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<br><br>19 targets | **General technology performance targets for 2030:**<br>8.4 Improve progressively… global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation…<br>8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation….<br>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….<br>**Issue-specific, quantitative technology performance targets for 2030:**<br>2.3 …double the agricultural productivity …. of small-scale food producers….<br>3.3 …end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases<br>3.6 …halve the number of global deaths and injuries from road traffic accidents<br>6.3 …halving the proportion of untreated wastewater<br>7.3 …double the global rate of improvement in energy efficiency<br>12.3 …halve per capita global food waste at the retail and consumer levels…<br>**Issue-specific, qualitative technology performance targets for 2030:**<br>3.9 …substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination<br>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<br>6.4 …substantially increase water-use efficiency across all sectors…<br>7.2 …increase substantially the share of renewable energy in the global energy mix<br>7.b …expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries…<br>12.3 …reduce food losses along production and supply chains, including post-harvest losses<br>12.5 …substantially reduce waste generation through prevention, reduction, recycling and reuse<br>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)<br>14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels<br>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<br><br>12 targets | **Access to basic services by 2030:**<br>1.4. …ensure that all men and women …. have… access to basic services…and…appropriate new technology…<br>6.1 …achieve universal and equitable access to safe and affordable drinking water for all<br>6.2 …achieve access to adequate and equitable sanitation and hygiene for all and end open defecation…..<br>7.1 …ensure universal access to affordable, reliable and modern energy services<br>11.1 …ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums<br>11.2 …provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety…<br>**Access to technology:**<br>3.b ….provide access to affordable essential medicines and vaccines….<br>9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, …., with a focus on affordable and equitable access for all<br>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<br>16.10 Ensure public access to information and protect fundamental freedoms…<br>**Technology use:**<br>5.b Enhance the use of enabling technology, in particular ICT, to promote the empowerment of women<br>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<br><br>17 targets | **Research, development and demonstration:**<br>3.b Support the research and development of vaccines and medicines for the communicable and non-communicable diseases that primarily affect developing countries….<br>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<br>9.b Support domestic technology development, research and innovation in developing countries…<br>14.a Increase scientific knowledge, develop research capacity and transfer marine technology… |
| | **Technology transfer and diffusion:**<br>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<br>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:**<br>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…<br>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:**<br>8.3 Promote development-oriented policies that support … entrepreneurship, creativity and innovation…<br>9.b …ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities<br>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:**<br>2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension<br>services, technology development and plant and livestock gene banks…<br>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.<br>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<br>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<br>12.a Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production<br>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.<br>• Incremental and radical technology and infrastructure performance improvements – all are needed.<br>• Barriers to technology deployment and diffusion in developing countries to be removed and R&D investments to be increased.<br>• Coherent and comprehensive techno-economic policies are needed.<br>• 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.<br>• 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.<br>• Science roadmaps, technology roadmaps and R&D roadmaps to agree on priority actions of the science and engineering communities.<br>• Technology investments need to be significantly increased.<br>• Share information and advice among countries on policies, actions, and partnerships.<br>• Communication, education and public awareness raising are essential, especially among consumers.<br>• Systems thinking and technologies for a circular economy.<br>• Integrated assessment models can be useful to design sustainable development policies.<br>• 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.<br>• Inclusive innovation policies to promote equity.<br>• Technology assessment and foresight to understand potential implications of new technologies and guide policy.<br>• Ecosystem approach to policy, in order to address technology gaps continually arising with new technologies.<br>• Taking into account the interests of underserved populations throughout the innovation process.<br>• Promote access to and use of assistive technology for people with disabilities.<br>• On-the-ground solutions and technological innovations to be considered a core component of livelihood strategies.<br>• Leverage the social technology of sharing in urban slums.<br>• Intervention research drawing on cognitive science, psychology, behavioural economics, and anthropology.<br>• 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.<br>• 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.<br>• Promote urban innovation units, living labs, open science, and science parks, to harness localised, inclusive innovations.<br>• Re-defining megacities' functions through legislation and balanced distribution of public resources.<br>• Institutions to promote development of low cost local technology solutions based on community knowledge.<br>• Better data need to be collected, openly shared and analysed.<br>• Partnerships at the city and national levels could bring together and share disaggregated data.<br>• 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.<br>**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.<br>**Transport:** integrated public transport infrastructure, electric vehicles (e-car and e-bike), hydrogen-fueled vehicles and supply infrastructures.<br>**Water:** mobile water treatment technology, waste water technology, advanced metering infrastructure.<br>**Buildings:** sustainable building technology, passive housing.<br>**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.<br>**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

2 Anadon, Laura Diaz, Gabriel Chan, Alicia Harley, Kira Matus, Suerie Moon, Sharmila L. Murthy, and William C. Clark. "Making Technological Innovation Work for Sustainable Development." Paper, Harvard Kennedy School, December 2015. Available at: https://research.hks.harvard.edu/publications/getFile.aspx?Id=1294.

