country to manage the process of technology change, which ultimately will be of use across many areas of the SDGs.[18, 19] Leveraging institutional innovation and changing consumer behaviour may be equally important as progress in technology performance.[20] In this view, interdependencies are considered between different technologies and the various stages of technology life cycles. It finds that investments are needed in both new and old technology systems, in both components at the technology frontier and those that promote technology access to all, as well as exploratory and even in "crazy" ideas and innovations.[21] Prioritising one at the expense of the other is counterproductive for the effective functioning of the system, as experience has shown.

Incremental and radical technology and infrastructure performance improvements – all are needed. Accelerated technology change and a deep transformation are required for the achievement of the SDGs. Incremental gradual technology and institutional improvements are needed as are radical, Schumpeterian "gales of creative destruction" of materials and emissions intensive human activities. Even in the case of successful radical new solutions, incremental improvements after initial market deployment are essential. To ensure a high quality of life, the transformation will need to encompass both the supply side and the end-use changes.[22] This is a major challenge, as some economic sectors might experience disinvestment, leading to winners and losers. Consumption needs to be oriented toward high efficiencies - e.g. through circular processes that reuse waste products as resources - and low energy, water and land use intensities.[23]

Infrastructures are essential for technological change, as they influence industries' capacity to maintain and expand their technological knowledge base.[24] In particular, Governments need to provide the basic and essential technological infrastructures in the economy, including electricity supply, Internet and broadband connectivity, computer hardware, software, and technical skills for support and maintenance,[25] all of which are essential for the knowledge economy.[26, 27, 28] Similarly, transport infrastructure, good schools and health centers are important. Infrastructures have long diffusion times and require large upfront investments, and thus political will, long-term commitment, coherent policies and the rule of law are essential.[29, 30] One example that illustrates the need for a nuanced perspective on technology and infrastructure is a recent programme to put broadband in every hospital in Ethiopia which was cancelled when it became evident that hospitals had more pressing concerns like keeping the lights on or finding money for diesel for a generator. A nuanced view was needed on how to properly sequence development and identify opportunities for leapfrogging, which do exist, but are probably overestimated.[31]

Granular, smaller-scale technologies with many units (e.g., mobile phones) tend to diffuse fast, but also require infrastructures and regulation just like the lumpier and larger-scale counterparts. All require human capacity, stable investment environments and institutional arrangements. *Granular technologies* often show rapid technological learning resulting in lower costs which makes them *useful solutions in rapidly growing parts of the developing world*.

Many technologies already exist, but their *deployment and diffusion in developing countries is lagging behind due to* many technical, economic, institutional, legal and behavioral *barriers*.[32, 33] Examples include IPR issues, private sector capacity, mismatched needs, trade tariffs, and limited access to trusted information, knowledge and capital.[34] At the same time, new and advanced technologies need to be developed, continuously improved, shared, and deployed, which requires R&D at all stages, from basic research to development and deployment and in an integrated manner across stages. Global private and public R&D investments reached US$1.6 trillion per year (or 2 per cent of GDP) in 2014.[35] However, 78 per cent of these investments were in USA, China, Japan and Europe. In contrast, R&D levels in most developing countries remained much lower than 2 per cent of GDP.[36]

Coherent and comprehensive techno-economic policies are needed. Externalities should be internalized by charging for pollution and emissions. To move towards full internalisation of externalities will take considerable time. In particular, least developed countries would not be expected to achieve full internalisation in the short- to medium-term, and OECD countries could provide them with stepped-up finance and technology transfer for development and adaptation, in order to support the transition process. Governments should avoid "picking of winners", but rather create a level-playing field for all low-polluting technologies on a life-cycle basis. Resources could be conserved by the introduction and incentives to switch to a circular economy (including 3R – reduce, reuse, recycle). Abolishment of tariffs on trade or transfer of environment friendly technologies is one example of how adoption of green technologies could be fostered. Systematic policies need to be instituted to shorten the time-to-market for produce from developing countries.[37]

Science, technology, and innovation (STI) literacy need to be strengthened in every country to create knowledge-based, innovative societies that utilize scientific evidence to help inform policy. This requires wise investments in human capital including education at all levels, in fundamental and applied research and development, in infrastructure. Also needed are wise government policies to facilitate "bottom-up" innovation by entrepreneurs in private companies and universities. These policies would reduce corruption, permit freedom of inquiry, establish rule of law, expand participation by women, and expand private sector investment and trade – all of which will unleash the creativity of many people, create new jobs, and accelerate scientific and technical advances.[38] Policies to institute participation of scientists in national decision making and to establish technology transfer mechanisms could potentially enhance national innovation capacities and link research communities to economic sectors and society at large.[39] One example of the benefits of science-based information in support of policy making is climate adaptation technology for water management,[40] without which many people will suffer water shortages, lack safe water, increased water pollution, biodiversity reduction, and increased frequency and intensity of floods, droughts, and heat waves.[41, 42]

There is a need to facilitate experiments of new SDG-related technologies in specific communities, to carry out social and scientific monitoring, to draw lessons in order to upscale with many small scale experiments and also with many sites on larger scale projects,[43] as well as to create trust with people involved making sure that the politicians and business people involved are not abusing the situation.[44]

Measures are needed to regularize learning across spheres of practice to improve understanding of how to re-orient innovation systems[45] towards sustainable development. Developing targeted interventions requires an understanding of innovation systems and their socio-technical nature. Many potential lessons are already available.[46] Socio-technical characteristics – such as mundaneness, role of standards and certification, network externalities, and modularity - can be used as heuristics to identify possible barriers to innovation that could emerge when selecting particular technologies or interventions. Actors with convening power should facilitate learning across disparate communities of practice. For example, they could organize conferences bringing together practitioners, policymakers, and scholars from more than one sector; they could fund comparative analyses drawing on more than one sector or location; and could teach students across disciplines to think broadly about technological innovation.

