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on

The impact of rapid technological change on sustainable development

Draft

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I. Introduction

The interest within the United Nations in new technologies is spurred by the opportunities of frontier technologies to address and monitor the ambitious Sustainable Development Goals. The 2030 Agenda for Sustainable Development, adopted by world leaders in 2015, aims to "leave no one behind" and therefore puts forward a broad and ambitious agenda for global action on sustainable development. The scale and ambition of the Sustainable Development Goals (SDGs) require new modalities for development, including bringing technology and innovation into the foreground of development strategies. Science, technology and innovation (STI) are not only an explicit focus of Goal 9 (Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation). They are key enablers of most of the Goals. Therefore, harnessing frontier technologies could be transformative in achieving the SDGs and creating more prosperous, sustainable, healthy and inclusive societies.

Recent decades have seen a dramatically accelerating pace in the development and adoption of new technologies, even though various gaps persist in terms of adoption in different parts of the world, especially in the least developed countries. This rapid technological change is affecting almost every area of the economy, society and culture. The *Technology and Innovation Report 2018* (UNCTAD, 2018) found that the pace of development and adoption of new technologies is likely to continue in the coming years. Frontier technologies are often at the center of discussions. They are characterized by their rapid development (Fogel, 1990; Anthony, 2016; Simonite 2016) and great possibilities for combination based on digitalization and connectivity (UNCTAD, 2017). This convergence of technologies to digital is enabled by the Internet (Manyika et al., 2016), which is facilitating ease of use, and dramatic reductions in the cost of computing. The convergence is resulting in the democratization of access and the emergence of new actors and forms of innovation.

Rapid technological change involves, among others, technologies like big data, the Internet of Things, machine learning, artificial intelligence, robotics, 3D printing, biotechnology, nanotechnology, renewable energy technologies, satellite, and drone technologies. These represent a significant opportunity to achieve the 2030 Agenda for Sustainable Development and the Sustainable Development Goals. Rapid technological change could contribute to many if not all of the Goals, especially those related to hunger (Goal 2), health (Goal 3), education (Goal 4), gender equality (Goal 5), clean energy (Goal 7), industry, innovation and infrastructure (Goal 9), sustainable cities and communities (Goal 12) and climate change (Goal 13) (United Nations Department of Economic and Social Affairs, 2018; UNCTAD, 2016a; UNCTAD 2017a).

At the same time, rapid technological change poses new challenges for policy-making. It can outpace the capacity of governments and society to adapt to the changes that new technologies bring about, as they can affect labor markets, perpetuate inequalities, and raise ethical questions. These are questions highly relevant for Goal 8 (decent work and economic growth) and Goal 10 (reduced inequalities) (United Nations Department of Economic and Social Affairs, 2018).

In recent years, there has also been growing interest by Member States to examine the impact of rapid technological change on sustainable development within the United Nations System. Discussions have been taking place in several fora, including the General Assembly, the United Nations Commission on Science and Technology for Development (CSTD), the Multi-stakeholder Forum on Science, Technology and Innovation for the Sustainable Development Goals (STI Forum), and various other regional and global workshops and expert group meetings.

This issues paper responds to General Assembly Resolution 72/242 which requests the CSTD, through ECOSOC, to give due consideration to the impact of key rapid technological changes on the achievement of the Sustainable Development Goals. Through the present issues paper the CSTD seeks to deepen the understanding of the impact of rapid technological change on sustainable development, especially the consequences for the central principle of the 2030 Agenda of "leaving no one behind", and the implications for the science, technology and innovation community. It examines the opportunities, risks and challenges brought about by rapid technological change, and looks at the role of science, technology and innovation (STI) policy. It identifies strategies, policies and immediate actions to take to use science, technology and innovation to empower people, especially those who are vulnerable, and ensure inclusiveness and equality.

Chapter II presents the opportunities of rapid technological change for achieving as well as monitoring the Sustainable Development Goals. It examines how new and emerging technologies can contribute to the economic, social and environmental aspects of sustainable development. Chapter III discusses the transformative and disruptive potential of rapid technological changes, including economic, social and ethical considerations. Chapter IV analyses how technological change perpetuates or mitigates existing socioeconomic divides within and between countries.