3 https://sustainabledevelopment.un.org/topics/science/crowdsourcedbriefs

4 Pan, Jiahua (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

5 Jiahua Pan, (2015a). China's Environmental Governing and Ecological Civilization. China Social Science Press and Springer-Verlag Berlin.

6 Grübler, A., (1998). Technology and Global Change. Cambridge, United Kingdom: Cambridge University Press.

7 Diamond, J., (2005). Collapse: How Societies Choose to Fail or Succeed. New York: Viking Press.

8 Holdren, J.P., (2006). The energy innovation imperative: addressing oil dependence, climate change, and other 21st century energy challenges. Innovations: Technology, Governance, Globalization, vol. 1, No. 2, pp. 3-23.

9 Acemoglu, Daron (2002). Technical Change, Inequality, and The Labor Market. Journal of Economic Literature, 40, March 2002: pp. 7-72. http://economics.mit.edu/files/4124

10 Fu, Xiaolan & Gong, Yundan, 2011. "Indigenous and Foreign Innovation Efforts and Drivers of Technological Upgrading: Evidence from China," World Development, Elsevier, vol. 39(7), pages 1213-1225, July, https://ideas.repec.org/a/eee/wdevel/v39y2011i7p1213-1225.html

11 Dilek Aykut & Andrea Goldstein (2006). "Developing Country Multinationals: South-South Investment Comes of Age," OECD Development Centre Working Papers 257, OECD Publishing., https://ideas.repec.org/p/oec/devaaa/257-en.html

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.

13 We could not identify any such review or assessment of current perspectives of scientists. Possible exceptions on the sectoral level are two SD21 studies that were undertaken by DESA in preparation for Rio+20: one on energy perspectives, the other on food and agriculture. However, they have a more general focus than merely technology.

14 DESA (2012). Perspectives on sustainable energy for the 21st century, UN SD21 study for Rio+20, https://sustainabledevelopment.un.org/content/documents/1131Energy_SD21.pdf

15 DESA (2012). Food and agriculture: sustainability for the 21st century, UN SD21 study for Rio+20, https://sustainabledevelopment.un.org/index.php?page=view&nr=625&type=400&menu=35

16 Roehrl, R., et al. (2016). Perspectives of Scientists on technology and the SDGs, Background paper for the GSDR 2016, May 2016, to appear http://sustainabledevelopment.un.org/globalsdreport/2016/

17 Kamp Adriaan (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

18 "Strengthening National Systems of Innovation to Enhance Action on Climate Change," TEC Brief No. 7, UNFCCC (2015).

19 Sagar, Ambuj (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

20 Pan Jiahua, (2015b). Ecological Civilization: A New Development Paradigm China Economist Vol.10, No.4, July-August 2015(p044-71).

21 Nakicenovic, Nebojsa, (2016). PGA High-level dialogue, New York, 21 April 2016.

22 Technologies closer to the consumer, like mobile phones, generally diffuse more rapidly than "lumpier" technologies such as power plants assuming of course that there are infrastructures available for their deployment and that they meet human needs.

23 Nakicenovic, Nebojsa (2016). Framing for the Narrative for the UN Forum on STI for the SDGs, Draft, May 2016.

24 OECD (2000) "Science, Technology and Innovation in the New Economy" Policy Brief. September 2000. Retrieved on April 22 from http://www.oecd.org/science/sci-tech/1918259.pdf

25 Evoh, C. (2015) Evoh, Chijioke J. (2015) "ICT and African Transition to the Knowledge Economy: Issues and Challenges Facing Nigeria" in Funso Adesola, Iwebunor Okwechime, Ronke Ako- Nai and Akin Iwilade (eds.) (2015), State, Governance and Security in Africa: A Festschrift in Honour of Professor Bamitale Idowu Omole, Tallahassee, (Florida, USA), SokheChapke Publishing Inc.

26 Salkowitz, R. (2010) Young World Rising: How Youth, Technology and Entrepreneurship are changing the World from the Bottom up. Hoboken, NJ: John Wiley & Sons Inc.