Learning and implementing lessons from existing technology-related initiatives is important. Scientists pointed out several examples. One example was Chile's programmes on cluster development. Following an analysis which showed that only 15 per cent of researchers in Chile were engaged in applied research,[47] the government strengthened coordination between public and private sectors and academia. It commissioned studies on cluster development,[48] a strategic market study, an energy policy roadmap, and eventually developed a strategic solar industry programme in which a private public committee allocated resources for applied research. In the case of the mining industry cluster, road-mapping was added to general cluster analysis and foresight exercises carried out by industry.[49] Another example was systematic information on incorporating mobile technologies into community health practices (mHealth) in Rwanda which has enabled learning from existing practices.[50] Information on mobile phone ownership, user characteristics (such as age and education), and technology design enabled health care providers to engage directly with patients.[51, 52] Another example is the creation of planted forests conservation units in the São Marcelo Park Forest in Brazil,[53] where technology was used to control good quality and humidity air which led to natural regeneration.[54, 55, 56, 57]

3.2.2. Plans, roadmaps and integrated assessment

National and international action plans and roadmaps should be developed for achieving the SDGs individually and together. This should include participation from government, private companies, academia, and NGOs. Feedback is needed from the STI community on what is working and what not.[58] Technology roadmaps, particularly at national and global levels could provide insights on implementation and the available options.[59] Action plans should include a strong mobilization of financial resources for their implementation and evaluations of technology transfer requirements in all countries.[60]

The science and engineering communities could develop science road maps for 10 to 20 years into the future, e.g., on key issues like geological assessment of carbon capture and storage (CCS) storage for which a global geophysical effort is needed. They could *develop technology roadmaps* *for most SDGs*, in cooperation with engineering academies. They could *develop research and development roadmaps* which would include a budget, a structure and R&D partnerships for 5 to 10 years. The communities could also cooperate conducting science and technology training worldwide which could be a global effort across universities and supported by science and engineering academies.[61]

Information and advice has to be shared effectively among countries on policies, actions, and partnerships. This could be done through many venues, such as the multi-stakeholder STI Forum and on-line platform of the UN Technology Facilitation Mechanism,[62] and through new communication technologies that can be utilized for maximizing STI contributions to the SDGs and for connecting innovators, developers, and investors of technologies with those who need solutions to their problems and challenges.[63]

Systems thinking and technologies for a circular economy. A circular economy is one in which industrial systems are restorative and regenerative by intention and design.[64, 65, 66, 67] Creating a circular economy requires bringing together academia, the private sector, the public sector and civil society. More sustainable production schemes and innovation in the private sector are needed. For example, industrial symbiosis which establishes cooperation and synergies between two or more industries, often including non-industrial partners, can make a significant contribution to improved resource efficiency.[68] Systems thinking is essential to manage trade-offs, especially in the nexi between human health and wellbeing,[69] urbanisation, and ecosystem services,[70] or the water-energy-food-nexus.[71, 72, 73]

Integrated assessment models can be useful to design sustainable development policies, as the SDGs are interlinked in complex and often subtle ways[74, 75, 76] Actions to achieve progress in one SDG sector may enhance or diminish performance in other sectors.[77, 78] Integrated assessment models can serve as experimental platform for testing the effectiveness of proposed interventions for achieving the SDGs. They have illustrated the importance of integrated design of urban and rural mobility will be key, notably a well-functioning public transport infrastructure, new mobility options such as e-bike or e-cars, and in suitable areas biofuel supply chains. One example of such models is the Millennium Institute's iSDG model.[79, 80, 81, 82]

Countries need to explore their own desired paths of economic diversification based on identification of promising technological trajectories and new industries. Empirical evidence shows that development is associated with the shift of labour from low- to high-productivity and high-wage activities.[83] The changes in the composition of the economic system occurring during this process give rise to an increasing variety and complexity of economic activities.[84] Increasing complexity is associated with higher levels of GDP and growth, and reduction of inequality.[85] That process is ultimately the result of innovation. Promising actions in all these strategies is the use of empirical data on production, exports and innovation to identify specific technology trajectories to guide the transition towards sustainable development. Promising technological trajectories and new industries can be identified, using patent databases, benchmarking early movers based on their comparative advantage, and/or by using the "product space" and measures of product complexity.[86]

Industrial policies. Contributing scientists saw as key to promote industries that are developing relevant technologies, especially those willing to manufacture in developing countries, while cutting subsidies and tax breaks for those that are not sustainable. In developing countries, some governments may be willing to legislate this, if the right incentives are provided by international development banks.[87] In high-income and innovative regions, high environmental standards for industry need to be enforced, in order to provide benchmarks for others and possibly enforce them via intergovernmental agreements with the help of NGOs. Others suggested to reconsider the desirability of ever increasing worldwide trade and exploring optimal forms of protectionism. In this view, regional or global policies with respect to sustainability standards could be explored, and development aid and trade could be directed more towards small-scale and local support with technologies that benefit the poor in terms of food accessibility, basic amenities such as electric light, water, health and education.[88]

3.2.3 Putting technology at the service of inclusion

Access to affordable, modern technology for everyone, especially in developing countries. Scientists underlined that developing countries, including SIDS and LLDCS need better technology access which is currently constrained by inadequate R&D funds and human skill formation. According to J.A. Schumpeter, it is the introduction of a new product and the continual improvements in the existing ones that lead to growth and development. Hence, innovation is the ultimate driver of long-run economic growth, and barriers to technology access limit development perspectives of countries.Against this background, policy-actions are needed that lead to comprehensive, non-discriminatory and transparent cooperation among developing, developed countries and SIDS.[89] Contributing scientists proposed that developed countries share technology and experiences with those developing countries that are lacking state-of-the-art green technology.[90] Some also stated that the latest technologies should be freely available in poorer countries, and that patents should not constitute barriers for technology diffusion to these countries. In this context, new business models and patent pools for sustainable technologies have proven useful. For example, within three years of NIKE's launch of a patent pool in 2010, more than 400 technologies have been made available and accessible through the platform.[91]

Inclusive innovation policies can help achieve more equitable, sustainable and inclusive development. Inclusive innovation refers to the inclusion in some aspect of innovation of groups that are currently marginalised.[92, 93] The group most often identified is that with the lowest income, but may also include women, youth, persons with disabilities and ethnic minorities. Various UN entities have studied and tested the issue technology and inclusive innovation and their implications for development.[94] For example, UNCTAD's work emphasizes the need to understand - in the context of innovation policies - the particular failures of innovation systems that hinder the attainment of inclusive goals. In particular, to integrate social objectives in STI policies, it is important to consider the specific situations and needs of poor people, women and other groups, as illustrated in UNCTAD research on STI policies[95] and technologies for women.[96] Technologies that create barrier-free environments can improve societal inclusion of deaf and blind people and even support disaster management and prevention.[97] On a related note, it should be noted that many technologies are associated with "jobless growth" as identified by the ILO. These technologies may lead to higher productivity but reduce employment and thus jeopardize "inclusive development".

Technology gaps between countries and groups of people have been a dynamic issue of concern in the sustainable development discourse. Technology gaps exist in all sectors and their nature and severity in terms of being a development constraint differ greatly. This is evident in the World Investment Reports which have analysed these gaps in infrastructure, low-carbon economy, agriculture, global value chains, and the SDG sectors.[98] *New technology gaps often emerge with the application of new technologies*, such as big data, the Internet of Things, 3D printing, and digital automation (see Section 3.3), which could have wide-ranging implications that widen - not minimize - existing inequalities.[99] While such technologies are at an early stage, it is important for countries to begin to understand them, identify potential implications, and use foresight activities to guide policy planning exercises.