Chapters V and VI discuss strategies and policies. These chapters draw on a range of national and regional case studies on how policies can address rapid technological change. Chapter V looks at examples of national strategies and policies for rapid technological change, while Chapter VI takes stock of regional, international and multi-stakeholder cooperation. It includes a focus on the role of international cooperation and recommendations to the United Nations Commission on Science and Technology for Development. Finally, Chapter VII concludes with the key messages.

II. Opportunities of rapid technological change for sustainable development

Many countries and regions are harnessing rapid technological change to address economic, social, and environmental challenges. The UNCTAD Secretariat sent out a questionnaire to all CSTD Member States and UN Regional Commissions soliciting inputs for case studies, lessons learned, and best practices on the impact of rapid technological change in sustainable development. Eleven countries and three UN Regional Commissions replied with extensive case studies of applications covering nearly all of the SDGs (e.g. health; decent work and economic growth; industry, innovation and infrastructure; agriculture; education; and sustainable cities and communities) across a range of technologies (e.g., artificial intelligence, 3D printing, nanotechnology, blockchain, biotechnology, big data and robotics). Based on the inputs provided and additional research conducted by the UNCTAD Secretariat, this chapter provides examples of how rapid technological change can contribute to sustainable development.

A. Eradicating poverty and monitoring SDG progress

Ending poverty in all its forms (Goal 1) requires not only income but also ensuring that "all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services […]" (Target 1.4) and building "the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters" (Target 1.5). Innovation and new technologies can contribute to eradicate poverty by raising living standards and contributing to economic diversification. Internet of Things-enabled devices and nanotechnology, for example, can be used to detect water contamination and purify water, while renewable energy technologies can provide electricity in rural areas far from the grid systems (see Chapter II.B.4 and II.C). More accurate weather forecasts can make smallholder farmers more resilient (see Chapter II.B.2). Foresight techniques, such as big data analysis can help policy makers to identify trends and support urban planning, while information and communication technologies are being widely used to deliver first-response emergency aid, as well as to share information and provide early warning.

In addition, frontier technologies, including big data and machine learning, can also be used to create measures, and develop and monitor the effectiveness of anti-poverty programs and progress towards the Sustainable Development Goals more broadly. Models based on both mobile phone activity and airtime credit purchases have been shown to estimate multi-dimensional poverty indicators accurately (UNCTAD, 2016b), while recent studies have validated the potential of satellite imagery and machine learning to predict poverty, using publicly available and non-proprietary data (Jean et al., 2016). For example, researchers have predicted the wealth and economic shocks within the East African region based on mobile phone data collected from mobile operators in the region (Blumenstock et al., 2011). Economists at the Massachusetts Institute of Technology (MIT) have developed PriceStats, an innovative platform that measures inflation in 22 economies on a daily basis using online prices, which can help predict inflation more quickly than national official statistics. Premise uses crowd-sourced data via the mobile phone to create real-time economic indicators that are often as accurate as official statistics but faster to collect. However, it remains to be seen whether these big data-derived indicators will continue to be as accurate as research and pilot projects suggest. While there are opportunities for big data to augment the evidence base for developing countries, in which traditional statistics are scarce, some algorithms may increasingly develop out of sync with the underlying socioeconomic, health or environmental reality over time (Lazer et al., 2014).

B. Improving food security, nutrition and agricultural development

About 795 million people, or every ninth person in the world, is undernourished, with the majority living in developing countries and rural areas. New, existing, and emerging technologies can address the four dimensions of food security, namely, food availability, access, use and stability. For example, genetic modification, methods for improving soil fertility, and irrigation technologies can increase food availability. Post-harvest and agro-processing technologies can address food accessibility, biofortification can make food more nutritious, and climate-smart STI solutions - including the use of precision agriculture and early warning systems - can mitigate food supply instability. New and emerging technologies, including synthetic biology, artificial intelligence, and tissue engineering, may have potential implications for the future of crop and livestock agriculture.

1. Improving agricultural productivity

Big data, the Internet of Things, remote sensing, drones, and artificial intelligence may catalyze precision farming, requiring fewer agrochemical inputs for existing agricultural processes. Nubesol offers crop health-related data to farmers and corporations based on a vegetation index it developed using satellite imagery that ultimately provides decision support to farmers about do's and don'ts for ensuring crop health. The Smart Pesticide project utilizes ultrasonic sensors to identify crop pests and sprinkle pesticides in a limited target area using a drone (Singh, 2015). The Indian start-up CropIn provides analytics and software solutions for crop management and has developed a vegetation index using satellite images that provides support to farmers to ensure crop health (Singh, 2015).