27 Houghton, J., & Sheehan, P. (2000) "A Primer on the Knowledge Economy" CSES Working Paper No. 18. Centre for Strategic Economic Studies Victoria University of Technology http://www.business.vu.edu.au/cses/documents/working_papers/cses/wp18_2000_cses.pdf

28 Yet, Africa with a penetration rate of eleven percent for mobile broadband service subscription continues to lag the other regions. Source: International Telecommunication Union (2014) Measuring the Information Society Report, 2014. Geneva: International Telecommunication Union

29 Chijioke Josiah Evoh (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

30 Evoh, C. (2015) Evoh, Chijioke J. (2015) "ICT and African Transition to the Knowledge Economy: Issues and Challenges Facing Nigeria" in Funso Adesola, Iwebunor Okwechime, Ronke Ako- Nai and Akin Iwilade (eds.) (2015), State, Governance and Security in Africa: A Festschrift in Honour of Professor Bamitale Idowu Omole, Tallahassee, (Florida, USA), SokheChapke Publishing Inc.

31 Donnenfeld, Zachary (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

32 Philibert, Cedric, (2006). Barriers to technology diffusion: the case of solar thermal technologies. International Energy Agency, document number COM/ENV/EPOC/IEA/SLT(2006)9, https://www.oecd.org/env/cc/37671704.pdf

33 Richardson, J.W. (2011). Challenges of Adopting the Use of Technology in Less Developed Countries: The Case of Cambodia. Comparative Education Review, 55(1), 8-29.

34 IPCC (2000) - Bert Metz, Ogunlade Davidson, Jan-Willem Martens, Sascha Van Rooijen and Laura Van Wie Mcgrory (Eds.). Methodological and Technological Issues in Technology Transfer. Cambridge University Press, UK. http://www.ipcc.ch/ipccreports/sres/tectran/index.php?idp=0

35 Batelle and R&DMag (2014). 2014 Global R&D Forecast. https://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf

36 According to the latest official statistics collected by UNESCO for the SDG progress report, in 2013, public and private investments into R&D were 2.36% of GDP for developed regions, 1.16% of GDP for developing regions and 1.7% of GDP for the world in 2013.

37 Rogner, Holger, (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

38 Colglazier, W. (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

39 Saidam, Muhammad (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

40 Bandala E.R., Patino-Gomez C. 2016. Phys. Chem. Earth 91, 1.

41 Bandala, Erick (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

42 L. Christiansen, A. Olhoff and S. Trærup (eds.): Technologies for Adaptation: Perspectives and Practical Experiences, UNEP Risø Centre, Roskilde, 2011.

43 Klein, Naomi (2014). This changes everything: Capitalism vs. The Climate. Simon & Schuster. ISBN-10: 1451697392

44 de Vries, Bert (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

45 An “innovation system” is the connected set of actors and institutions that shape the process of technological change, where the term “technology” includes both physical artifacts and practices. Innovation can be conceptualized as a nonlinear process that includes multiple stages including invention, selection, production, adoption, adaptation and retirement.

46 Harley A, et al. (2014) Innovation and Access to Technologies for Sustainable Development: A Global Systems Perspective (Sustainability Science Program Working Paper Working Paper No. 2014-02, Kennedy School of Government, Harvard University, Cambridge, MA).

47 Brunner, José Joaquín & Gregory Elacqua (2003): Informe de Capital Humano En Chile, ediciones Universidad Adolfo Ibañez, Mayo.

48 The Boston Consulting Group (2007): Hacia una estrategia nacional de innovación para la competitividad: Consejo de Innovación para la competitividad.

49 Huepe Minoletti, Claudio, (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

50 Mwendwa, P. (2015). Assessing the fit of RapidSMS for maternal and new-born health: perspectives of community health workers in rural Rwanda. Development in Practice, 26(1), 38-51. doi:10.1080/09614524.2016.1112769

51 Mwendwa, P. (2016 Forthcoming). What Encourages Community Health Workers (CHWs) to Use Mobile Technologies for Health Interventions? Emerging Lessons from Rural Rwanda. Development Policy Review.

52 Purity Mwendwa (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

53 located in the city of Mogi Guaçu, in the region of Campinas, 170 km from São Paulo

54 Ribeiro,J.H. (2016). G1 Natureza. Edição do dia 06/12/2015 Mogi-Guaçu, SP. 2015. Disponível em: <http://g1.globo.com/natureza/noticia/2015/12/floresta-recriada-tem-hoje-mais-de-100-especies-de-arvores-nativas.html> Acesso em: 25 abr. 2016.