An ecosystem approach to policy can help bridging existing technology gaps.[100] Prominent examples include digital technology gaps which comprise connectivity, capability and content elements. There remain considerable connectivity divides in LDCs, SIDS and developing countries as a whole.[101] The connectivity divide is greatest in countries with high rural population shares. To bridge the divides in terms of capabilities at the individual, government and enterprise levels, ICT usage and other complementary skills are needed. Policy actions include creating alternate spaces for learning, involving community centres, creating better metrics of ICT usage, making efficient use of digital platforms, engaging in continuous experimentation, exploring strategic collaborations, popularizing open government data models, developing comprehensive citizen engagement strategy, and adopting participatory e-governance models for the 'shared economy'. The divides in terms of content continue to be large, with the virtual content being highly skewed along language, geography and themes. Locally relevant content can be promoted by establishing local innovation centres and technology hubs, promoting local internet exchange points, increasing support for open data initiatives and organize contests and challenges.

Interests of underserved populations should be systematically taken into account throughout the innovation process. Otherwise, impoverished and future populations may have to deal with technologies poorly suited for them which were chosen by others. There is also untapped potential for end-users to adapt technologies for use in new settings.[102] In fact, a survey of research project "The Diffusion of Innovation in Low-Income Countries" in Ghana identified that responding to customers' needs and requirement as the most important source of innovation in Africa.[103] Channels of communication between underserved populations and powerful actors could improve innovation systems. Therefore, it is proposed that actors with convening power and normative authority should identify ways to more meaningfully engage marginalized populations in innovation systems.[104] For example, international NGOs and UN entities can help governments to directly engage marginalized populations when negotiating norms and establishing priorities. This requires capacity-building among less-powerful populations to represent their interests in global forums. Previously, international organizations primarily focused on technology transfer, often through financing arrangements to export technology from more advanced countries to developing countries. However, newer forms of cooperation seek to more deeply engage developing country actors in the process of technology invention and selection [105] and fostering new collaborative R&D arrangements.[106]

Access to and use of "Assistive Technology" for people with disabilities should be promoted. Assistive Technology enables people with disabilities to participate in social life and to live independently. Assistive Technology, inter alia, helps in the following personal areas: medical treatment, training, personal care and protection, mobility, housekeeping, communication, handling objects, and accessing employment. These technologies are a key element captured in the *UN Convention on the Rights of People with Disabilities (CRPD) of 2006*. The CRPD includes accessibility as a general principle and obliges state parties to "promote the availability, knowledge and use of assistive devices and technologies relating to habilitation and rehabilitation."[107] The use of Assistive Technology is increasing[108] and the trend is likely to continue, as there is not enough human labour available to provide one-on-one dedicated, individualised care. Exploring the socio-cultural context is important, as cultural norms can act as barriers to access and usage of Assistive Technology by people with disabilities.[109] In multi-ethnic, multi-cultural societies, there are typically significant differences in the uptake of assistive technology by people with disabilities from various ethnic backgrounds.[110] Most access and usage challenges in relation to assistive technologies are not related to technological advancements or developments, but are connected to the barriers associated with its uptake.[111, 112]

On-the-ground solutions and technological innovations should be considered as a core component of livelihood strategies and an enabling factor of current urbanization processes, in addition to pre-existing models of resource provision through large-scale technological networks. [113, 114] Flexible technological configurations and residents´ collaborative practices are essential for meeting the daily water needs of people who do not have access to piped water.[115] Such configurations work outside large-scale networked piped water systems and make use of locally ready-to-use solutions to access and store water such as plastic storage containers, mobile vehicles, etc. This is also the case of energy provision and housing and transport.[116] Local governance processes play a crucial role in the introduction and use of new technologies. These need careful consideration to avoid generating new problems while dealing with existing ones.[117, 118]

Intervention research drawing on cognitive science, psychology, behavioural economics, and anthropology. An important policy element to leverage technology is to ensure programs understand and address the psychological and social dimensions that limit individuals from optimally engaging with technology.[119] For example, certain technological solutions in the health sector are only as effective as an individual's capacity to understand, use and innovate around them. Examples of how cognitive-behavioural approaches can be effective include text reminders to patients to increase drug adherence[120] and inspirational videos showing how similar groups improved their socio-economic status.[121] New development approaches are required that not only take into account how people think, feel and do within their local context, but must move beyond to create interventions that directly foster individual's power, voice and agency. Recent research on targeted empowerment interventions for women that strengthen individual agency demonstrated a nearly tripling of sales for clean energy micro-entrepreneurs in Kenya[122] and significant enhancements in relationships and well-being.[123] Intervention research drawing on cognitive science, psychology, behavioural economics, and anthropology is critical to advance human capacity to leverage technology for the SDGs.[124]

Informal cultural norms and the nexus to formal rules need to be explicitly considered when assessing technology needs and gaps. Technology needs and gaps are context specific, and that the lineaments of the context need to go far beyond the ones currently being considered, namely, city size, development stage, and countries in special situations. Communities and societies are held together by shared and symbiotically interacting formal 'rules' and informal cultural 'norms'. A mutually supportive evolution of rules and norms is a prerequisite for sustainable and inclusive development. The introduction of new technologies meant to promote sustainable and inclusive development has the potential to cause - and often does, as human experience has shown - incongruity between the pace of evolution of rules and norms. This could dampen community's enthusiasm for the uptake of new technologies and, more seriously, engender outright hostility towards them, thereby frustrating the objective of sustainable development.[125, 126, 127, 128, 129]

3.2.4 Building institutions that support sustainable technology progress

Institutions are critical for leveraging technologies. These rules and regulations in society can open opportunity spaces for innovating and making best use of technological innovations.[130, 131] *Institutions need to be reformed to re-orient innovation systems towards sustainable development*. All stages of innovation and all relevant decision-making levels need to be considered at the outset. For example, reform efforts in the biomedical innovation system previously focused on just one stage, such as driving invention for neglected diseases, adapting vaccines to be heat-stable, or decreasing the price of HIV/AIDS medicines. More recently, institutional reforms involve using publicly-financed "push" and "pull" incentives, whereby affordability measures are being built into the R&D processes from the very beginning. Governments of both industrialized and developing countries are being asked to contribute to a global biomedical R&D fund for this purpose.[132] Other examples are the creation of carbon prices through various carbon markets which typically require better incentives for private energy R&D and concerted public R&D investment.[133]

There is a need for research and development and incentives for the deployment of cheaper, highly efficient technologies with systemic benefits. These technologies have the potential to transform existing technology systems leading to multiple benefits across the SDGs. Examples include off-grid electricity systems with storage, electric mobility, and novel antimicrobial medicines.