Drones also represent a potential leapfrogging opportunity for Africa in precision agriculture to more effectively measure and respond to variability in crop and animal production. Drones have several applications in precision agriculture, including, but not limited to, land tenure and land use planning, cargo delivery, scientific research, inspection monitoring and surveillance, crop and infrastructure damage assessment, and management of agricultural assets. For example, the Third Eye project in Mozambique used low-cost drones to help small-scale farmers improve crop production by 41 per cent and reduce water use by 9 per cent[2] (de Klerk et al., 2017; African Union and New Partnership for Africa's Development, 2018). In the area of land use planning and land tenure, drones are being used to create an aerial base map of Zanzibar to support urban planning, health promotion, seaweed mapping, sustainable tourism and coastal monitoring (Zanzibar Commission on Land, 2017).

Genetic sequencing, along with machine learning, is being used to detect soil quality and help increase crop quality.[3] Machine learning is being applied to drone and satellite imagery to build detailed weather models that help farmers make more informed decisions to maximize their yield.[4] It is also being used with plant genomic and phenotypic data to predict the performance of new plant hybrids.[5] Robots are increasingly automating farming through the ecological and economical weeding of row crops.[6] Beyond rural areas, big data and the Internet of Things is enabling urban, indoor and vertical farming, which in some cases can improve agricultural productivity and water efficiency with minimal or negligible need for pesticides, herbicides, and fertilizers.[7]

2. Building resilience for farmers

New technologies are enabling novel early warning systems conferring unique predictive advantages. For example, Sweden-based Ignitia accurately predicts weather forecasts in tropical areas with a combination of algorithmic techniques based on convective processes, complex modeling of physics, and small (spatial and temporal) forecasting windows. The result is a reported 84 per cent accuracy rate over two rainy seasons in West Africa (2013 and 2014), compared to other weather service providers with a 39 per cent rate (Ignitia, 2018). Low-cost daily messages help farmers anticipate rainfall for the next 48 hours. In addition, the International Centre for Tropical Agriculture uses big data on weather and crops to better adapt to climate. Analyzing big volume of weather and crops data in last decade in Colombia, this initiative can predict upcoming changes in the climate. The projections help farmers to carry out sowing at the right time, and thus avoid economic losses.

Other uses of technology involve the building of financial resilience to weather and climate changes that negatively affect the incomes of agricultural workers. The International Livestock Research Institute (ILRI) created a program known as Index-Based Livestock Insurance to provide financial protection based on a rainfall index to trigger payments for pastoralists in the Horn of Africa (World Food Prize, 2018). Results of a household survey on impact evaluation in that region demonstrate that

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[2] These results illustrate the systemic nature of the innovation process: the positive outcomes of the pilot project are not only a result of the application of drone technology but also the training of local drone operators, communication of relevant agronomic information to farmers, and the widespread availability of mobile phones, among other factors.

[3] See https://www.tracegenomics.com.

[4] A number of companies provide satellite imagery solutions based on machine learning and artificial intelligence. Examples include: https://www.nervanasys.com/solutions/agriculture/; http://www.descarteslabs.com/; https://pix4d.com/; http://gamaya.com/; http://www.bluerivert.com/; http://prospera.ag/; https://www.tuletechnologies.com/; http://www.planetaryresources.com.

[5] A number of companies provide satellite imagery solutions based on machine learning and artificial intelligence. Examples include: https://www.nervanasys.com/solutions/agriculture/.

[6] See: http://www.ecorobotix.com/ and https://www.deepfield-robotics.com/.

[7] See: https://urbanfarmers.com/; http://cool-farm.com/; http://light4food.com/en/; http://www.newsweek.com/2015/10/30/feed-humankind-we-need-farms-future-today-385933.html.

households insured by the program were less likely to reduce meals or sell livestock and more likely to have veterinary services, higher milk productivity, and more nourished children (Jensen et al., 2018).