55 This is a high-impact intervention, as forests control the humidity and temperature, reduce flooding and refilling the river, improve water quality, soil and river, reduce air pollutants, produce oxygen and carbon sequestration gas, prevent wind and noise, provide recreation and education, medicines, food and biomass. Please refer to: Kobiyama, M. (2000). Ruralização na gestão de recursos hídricos em área urbana. Revista OESP Construção. Ano 5, n. 32, p. 112-117. São Paulo. 2000

56 They conserve water sources, control erosion, provide slope stability, maintain ecosystems, and provide protection against flooding, the tide, drought, blizzards, fogs, falling rocks. Please refer to: Kobiyama, M. (2012). Relação entre desastres naturais e floresta. Revista Geonorte, V.1, N.6, p.17–48, 2012.

57 Vania Aparecida dos Santos (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

58 Colglazier, W. (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

59 Nakicenovic, Nebojsa (2016). Framing for the Narrative for the UN Forum on STI for the SDGs, Draft, May 2016.

60 Diarra, Birama (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

61 Sachs, Jeffery (2016). PGA High-level dialogue, New York, 21 April 2016.

62 https://sustainabledevelopment.un.org/TFM

63 Colglazier, W. (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

64 EC (2015). From Niche to Norm – Suggestions by the group of experts on a ‘Systemic approach to eco-innovation to achieve a low-carbon, circular economy’. European Commission, Brussels http://bookshop.europa.eu/en/from-niche-to-norm-pbKI0115206/ (accessed 24 April 2016).

65 Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment (2015). Growth within: a circular economy vision for a competitive Europe. http://www.ellenmacarthurfoundation.org/ (accessed 24 April 2016).

66 Wijkman, A. and Skanberg, K. (2015). The circular economy and benefits for society. The Club of Rome. http://www.clubofrome.org/wp-content/uploads/2016/03/The-Circular-Economy-and-Benefits-for-Society.pdf (accessed 24 April 2016).

67 EC (2016). Circular economy strategy. Thematic website, European Commission, Brussels http://ec.europa.eu/environment/circular-economy/index_en.htm (accessed 24 April 2016).

68 Kusch, S. (2015). Industrial symbiosis: powerful mechanisms for sustainable use of environmental resources. Brief for the UN Global Sustainable Development Report 2015. https://sustainabledevelopment.un.org/topics/science/crowdsourcedbriefs (accessed 24 April 2016).

69 Gatzweiler, Franz W., and members of the scientific committee of the ICSU-UNU-IAMP global, interdisciplinary science programme on Urban Health and Wellbeing: a Systems Approach (2016). Brief for GSDR - A systems approach to urban health and wellbeing to meet the sustainability challenges of urban change. https://sustainabledevelopment.un.org/content/documents/9461GSDR_2016_Brief_Urban%20health%20and%20Wellbeing.pdf

70 Kusch, S.; Fleming, A.; Cradock-Henry, N.; Schmitz, N.; Pereira, L.; Vogt, J.; Lim, M.; Kharrazi, A.; Evoh, C.J.; Hamel, P.; Bollmohr, S.; Patterson, J.; Adler, C.; Waterlander, W.; Sugiura, A.; Augustyn, A.M.; Dogra, A.; Mukherjee, N.; Onzere, S.; Mahomoodally, F.; Hughes, A.C.; Bowen, K.; Tironi, A.; Smith, K.; Hoffenson, S.; Udenigwe, C.C.: Sustaina-bility in a changing world: integrating human health and wellbeing, urbanisation, and eco-system services. Brief for the UN Global Sustainable Development Report, 2016. https://sustainabledevelopment.un.org/topics/science/crowdsourcedbriefs (accessed 24 April 2016).

71 Nexus Network (2016). Resources. Material made available on the website of the Nexus Network. http://www.thenexusnetwork.org/about/resources/ (accessed 24 April 2016).

72 Nexus Resource Platform (2016). Nexus knowledge. Available on the website of the Water, Energy & Food Security Nexus Resource Platform. http://www.water-energy-food.org/en/knowledge.html (accessed 24 April 2016).

73 Kusch, Sigrid (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

74 The SDGs are best thought of as a dynamic system of interlinked feedback loops and time delays running across the three dimensions of sustainability.

75 Groesser, S.N. and M. Schaffernicht. 2008. Mental models of dynamic systems: taking stock and looking ahead. System Dynamics Review. Vol. 28. No. 1. 46-68.