Significant R&D is needed for urban and rural decentralized electric power systems (perhaps even direct current[134, 135]) and for interactions with new options such as heat pumps for space heating, heat and power storage and electric mobility. These systems must become central to the UN or most governments' sustainability agendas.[136] In addition, adequate community and business models need to be found to operate such systems in terms of reliability, affordability, sustainability and safety (incl. privacy).[137, 138] In this context, the existing research gaps need to be bridged between those in the social sciences, in policy and those in the electrical engineering[139, 140] Off grid electricity systems have multiple SDG benefits. For example, they can be used for storage and transportation of perishable food, as well as for drying grain[141] and thus can help reducing food spoilage.[142]

Cheaper, highly efficient technologies must become available in key SDG areas. R&D in innovative technologies, general purpose technologies, and basic science are prerequisites, as are energy efficiency laws. A successful example is Japan's top-runner programme[143] which could be a model to be explored by other countries. Global explicit carbon prices could help reducing greenhouse gas emissions, but - to be effective - they would require all countries to introduce similar levels of carbon prices which appears unrealistic a present and might also raise concerns with regard to ensuing impacts on the achievement of other SDGs.[144, 145] Cheaper, highly efficient bio-energy technologies, solar energy equipment, improved cookstoves, low emissions power plants and less dirty coal technology might also be key.[146]

More R&D investments are needed in the field of antimicrobial research and diagnostic technology. Innovation in technologies is crucial on all levels of healthcare and beyond from point of care diagnostics with an aim to rationalise use of antibiotics to novel antibiotics themselves and their pharmacological alternatives. SDGs should be used as an instrumental inter-sectoral platform through which an underlying antimicrobial resistance as a threat to the world's sustainable development can be addressed collaboratively.[147]

The needed technologies and priorities in cities vs. rural areas often differ greatly in both developed and developing countries. More than half of all people already live in cities, and by mid-century it will be two-thirds. Technology progress has enabled mega-cities to emerge, but continued progress is required even to sustain basic service delivery and reasonably healthy lives in these growing cities. "Smart cities" are emerging with hundreds of smart city projects underway in developed and developing countries. Smart cities and infrastructure can be used to pave the way for inclusive urbanization, or they can exclude poorer sections of the society. To make city development inclusive, some smart infrastructure applications are designed exclusively for marginalized people, including those in informal settlements, people of old age and people with disabilities.[148]

It is important to *harness the local innovation system to sufficiently localize the smart infrastructure concepts. Policy instruments for this purpose include establishing urban innovation units and living labs, promoting open data and open science models, exploiting regional innovation networks and global collaborations, and bringing together science parks, business incubators and innovation hubs*.[149]

The level of concentration of public resources must be kept within environmental carrying capacity. Mega-cities require specific attention. The urban scale of cities is constrained by spatial, land, water, and energy resources, but these constraints can be relaxed via technological breakthroughs, hence allowing the city to grow further. As, technological breakthroughs are not unlimited, non-technological solutions need to explored.[150] In the case of megacities, institutional approaches can provide environmental solutions through *re-defining megacities' functions through legislation and balanced distribution of public resources, in particular, quality educational and medical care facilities*.[151]

Institutions could promote development of low cost local technology solutions based on community knowledge, in particular for disaster risk reduction, urban health and well-being. The crowd sourcing technique for neighbourhood mapping can prove to be very effective for collecting risk information for disaster risk reduction. Technologies using innovative geospatial techniques, such as disaster/urban zonation, urban heat island mapping and exposure/vulnerability analysis in a multi-hazard framework are promising for mitigating risks and pursuing sustainability.[152] Development of green resilient infrastructure-enabled urban spaces could provide multiple benefits and support the SDGs.[153, 154] It involves less resource-intensive green engineering, allowing traditional knowledge to build and manage and inclusive participation during the process of re-generation. It enriches ecological and socio-cultural resources and provides resiliency towards extreme events, as urban climate modification[155] and water management[156] increases coping capacity of urban areas.[157, 158, 159, 160, 161]

Coordinated global monitoring and modelling of many different types of data sets requires *new tools and scientific innovations for data collection and analysis*. Devising metrics, establishing monitoring mechanisms, evaluating progress, enhancing infrastructure, standardizing and verifying data should be top priorities for the scientific community and policymakers alike.[162] In this context, the International Council for Science, the International Social Science Council, the Inter-Academy Partnership, and the World Academy of Sciences have developed a new global accord that identifies the opportunities and challenges of the data revolution as today's predominant issue for global science policy, and proposes principles and practices for open access to research data.[163, 164] Guiding frameworks might be useful for assessments of large, international projects. They could be supported by firmer and more consistently enforced policies of international development banks and other donors.[165]

Big data which has emerged as a new ecosystem of new data, new tools and new actors[166] *can help both monitor and promote the SDGs*.[167] It is particularly promising for inferring or proxying SDGs at fine levels of temporal and geographical granularities. Examples include poverty mapping, disasters monitoring, urban dynamics,[168] resilience to climate change-induced shocks.[169, 170] Big Data can and will also be increasingly used directly by people and groups outside of the realm and reach of traditional policy and measurements systems.[171] Individuals and communities can be allowed and incentivized to engage in policy debates through and about 'their' data seeking greater control over the use of their data and holding those in power to higher standards. Big and Open data need to meet in a "new deal on Data" in which the most vulnerable would have a stronger say in how and for whom policies are designed. Technologies for GIS analysis of geospatial data could also support interventions in many areas, for example, to identify suitable areas for mobile water treatment.[172] At the same time, it is important to strengthen official statistics for monitoring SDG indicators, in view of Member States emphasis on nationally owned data, and in order to make actual measurements rather than rely merely on proxy data.[173]

3.3 Scientists' perspectives on crucial emerging technologies for the SDGs until 2030

A number of science-related processes routinely identify emerging technologies and elements of technology solutions for achieving the SDGs. Those include academies of sciences, individual academics, NGOs, the private sector and the UN system.[174] Mapping these lists to the SDGs could be a productive way to engage the science and engineering community more broadly in contributing to the goals, as illustrated by WFEO's mapping of the US National Academy of Engineering's Grand Challenges.[175]

For the present chapter, scientists were asked: *"Which technologies and what level of their performance and deployment will be most crucial until 2030?"*. Sixty-one scientists provided inputs in response to the question and another 97 scientists had discussed various technologies in their GSDR science-policy briefs.[176] Many of them also pointed out specific opportunities and threats related to the identified technologies. Table 3-3 provides an overview of perspectives. Identified technologies fall into the bio-tech, digital-tech, nano-tech, neuro-tech and green-tech clusters.

New technologies are developing at exponential pace, faster than ever before. The Fourth Industrial Revolution is fundamentally different from the three previous revolutions.[177] It fuses fields of physics, biology, computer science and many more, impacting all disciplines, industries and the world's economy. By 2030, many new technologies will emerge, while current nascent or immature technologies will reach the commercialization stage and may help addressing some of the SDGs. Conversely, the SDG agenda may play an important role in this transformation, as it will direct and could guide future developments, at the same time serving as a tool and change framework.[178]

Two most crucial technology clusters for the SDGs may be energy technologies lowering the cost of clean, non-carbon based energy technologies and carbon sequestration, and *information, communication, and computer technologies* providing new information and analytics that can help us to make smarter decisions and provide more effective services and new innovation in every SDG area. New rapid advances in *biotechnology, nanotechnology and neurotechnology* are other areas with great potential for affecting many sectors. The biggest challenges will likely be in sectors, such as manufacturing, construction, and transportation, where new innovations are needed that can expand rather than reduce employment opportunities and ensure that more people move out of poverty into the middle class in all countries.[179] Reflecting this, science-policy briefs submitted for the GSDR highlight the importance of synthetic biology,[180] biotechnology,[181] nanotechnology,[182] and renewable energy technologies,[183] in order to provide clean water and energy for all. Some contributing scientists are convinced that *"there is no limit to the number of innovations that could help nations accelerating implementation of SDGs"*.[184]

While these technologies have great potential and are a testament to human ingenuity, it will also be important to *minimize risks* and draw attention to potential problems or dangers arising from new technologies and chemicals such as synthetic biology, nanotechnology applications, or genetically modified organisms. There are no risk-free technologies. Even the most sustainable technologies have had unintended and known adverse impacts. Another concern is that emerging information and bio-technologies could have adverse impacts on community and society cohesion and value systems. Some scientists even suggest that *"Sustainable technologies do not exist!"*.[185]

Some warn against looking at technology as a panacea, and point out the limits of technology to address ultimate limits of the ecosystem, and its subordination to politics.[186] According to them, high performance technologies alone will be insufficient for SDG achievement. *Alternative social technologies* and perspectives may also be needed that go well beyond current approaches.[187, 188, 189] Some contributing scientists see this as the most crucial issue from now to 2030.[190]

Table 3-3: Crucial emerging technologies for the SDGs until 2030, as identified through outreach of the GSDR team to scientific communities around the world

Technology cluster	Crucial emerging technology for the SDGs until 2030	Opportunities in all SDG areas, including:	Potential threats, including:
Bio-tech	Biotechnology, genomics, and proteomics; gene-editing technologies and custom-designed DNA sequence; genetically modified organisms (GMO); stem cells and human engineering; bio-catalysis; synthetic biology; sustainable agriculture tech;	Food crops, human health, pharmaceuticals, materials, environment, fuels.	Military use; irreversible changes to health and environment.
Digital-tech	Big Data technologies; Internet of Things; 5G mobile phones; 3-D printing and manufacturing; Cloud computing platforms; open data technology; free and open-source; Massive open online courses; micro-simulation; E-distribution; systems combining radio, mobile phone, satellite, GIS, and remote sensing data; data sharing technologies, including citizen science-enabling technologies; social media technologies; mobile Apps to promote public engagement and behavioural change; pre-paid system of electricity use and automatic meter reading; digital monitoring technologies; digital security technology.	Development, employment, manufacturing, agriculture, health, cities, finance, absolute "decoupling", governance, participation, education, citizen science, environmental monitoring, resource efficiency, global data sharing, social networking and collaboration,	Unequal benefits, job losses, skills gaps, social impacts, poor people priced out; global value chain disruption; concerns about privacy, freedom and develop-ment; data fraud, theft, cyber-attacks.
Nano-tech	Nano-imprint lithography; nano technology applications for decentralized water and wastewater treatment, desalination, and solar energy (nanomaterial solar cells); promising organic and inorganic nanomaterials, e.g., graphene, carbon nanotubes, carbon nano-dots and conducting polymers graphene, perovskites, Iron, cobalt, and nickel nanoparticles, and many others;	Energy, water, chemical, elec-tronics, medical and pharma-ceutical industries; high effi-ciencies; resources saving; CO_2 mitigation.	Human health (toxicity), environmental impact (nanowaste)
Neuro-tech	Digital automation, including autonomous vehicles (driverless cars and drones), IBM Watson, e-discovery platforms for legal practice, personalization algorithms, artificial intelligence, speech recognition, robotics; smart technologies; cognitive computing; computational models of the human brain; meso-science powered virtual reality.	Health, safety, security (e.g., electricity theft), higher efficiency, resource saving, new types of jobs, manufacturing, education.	Unequal benefits, de-skilling, job losses and polarization, wide-ning technology gaps, military use, conflicts.
Green-tech	**Circular economy:** technologies for remanufacturing, technologies for product life-cycle extension such as re-use and refurbishment, and technologies for recycling; multifunctional infrastructures; technologies for integration of centralized systems and decentralized systems for services provision; CO_2 mitigation technologies; low energy and emission technology. **Energy:** modern cookstoves with emissions comparable to those of LPG stove; Deployment of off-grid electricity systems (and perhaps direct current); mini-grids based on intermittent renewables with storage; advances in battery technology; heat pumps for space heating, heat and power storage and electric mobility (in interaction with off-grid electricity; smart grids; natural gas technologies; new ways of electrification; desalination (reverse osmosis); small and medium sized nuclear reactors; biofuel supply chains; solar photovoltaic, wind and micro-hydro technologies; salinity gradient power technology; water saving cooling technology; LED lamps; advanced metering. **Transport:** integrated public transport infrastructure, electric vehicles (e-car and e-bike), hydrogen-fueled vehicles and supply infrastructures. **Water:** mobile water treatment technology, waste water technology, advanced metering infrastructure. **Buildings:** sustainable building technology, passive housing. **Agriculture:** Sustainable agriculture technology; Innovations of bio-based products and processing, low input processing and storage technologies; horticulture techniques; irrigation technologies; bio-organometallics which increase the efficiency of biomimetic analogs of nitrogenase. **Other:** Marine Vibroseis, artificial photosynthesis	Environment, climate, biodiversity, sustainable production and consumption, renewable energy, materials and resources; clean air and water; energy, water and food security; development, employment; health; equality.	New inequalities, job losses; concerns about privacy, freedom and development.
Other	Assistive technologies for people with disabilities; alternative social technologies; fabrication laboratories; radical medical innovation; geo-engineering technologies (e.g. for iron fertilization of oceans); new mining/extraction technologies (e.g., shale gas, in oceans, polar, glacier zones); deep sea mining technologies;	Inclusion, development, health, environment, climate change mitigation, resource availability.	Pollution, inequalities, conflict.

Sources: Results of an online survey among scientists and experts conducted in April 2016 and GSDR science-policy briefs.

The groups of technologies listed in Table 3-3 are discussed in more detail in Annex 2, entitled "Scientists' perspectives on crucial emerging technologies for the SDGs until 2030".