76 Sterman, J. 1994. Learning in and about complex systems. System Dynamics Review. Vol. 10, No. 2-3, 291-330.

77 Young, O.R., A. Underdal, N. Kanie, S. Andresen, S. Bernstein, F. Biermann, J. Gupta, P. M. Haas, M. Iguchi, M. Kok, M. Levy, M. Nilsson, L. Pintér and C. Stevens. 2014. United Nations University. Policy Brief #1. Downloaded from http://www.earthsystemgovernance.org/sites/default/files/publications/files/Policy-Brief-1.pdf

78 Pedercini, M. and Barney G.O. 2010. Dynamic analysis of interventions designed to achieve Millennium Development Goals (MDG): The case of Ghana. Socio-Economic Planning Sciences, 44(2):89-99.

79 The iSDG model is based on the Threshold-21 model that has been used extensively for assessments of green economy and sustainable agriculture.

80 UNEP, 2011, Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers, www.unep.org/greeneconomy

81 Zuellich, G., Dianati, K., Arquitt, S. and M. Pedercini. 2015. Competing agricultural paradigms to meet urban and rural food needs in Senegal – an integrated systems approach. Food and Agriculture Organization, Meeting Urban Food Needs (MUFN) project. http://www.fao.org/fileadmin/templates/ags/docs/MUFN/CALLS_FILES_EXPERT_2015_b.pdf

82 Matteo Pedercini and Steve Arquitt (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

83 Kuznets, 1979; Amsden, 2001; McMillan and Rodrik, 2011.

84 Saviotti and Pyka, 2004, Imbs and Wacziarg, 2003.

85 Cristelli, Tacchella and Pietronero, 2015; Hartmann et al, 2015.

86 Freire, Clovis (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

87 Reuter, Thomas (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

88 de Vries, Bert (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

89 V.N. Attri (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

90 Qinqi Dai and Yu Yang (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

91 V.N. Attri (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

92 Foster and Heeks, 2013.

93 It is important to note that the development of inclusive innovation is not necessarily restricted to higher technical specifications. Inclusive innovation can be developed from cutting-edge research or it can consider fairly rudimentary or previously existing technologies. This, however, does not limit its potential to produce significant impact (UNCTAD, 2014, Innovation policy tools for inclusive development p 5,(TD/B/C.II/25))

94 Ibid.

95 UNCTAD, 2011, Applying a gender lens to STI (UNCTAD/DTL/STICT/2011/5)

96 UNCTAD, 2013, Technology in Action: Good Practices in Science, Technology and Innovation Policies for Women in South Asia - UNCTAD Current Studies on Science, Technology and Innovation No 12 (UNCTAD/DTL/STICT/2013/3).

97 Steffen Helbing (2016). Suggestions for the conception of barrier-free disaster prevention in Germany. Zentrum für Kultur und visuelle Kommunikation der Gehörlosen in Berlin/Brandenburg e.V.

98 Please refer to UNCTAD's World Investment Report in 2008, 2010, 2009, 2013 and 2014, respectively.

99 A recent UNCTAD study entitled "Bridging Digital Divides to Reap Digital Dividends" found that while ICT usage is leading

to transformative impacts across all sectors of the society, new divides are continuously emerging. It identified public policy instruments to facilitate application of emerging technologies.

100 Foster C and Heeks R (2013). Conceptualising Inclusive Innovation: Modifying Systems of Innovation Frameworks to Understand Diffusion of New Technology to Low-Income Consumers. European Journal of Development Research. 25(3):333–355.

101 When measured in terms of fixed broadband connectivity or the percentage of people using internet.

102 Lebel L, Lorek S (2008) Enabling sustainable production-consumption systems. Annu Rev Environ Resour 33:241–275.

103 Fu, X., Hou, J., Mohnen, P. (2015) The impact of China-Africa trade on the productivity of African firms: Evidence from Ghana. Working paper. Oxford: Oxford Department of International Development.

104 van Kerkhoff L, Lebel L (2006) Linking knowledge and action for sustainable development. Annu Rev Env Resour 31:445–477.

105 By reducing information asymmetries, decreasing social distance between actors with expertise and skills

106 Ockwell D, Sagar A, de Coninck H (2015) Collaborative research and development (R&D) for climate technology transfer and uptake in developing countries: towards a needs driven approach. Clim Change 131(3):401–415.

107 Mutanga, Oliver (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

108 Bauer, S.M., Elsaesser L.J. & Arthanat, S. 2011. Assistive technology device classification based upon the World Health Organization's, International Classification of Functioning, Disability and Health (ICF). Disability and Rehabilitation: Assistive Technology 6(3): 243-259.