Some scenario analysts provided initial quantifications for technology deployment until 2030. For example, according to one energy economist, in the case of green-tech in industrialized countries, market penetration of smart grids might reach 20 per cent of the electricity market, all new buildings would be energy efficient while all buildings existing today would be refurbished to become energy efficient, electric vehicles would reach market shares of 50 per cent of new registrations due to vastly improved battery performance and low costs, nuclear power would provide some 60 per cent of baseload generation,[191] hydrogen-fueled vehicles and supply infrastructures would be commercialized and natural gas would become the largest fossil fuel.[192] In developing countries, electrification not only of households but of small urban and rural businesses and agricultural small holders could be fully achieved, desalination (reverse osmosis) deployed, small and medium sized nuclear reactors could provide some 10 per cent of baseload generation, agriculture would be mechanised; mini-grids development would be based on intermittent renewables with storage, grid expansion would be twice today's rate, and IT for education deployed even in remote areas.

Long-term technology roadmaps can support business development and policy planning. Systematic road-mapping and scenario work for all SDG areas would be highly beneficial and help engaging a broader cross-section of scientists, engineers and other stakeholders. A number of technology foresight experts have developed indicative timelines for deployment of the technology clusters from 2016 to 2030 which could serve as a good basis for a comprehensive analysis that encompasses the full SDG range.

The CSTD Secretariat at UNCTAD has recently pioneering technology foresight for areas under debate in the UN. For example, one priority theme for the 19th session of CSTD was "Foresight for Digital Development." Several CSTD documents, [193, 194, 195] focused on how countries can use foresight to assess the likely impact of emerging digital developments. They offered potential global scenarios for the trajectory of each technological trend. These could potentially serve as a starting point for countries to initiate their own foresight exercises based on their specific contexts.

3.4 Conclusions

The 158 scientists who contributed their perspectives to this chapter represent 43 disciplines and all world regions. The collection of their views provides initial guidance that could prove useful in the preparation of an in-depth technology chapter for the Global Sustainable Development report in 2019. Much in-depth work remains to be done – collaboratively by external scientists, engineers, UN staff experts, in consultation with the Scientific and Technological Community Major Group co-organized by ICSU, ISSC and WFEO.

Selected actions or policy elements suggested by scientists included: national and international action plans and technology roadmaps; build effective national science-policy interfaces (scientists to analytically support public decision-making); facilitation learning across communities and including underserved communities; cluster analysis, foresight and scenarios; science roadmaps to include affordability and inclusion measures to be built into R&D processes from the outset; invest in both new and old technologies, in infrastructures and granular technologies, in increased performance of advanced technologies and technology adaptations for underserved communities; identify promising technological trajectories and new industries for each country; and engage communities and the poorest and most vulnerable in identifying needs.

Scientists identified many crucial emerging technologies for the SDGs and suggested for further policy elaboration. They fall into the bio-technology, digital-technology, nano-technology, neuro-technology and green-technology clusters. However, very little information exists on the expected or desired level of performance and deployment of these technologies until 2030. To estimate these levels in various contexts, collaboration on SDG scenarios and roadmaps will be important. Systematic road-mapping and scenario work for all SDG areas would be highly beneficial and help engaging all stakeholders.

The technology we have today is robust enough to keep scientists, engineers and all relevant stakeholders engaged and networked. New technologies in the future will be even more powerful tools for building an effective, global science-policy cooperation leveraging technology for a better future for all as envisioned in the SDGs.

Online Annex: List of technology-related science-policy briefs for the GSDR see http://sustainabledevelopment.un.org/globalsdreport/2016

Endnotes

1 Harvard's Sustainability Science Program's Initiative on Innovation and Access to Technologies for Sustainable Development https://www.hks.harvard.edu/centers/mrcbg/programs/sustsci/activities/program-initiatives/innovation/documents

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12 Good arguments were also made for - but no consensus reached on - inclusion of additional SDG targets in Table 1: 1.5, 4.7, 6.5, 6.6, 11.3, 11.5, 11.6, 12.1, 13.1, 15.1, 15.3, 15.5, 15.8, and 16.5. Further in-depth interdisciplinary debate among scientists, including objective selection criteria would be useful.

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ANNEX 3

Scientists' perspectives on crucial emerging technologies for the SDGs until 2030

Bio-technology

Biotechnology, genomics, and proteomics[1] are now major driving forces in the biological sciences and are increasingly being applied in the study of environmental issues, medicine and pharmaceuticals, infectious diseases, and modifications of food crops.

Bio-technology has the potential to lead to sustainable solutions for a range of sustainable development issues.[2] or example, genetically modified organisms could help address food insecurity in developing countries, but their impact on ecosystems, human health and community values may need to be better understood to be considered a truly sustainable solution.[3] Experience has shown that deployment of such technologies needs to consider the local situations and possible trade-offs.[4]

Synthetic biology is a field of great promise and possible dangers. Tailor-made medical solutions, gene therapy, technology disruption in the food industry, bio-engineered medicines, and precise bio-inspired drug delivery systems that target specific infected cells - together with stem cells - give many promises. However, if inappropriately used, it could cause irreversible changes to human health and environment.[5, 6, 7] Synthetic biology requires effective policies and frameworks to manage all stages of their life-time, including manufacturing, distribution and use, as well as safe disposal or where possible effective recycling.[8, 9, 10]

New and emerging gene-editing technologies and their implications, benefits, and potential ethical problems for biotechnology and medicine have generated international scientific debate, with recommendations to establish norms concerning acceptable uses of human germline editing and harmonize regulations.[10] Genuine "human engineering" may not be far off in the future, when technologies related to gene-editing, stem cells and computational models of the human brain will be combined.

Digital technology

Digital information and communications technologies (ICTs) have continued to rapidly advance. All parts of the world are now major users. Mobile phone ownership in Africa is now comparable to that in the USA, with about one connection per capita. Yet, while some digital gaps have closed, others continually open with the introduction of new technologies. In the context of implementing SDGs in Africa, information and communications technologies may play a role comparable to that of machines in the replacement of labour in the industrial age.[11] However, whereas the machines of the industrial era functioned as isolated and individual artefacts in one local environment, ICTs and knowledge creation exist as a hierarchy of networks that bring about innovations.[12, 13]

Great technology potential has been accompanied by equally great concerns about social, political, economic and environmental impacts. The new fifth generation (5G) mobile phones enable vastly faster data connections than traditional phones. The "Internet of Things" is emerging and it interconnects physical objects to internet infrastructure. 3D printing enables the making of three-dimensional objects from a digital file, and together with robotics it has the potential to significantly alter the geographical distribution of manufacturing with important impacts on global labour markets and imbalances. "Big data" technologies transform the way governments, citizens, and companies do business, but they have led to concerns about erosion of privacy and freedom of expression. Similarly, wireless sensor networks have great efficiency potentials in many areas, but there are concerns about their impact on privacy, freedom and development.