109 Oishi, M., Van der Loos, M., & Mitchell, I. 2010. Design and use of assistive technology: Social, technical, ethical, and economic challenges, Springer: New York, NY.

110 Balcazar, F.E, Suarez Balcazar, Y., Taylor Ritzer, T. & Keys, C.B. 2010. Race, Culture and Disability: Rehabilitation Science and Practice. James and Bartlett Publishers: Massachusetts.

111 The 2015 Association for the Advancement of Assistive Technology in Europe and the World Health Organisation report 'Global Challenges in Assistive Technology' (World Health Organisation, 2015:3).

112 Mutanga, Oliver (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

113 Antje Bruns and Rosella Alba (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

114 The suggestions above are based on on-going empirical research carried out within WaterPower research project (www.waterpower.science) and the Governance and Sustainability Lab, Trier University.

115 Alba, R. and A. Bruns (2016). "Beyond the pipe: rethinking urban water supply in African cities", Paper presented at Southern African Cities Studies Conference 2016 , 17-19 March, Durban South Africa.

116 Silver, J. (2014). "Incremental infrastructures: material improvisation and social collaboration across post-colonial Accra." Urban Geography 35.6: 788-804.

117 Stoler, J. (2012) "Improved but unsustainable: accounting for sachet water in post-2015 goals for global safe water." Tropical Medicine & International Health 17.12: 1506-1508.

118 Brenner, N. (2014). "Implosions/Explosions. Towards a Study of Planetary Urbanization".

119 Freese, J. 2009. "Preferences." In The Oxford Handbook of Analytical Sociology, edited by Peter Hedström and Peter Bearman, 94–114. Oxford, U.K.: Oxford University Press.

120 Finitsis, DJ, Pellowski, JA and Johnson BT. Text Message Intervention Designs to Promote Adherence to Antiretroviral Therapy (ART): A Meta-Analysis of Randomized Controlled Trials. PLoS One. 2014; 9(2): e88166.

121 Bernard T, Dercon S, Orkin K, Seyoum Taffesse, A. 2014. "The Future in Mind: Aspirations and Forward-Looking Behaviour in Rural Ethiopia." Working Paper, Centre for the Study of African Economies, University of Oxford, Oxford, U.K.

122 Shankar, AV, Onyura, M and Alderman, J. Agency-based empowerment training enhances sales capacity of female cookstove entrepreneurs in Kenya. Journal of Health Communications 2015 (a);20 Suppl 1:67-75.

123 Shankar, AV, Onyura, M, Ojode, M and Milliam, E. Fostering agency and wellbeing in women: an evaluation of the IMAGINE Initiative. Development in Practice, 2015 (b) Vol. 25, No. 3, 375–388.

124 Shankar, A., (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

125 Sharma, Deepak (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

126 OECD (2011) Divided We Stand: Why Inequality Keeps Rising, OECD Publishing, Paris.

127 OECD (2012) Innovation for Development: The challenges ahead, in OECD Science, Technology and Industry Outlook 2012, OECD Publishing, Paris.

128 OECD (2015) Innovation Policies for Inclusive Growth, OECD Publishing, Paris.

129 UN (2013) Science, technology and innovation for sustainable development in the global partnership for development beyond 2015, Thematic Think Piece of the UN System Task Team on the post-2015 UN Development Agenda, March.

130 Gatzweiler, Franz, (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

131 Gatzweiler, F.W., von Braun, J., (2016). Technological and Institutional Innovations for Marginalized Smallholders in Agricultural Development, Springer, http://link.springer.com/book/10.1007%2F978-3-319-25718-1

132 WHO (2016) Health product research and development fund: a proposal for financing and operation (Special Programme for Research and Training in Tropical Diseases (TDR), Geneva, Switzerland).

133 Jaffe AB, Newell RG, Stavins RN (2005) A tale of two market failures: Technology and environmental policy. Ecol Econ 54(2-3):164–174.

134 Kinn, M. . (2011a). Benefits of Direct Current Electricity Supply for Domestic Application. (MPhil Thesis), The University of

Manchester. Retrieved from http://www.dcisthefuture.org/papers

135 Kinn, M. . (2011b). Proposed components for the design of a smart nano-grid for a domestic electrical system that operates at below 50V DC. Paper presented at the Innovative Smart Grid Technologies (ISGT Europe), 2011 2nd IEEE PES International Conference and Exhibition on.