Big Data and the Internet of Things through the use of huge datasets and Internet-connected sensors potentially adds to the existing toolkit for sustainable development (e.g., in health, agriculture, food security, sustainable urbanization, etc.), but can also introduce risks related to data privacy and security. Because of cloud computing platforms that provide low-cost access to compute and storage capabilities as well as Free and Open Source Big Data and Internet of Things technologies, such technologies can serve as platforms for locally-relevant, pro-poor innovation without significant capital investments. However, this requires the requisite local talent to tailor solutions to local needs. National governments must also consider the limits of big data analysis (especially for causal inference and policy analysis), how such technologies can serve existing national development planning, regulatory frameworks for securing the rights of citizens with respect to privacy and security, and strengthening human capital and the larger ecosystem to effectively use such tools.[14]

"Big data" has transformed the volume, velocity, and character of the information that we are able to procure regarding virtually every aspect of human life.[15] Online participatory tools increasing transparency and accountability in global sustainable development governance allow greater access to sharing of substantive information on the issues addressed by the civil society, international organisations and member states for realization of agenda 2030.[16] At the same time, the scientific community highlighted the idea that the most sustainable way to bring the deepest results of the digital revolution to developing communities is to enable them to participate in creating their own technological tools for finding solutions to their own problems.[17]

3D Printing (3DP) can cost-effectively lower manufacturing inputs and outputs in markets with low volume, customized and high-value production chains. It could potentially help countries and regions that did not participate in the industrial revolution develop new manufacturing capabilities, especially for low volume, highly complex parts. Applications range from automobile and aerospace manufacturing to rapid-prototyping, healthcare, and education. Low cost consumer 3DP printers can help local people in developing and developed countries to produce a range of useful products, from basic assistive technologies to educational aids. For example, the projects of the Rapid Foundation in India and Uganda have shown that low cost printers are easy to build, use, fix or modify and are robust in remote locations. With expert training, anybody can become comfortable with using these printers in a few hours.[18] Further low-cost applications in science, education and sustainable development are detailed in a recent ICTP open book.[19]

3D printing presents a number of challenges, including possibly disrupting existing manufacturing global value chains, decreasing labour demand for housing and construction, and potentially enabling the physical production of illegal 3D models that could pose both economic and security threats. There are potential environmental benefits (lower energy use, resource demands and CO_2), if 3D printing displaces existing transportation and logistics routes for shipping of goods and products. A recent study concluded: "*If 3DP was applicable to larger production volumes in consumer products or automotive manufacturing, it contains the (theoretical) potential to absolutely decouple energy and CO_2.*"[20] However, as 3DP is expected to remain a niche technology by 2025 reductions in energy and CO_2 emission intensities of industrial manufacturing could only be reduced by a small factor through 3DP by that date.

Massive Open Online Courses potentially provide resource-poor regions and individuals more equitable access to world-class education content. Widespread global Internet access is impacting how we learn, as seen in the availability of various online learning platforms such as massive open online courses (MOOCs).[21] With low-cost replication of recognized content and education, personalized, self-paced learning, and interactive data-driven user interfaces, students potentially have access to material that previously would have been out of reach. However, MOOCs may not provide locally-relevant content tailored to a specific national context. Furthermore, MOOCs could replace the jobs of existing teachers and widen existing educational divides (i.e., providing a disproportionate advantage to individuals with access to the Internet and education). One nonprofit university based in Rwanda combines online learning content with in-person seminars to deliver degree programs that are locally-relevant, appropriately priced, and stimulate local employment. At this point, the potential impact of MOOCs requires more study, both globally in terms of existing platforms as well as of users in specific national contexts, along with implications for educational systems and employment.

Optimal system use of radio, mobile phone, GIS and remote sensing technologies is considered vital for transforming rural populations.[22]

The use of GIS to monitor an ever wider array of parameters at ever higher spatio-temporal resolutions allows us to consistently and constantly measure and monitor a huge array of environmental factors, allowing the enforcement of regulations, which would otherwise be impossible.[23, 24] Yet, *data management* remains a challenge for many countries, as they lack both skilled staff and technologies for effectively collecting or reporting reliable data. Many of the commonly used spatial database platforms are proprietary and are too expensive for many organizations in developing countries.[25]

Nanotechnology

Nanotechnology[26] is a field of enormous promise and big challenges. It is reported to have high potential for increasing innovation for sustainable development in the energy, water, chemical, medical and pharmaceutical industries.[27] *Nanoimprint lithography* is expected to lead to large-scale manufacturing of nanotechnology products with various positive and negative sustainable development challenges. Nano-products might revolutionize many fields including medicine, electronics, energy and water, as well as food industry in the coming years. At present, there are high expectations about high-performing nanomaterial solar cells and nano-technology applications for decentralized water and wastewater treatment, and desalination.[28] Recently, scientists in Singapore have demonstrated converting CO_2 into methane using light and amine-functionalized titanium dioxide nanoparticles – this would allow storing intermittent solar energy in the form of natural gas which could then be burned in a carbon neutral way.

The implications of unethical and uncontrolled use of nanotechnology have created an ongoing debate in the scientific community around concerns about their toxicity and environmental impact (e.g., nanowaste).[29, 30, 31] The OECD and IUCN are currently working with several governments to develop suitable and efficient regulations and policies, and urge a more unified and collaborative approach at all levels to address this potentially hazardous issue through experience- and knowledge-sharing, coordinated research activities, development of guidelines for producers, users and waste-processing facilities[32, 33] and examination of existing guidelines or policies.[34]

As nanotechnology can be damaging to environment and human health, it requires effective policies and frameworks to manage all stages of their life-time, including manufacturing, distribution and use, as well as safe disposal or where possible effective recycling.[35, 36]

There are many promising future, inorganic and organic nanomaterials. Examples include perovskites, gold nanoparticles, graphene, carbon nanotubes, carbon nanodots and conducting polymers. *Carbon based nanomaterials* are very interesting as they rely on abundant carbon and have much potential as high performance substitutes for many materials that are scarce and highly resource intensive in their extraction process. *Iron, cobalt, and nickel nanoparticles can be alternatives to scarce metals* like platinum, rhodium, and gold *for catalysis*. For example, layered iron and nickel nanomaterial are a more sustainable alternative to rare-earth "supermagnets".

Neuro-technology

Smart technologies will be crucial technologies until 2030 and beyond. They will help societies to monitor, detect as well as respond or adapt to changes in their environment. Smart technologies are already and will become a part of our daily lives.[37] For example, smart electricity metering has addressed the problem of the losses of electricity due to theft.[38]

Emerging technologies in the area of artificial intelligence have received much attention in which computer systems that carry out tasks normally done by humans, such as speech recognition and decision making. Another example is *robotics* which is understood as machines or mechanical systems that automatically handle tasks.

Mesoscience[39] *powered virtual reality* gives us the possibility to realize the logic and structural consistence between problems, physical models, numerical methods and hardware, which, together with the dramatic development of computing technology, is opening a new era for virtual reality.

Digital Automation characterizes the increasing ability of computers to overtake cognitive - and not just physical - tasks, enabling recent innovations like driverless cars, IBM Watson, e-discovery platforms for legal practice, and personalization algorithms for Web search, e-commerce, and social networks. The *potential consequences of automation and artificial intelligence on employment* are emerging areas in need of examination; the expansion of computing and machine intelligence is likely to affect healthcare, education, privacy and cybersecurity, and energy and environmental management. Recent studies are pointing to the possibility that a significant number of jobs - or job tasks - are amenable to automation, leading to a job polarization where demand for middle-income jobs are reduced while non-routine cognitive jobs (e.g., financial analysis or computer programming) and non-routine manual jobs (e.g., hairdressing) would be less unaffected. At this point, more study is warranted to understand implications for employment and socio-economic development in a specific national context.

Autonomous vehicles or self-driving cars hold the promise to increase traffic efficiency, productivity, reduce traffic congestions and pollution, and save driving time. In 2016, the Dubai Autonomous Transportation Strategy was launched which foresees 25 per cent of all trips in Dubai to be driverless by 2030. The Autonomous Transportation Challenge as launched as a request for proposals to global R&D centres to apply this technology in Dubai. It will make Dubai the world's largest R&D lab for driverless transportation.[40]

Green technology

Green technology refers to environmentally sound technology. Existing technologies as well as new nanotechnology, biotechnology, and digital technology may all be deployed in new ways to reduce non-renewable resource use and to utilise and support ecosystem processes.

Technology change in the energy and materials sectors are key.[41]

In the energy sector of developed countries, crucial technologies suggested by experts include smart grids, highly energy efficient buildings, electric vehicles, vastly improved and cheap batteries, nuclear power, hydrogen-fueled vehicles and supply infrastructures, and natural gas technologies. In developing countries, they included new ways of electrification, desalination based on reverse osmosis, small and medium sized nuclear reactors, and mini-grids based on intermittent renewables with storage.[42]

Cheaper and highly energy efficient fossil fuel power plants will be needed. Highly efficient vehicles including hybrid cars and intelligent transport systems (ITS) technologies for controlling traffic flows will be important.[43, 44] Large-scale deployment of solar power, and technologies to replace aluminium and other high impact materials are equally important.[45] Salinity gradient power technology could potentially produce 80 per cent of the global energy demand.[46] Passive housing technology could make a big difference in energy use, as it results in ultra-low energy buildings that require little to no energy for space heating or cooling.

Decentralized electric power systems are expected to play a very important role in coming years, especially for ensuring that no one is left behind. To this end, RD&D is needed in such systems (efficient appliances, intermittent supply solar, wind) and in interactions with heat pumps for space heating, heat and power storage and electric mobility. Innovative community and business models will be needed to operate such systems in terms of reliability, affordability, sustainability and safety and privacy. Another component of this emerging technology system will be integrated urban and rural mobility, notably a well-functioning public transport infrastructure, new mobility options (e.g., e-bike, e-car, greenwheels) and in some areas biofuel supply chains.[47] Hence, deployment of off-grid electricity systems and even direct current can be a core solution to achievement of the SDGs.[48, 49] They should be given ample research funding.[50, 51] For example, off-grid electricity could be used to dry grain[52] and to store and transport perishable food,[53] in order to reduce food wastage.[54, 55] Institutional innovation does not only promote the development and deployment of technologies, but also provides the foundations for paradigm shift. In China, block tariff of household electricity consumption accelerated replacement of incandescent fluorescent lamps with LED lamps. Feed-in pricing of wind-power and solar PV are thought to have contributed to make China the country with highest increase in and the largest installed capacity of wind and solar PV in the world.[56, 57, 58]

Cookstoves with the emissions comparable to those of an LPG stove would play an important role in the achievement of the SDGs, given the enormous and multiple benefits that could come from the large-scale deployment of such a stove.[59, 60] Globally, more than 2 billion people rely on traditional use of biomass fuels for cooking and heating and have limited access to clean and efficient energy for lighting. Increasing access to clean and efficient cookstoves and fuels can also ensure lasting, inclusive gains in the areas of poverty eradication, food security, health and well-being, education, gender equality, economic growth, reducing inequalities, sustainable cities, environmental protection, and climate change mitigation. Effective deployment of these technologies requires substantial engagement of women. Developers need to put female users at the center of their concepts, design and deployment stages.[61]

Technologies for pollution purification will be of the utmost importance until 2030. New technologies for detection and removal emerging contaminants in stormwater, for drinking water, and wastewater treatment and reuse are emerging. In the future, every gasoline-powered motor vehicle would be equipped with emission purification plant, and polluting enterprises would be installed with comprehensive purifying equipment. Meanwhile, environmentally-friendly energy would be widely used in diverse industries.[62]

New technologies are emerging that support a transition to a circular economy.[63] These include technologies for remanufacturing, technologies for product life-cycle extension such as re-use and refurbishment, and technologies for recycling.[64] Social innovation will also play an important role. The level of performance and deployment will depend on material streams and the specific context. Proposed by the EU Circular Economy Package of December 2015, a recycling rate of 65 per cent for municipal solid waste may be achievable by 2030.[65]

Technological advancement should foster an urban metabolism that is sustainable in itself not dependent on other regions for the supply of resources and the discharge of waste.[66] In this direction, new recycle and reuse technologies and multifunctional infrastructures play a pivotal role. Technologies for integrating centralized systems and decentralized systems for provision of services such as energy and potable water are also emerging.[67, 68, 69, 70, 71]

A whole range of new *deep sea mining technologies* are emerging, but many of them are not yet commercially viable. These technologies could have greatly impact sustainable development, in view of their impacts on global resource use and their potential benefits for island nations.[72]

The production of food for half of the world's population continued to depend on fertilisers made by fixation of nitrogen through the Haber-Bosch process. Technologies for nitrogen fixation that are less energy intensive and that avoid very high H_2 pressure would be highly desirable. Advances *in bio-organometallics and materials chemistry are greatly increasing the efficiency of biomimetic analogs of nitrogenase*, a natural enzyme that can fix atmospheric nitrogen at room temperature and pressure without the need of molecular hydrogen.

Improvements in geophysical research and seismic exploration of the ocean floor, through the application of *marine Vibroseis* (MV), show potential in providing an environmentally safer alternative to airguns, which have negative effects on marine animals.[73]

Artificial photosynthesis is close to commercialization. It is now possible to produce different carbohydrates directly from CO_2 and water using merely sunlight. Artificial leafs, when immersed in water, directly produces hydrogen and oxygen. These leafs consist of wireless, low-cost, thin film amorphous silicon multi-junction cells.[74]

Endnotes

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Chapter 2

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