136 Kinn, Moshe (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

137 de Vries, Bert (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

138 See http://www.dcisthefuture.org/papers for more information.

139 Kinn, M, C, & Abbot, C. (2014). The use of direct current voltage systems to increase a city's resilience and reduce the vulnerability of economic activity from a disaster.

140 Kinn, Moshe, & Abbott, Carl. (2014). To what Extent is Electricity Central to Resilience and Disaster Management of the Built Environment? Procedia Economics and Finance, 18(0), 238-246. doi: http://dx.doi.org/10.1016/S2212-5671(14)00936-8

141 IMECHE. (2013). Global food waste not want not (pp. 31).

142 J.Gustavsson, C.Cederberg, U. Sonesson. (2011). Global food losses and food waste: FAOUN.

143 In 1998, Japan initiated the Top Runner Programme to improve energy efficiency of end-use products, as a cornerstone of its climate change policy. The idea is that the most energy-efficient product on the market during the standard-setting process establishes the "Top Runner standard" which all corresponding product manufacturers will aim to achieve in the next stage.

144 K. Akimoto et al., Assessment of the emission reduction target of halving CO2 emissions by 2050: Macro-factors analysis and model analysis under newly developed socio-economic scenarios, Energy Strategy Reviews, 2, 3–4, 246–256 (2014).

145 Akimoto, Keigo (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

146 Qinqi Dai and Yu Yang (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

147 Jasovsky, D., et al. (2016). Antimicrobial resistance - A threat to the world's sustainable development. Development Dialogue Paper 16. April 2016.

148 For example, a case study of M-KOPA reveals an innovative provisioning of affordable electricity to low income customers in East Africa through off-grid energy by offering a pay-as-you-go solar energy service. Similarly, the Jisomee Mita programme in Nairobi informal settlements enables access to piped water facilitated by self-metering and mobile payments.

149 This note is based on the issues paper prepared by the CSTD secretariat on 'Smart Cities and Infrastructure' presented at the CSTD inter-sessional Panel 2015-16 in Budapest, Hungary, available at: http://unctad.org/meetings/en/SessionalDocuments/CSTD_2015_Issuespaper_Theme1_SmartCitiesandInfra_en.pdf

150 Pan, Jiahua (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

151 Pan, Jiahua. 2015c. Environmental Sustainability in Mega-cities: Technological Breakthroughs and the Rigidity of Environmental Constraints. Chinese Journal of Urban and Environmental Studies Vol. 3, No. 4 (2015) 1550027 (10 pages), World Scientific Publishing Company. DOI: 10.1142/S234574811550027X

152 Singh, R.B. (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

153 Mukherjee, Mahua (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

154 Especially SDGs 6, 9, 11, 13, 15 and 17

155 i.e., air pollution, Urban Heat Island, Heatwave impact.

156 i.e., ground water quality improvement, flood mitigation and storm water management.

157 Ahern, J. (2010), Planning and design for sustainable and resilient cities: theories, strategies, and best practices for green infrastructure, In: Novotny, V., Ahern, J., and Brown, P. (eds.), Water-Centric Sustainable Communities, pp. 135-176, John Wiley and Sons, Hoboken.

158 Asian Development Bank (2015) 'Green city development tool kit', Asian Development Bank, Mandaluyong City, Philippines, pp. 11-13.

159 Bowler, D.E., Buyung-Ali, L., Knight, T.M., and Pullin, A.S. (2010) 'Urban greening to cool towns and cities: A systematic review of the empirical evidence', Landscape and Urban Planning, Vol 97, pp.147-155.

160 Konijnendijk, C.C., Annerstedt, M., Nielsen, A.B, Busse, A., and Maruthaveeran, S. (2013) 'Benefits of Urban Parks - A systematic review', A Report for IFPRA , Copenhagen & Alnarp.

161 Wolf, K. L. (2003) 'Ergonomics of the City: Green Infrastructure and Social Benefits', in C. Kollin (Ed.), Engineering Green: Proceedings of the 11th National Urban Forest Conference, Washington D.C., American Forests.

162 Lu et al.

163 Ebikeme et al. *Open Data in a Big Data World: challenges and opportunities for sustainable development*.

164 Science International (2015): Open Data in a Big Data World. Paris: International Council for Science (ICSU), International Social Science Council (ISSC), The World Academy of Sciences (TWAS), InterAcademy Partnership (IAP), http://www.icsu.org/science-international/accord

165 Hughes, Alice (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

166 Big Data & Development Overview on the 3 C's, the future of big data, and key terms.

167 Big Data and the SDGs more particularly: http://datapopalliance.org/item/reflections-on-big-data-the-sustainable-development-goals-measuring-achieving-development-progress-in-the-big-data-era/

168 see notably: http://arxiv.org/pdf/1603.04012v1.pdf

169 DFID paper for more case studies examples of the usefulness of Big data to monitor, predict, and direct recovery

from disasters and related or follow up posts: http://datapopalliance.org/10-key-take-aways-cop21data/; http://datapopalliance.org/unevenly-distributed-resilience/; http://datapopalliance.org/leveraging-the-crowd-how-people-can-contribute-to-disaster-management/; http://datapopalliance.org/the-real-promise-of-big-data-seeing-like-a-state-and-like-a-citizen/ ; http://datapopalliance.org/using-big-data-to-detect-and-predict-natural-hazards-better-and-faster-lessons-learned-with-hurricanes-earthquakes-floods/ ; http://datapopalliance.org/urban-identity-and-the-fragility-resilience-double-helix/

170 For instance, Data-Pop Alliance's Flowminder analyzed mobile network data to estimate population movement and distribution after a Nepal earthquake in 2015.

171 Emmanuel Letouze and Anna Swenson (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

172 Nicholas Zimmermann, *Deployment of Technology to Mitigate Drought Risk in Syria*, Brief for GSDR. https://sustainabledevelopment.un.org/content/documents/5570Deployment of Technology to Mitigate Drought Risk in Syria.pdf

173 Submission by UN Statistics Division.

174 A sample of processes that this report examined include: World Economic Forum, The Global Risks Report 2016; Swiss Re SONAR: New Emerging Risk Insights, 2015; DNV-GL, UN Global Compact, Mondaymorning-Global Institute, Global Opportunity Report 2016; and Sutherland et al, A Horizon Scan of Global Conservation Issues for 2016, 31(1) Trends in Ecology & Evolution (2016).

175 WFEO Engineers for a Sustainable Post 2015, July 2015, http://www.aaes.org/sites/default/files/WFEOENGINEERSFORASUSTAINABLEPOST2015%20V1.6.pdf

176 https://sustainabledevelopment.un.org/topics/science/crowdsourcedbriefs

177 Schwab, K. (2016) The Fourth Industrial Revolution. World Economic Forum.

178 Kolodziejczyk, Bartlomiej (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

179 Colglazier, W. (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

180 Friedrich Soltau, The promise of synthetic biology for sustainable development, Brief for GSDR.

181 Manish Anand, Innovation and Sustainable Development: A Bioeconomic Perspective. Brief for GSDR.

182 Addie, Ali J. *Nanotechnology and Sustainable Development in Iraq*, Brief for GSDR.

183 Steven A. Moore, Reframing Social Housing as an Infrastructure of Production and Consumption, Brief for GSDR.

184 Ashish Jha et al., Accelerating achievement of the sustainable development goals. A game-changer in global health , Brief for GSDR.

185 Kemp, Rene (2010). Ekonomiaz N.º 75, 3.er cuatrimestre, 2010.

186 Reuter, Thomas (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

187 Okabe, A. (2016) E-VOIDs: a bottom-up micro-intervention for better lighting and ventilation in high density slums, Jakarta (Indonesia), https://sustainabledevelopment.un.org/

188 Pitria, M., Yoshikata, Y. and Okabe, A. (2015) Involution: A Strategy of Kinship based Living Spaces to Deal with High Density Population Urban Kampung, A Case Study in Kampung Cikini, Jakarta, Indonesia, The 5th International Conference of JABODETABEK Study Forum 2015, IICC: Bogor.

189 Amemiya, T., Okabe, A., Evawani, E. et al. (2014), Holcim Awards 2014 Asia Pacific Acknowledgement Prize: Megacity Skeleton, Stakeholder participation for urban upgrading, http://www.lafargeholcim-foundation.org/Projects/megacity-skeleton

190 Okabe, Akiko (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

191 Base-load power refers to electric generation resources that operate continuously and are available 24 hours a day.

192 Rogner, H., (2016), submission to UN survey among scientists on technology and the SDGs, conducted in April 2016.

193 http://unctad.org/meetings/en/SessionalDocuments/CSTD_2015_Issuespaper_Theme2_ForesightDigitalDev_en.pdf

194 http://unctad.org/meetings/en/SessionalDocuments/ecn162016crp1_en.pdf

195 0http://unctad.org/meetings/en/SessionalDocuments/ecn162016d3_en.pdf