3. Monitoring food insecurity

Frontier technologies can also support initiatives to monitor food security and innovatively distribute food assistance. A study carried out by the World Food Programme used mobile data to assess food security. The results showed that airtime could serve as a proxy indicator for marketplace food expenditures. In addition, models based on both mobile phone activity and airtime credit purchases were shown to estimate multi-dimensional poverty indicators accurately (UNCTAD, 2016b). Another program coordinated by United Nations Global Pulse, the Indonesian government, and the World Food Programme used public tweets mentioning food prices to develop a real-time food index (United Nations Global Pulse, 2018). The World Food Programme has also piloted the use of blockchain to carry out cash and food assistance in Jordanian and Syrian refugee camps, reducing overhead, improving security and speeding up aid (World Food Programme, 2017).

4. Improving water availability and efficiency

Beyond physical technologies and crop inputs, data can be used as a resource to improve water availability and efficiency. In Peru, information access to weather and climate patterns is expensive and limited. The Institute for University Cooperation Onlus provides an irrigation scheduling system that recommends the best irrigation practices based on climate, meteorological, and soil data through a mobile platform (McMahan et al., 2015). In countries like Mozambique, farmers may not have reliable information on crop status and may be afraid of using costly inputs (high-quality seeds, fertilizer, irrigation) in the absence of such information. FutureWater's Flying Sensor use near-infrared sensors that can detect crop stress up to two weeks before visibly observable. In its first year of operation, a subset of households benefitting from the technology reported 39 per cent reduction in water usage (McMahan et al., 2015). Furthermore, in Bangladesh, Internet of Things data is being used to get a better understanding of the groundwater chemistry and protect tens of millions of people in the Ganges Delta that face the threat of drinking groundwater contaminated with arsenic (Zennaro et al., 2008).

5. Improving preservation of crops

Nanotechnology is being used in several projects to improve the preservation of crops (UNCTAD, 2017a). The Canadian International Food Security Research Fund and the International Development Research Centre support a program to enhance the preservation of fruits in collaboration with five other countries: India, Kenya, Sri Lanka, Trinidad and Tobago, and the United Republic of Tanzania. It aims to increase environmentally sustainable food security for poor people, especially small-scale farmers and women, through applied, collaborative, results-oriented research that informs development practice. A key part of the project involves hexanal, an affordable and naturally occurring compound produced by all plants to slow the ripening of soft fruits and extends their storage life. The use of hexanal spray has increased fruit retention time by up to 2 weeks in mango and 5-7 days in peaches and nectarines. A nanotechnology smart packaging system was also developed with hexanal impregnated packaging and coatings made from banana stems and other agriculture waste to keep fruit fresh. The technologies are transferred using different mechanisms, including through technology transfer workshops, field days, seminars, and public private model centers.

C. Promoting energy access and efficiency

The development of decentralized renewable energy systems could provide electricity in rural areas far from the grid systems (UNCTAD, 2017b). International prices in renewables have fallen dramatically in recent years as investments in their development have increased. The cost of wind turbines has fallen by nearly a third, and that of solar photovoltaic (PV) modules by 80 per cent since 2009 (International Renewable Energy Agency, 2016), making both increasingly competitive with fossil fuel generation. Solar energy is now the cheapest generation technology in many parts of the world (Dorrier, 2017). Hybrid systems utilizing solar PV and battery storage are currently applied to provide energy access. Potentially, these off-grid solutions could become the technical foundation of interconnected mini-grids as a future cellular grid and a decentralized energy system.[8]

Access to electricity plays a critical role not only for improving the lives of households but also in enabling new productive and income-generating activities in rural areas. The transition from fossil fuels to renewable energy could be a catalyst for industrial development and structural change if backed by finance and investment, technology transfer and other supportive measures to ensure adequate energy supply at reasonable costs. In the least developed countries particularly, such a transition requires overcoming important technological, economic, financial and governance obstacles.

Several countries have strategies to promote the development of renewable energy technologies. Chile is developing the technologies to change the energy mix in the electricity sector through renewable energy, becoming a leading country to manage energy transition in the region[9]. The Government of Canada is also working to leverage the opportunity to be a leader in the clean technology sector, by tackling the unique challenges that clean technology companies have related to access to long term capital and both domestic and international markets. This includes the recapitalization of Sustainable Development Technology Canada to help Canadian innovators bring their ground-breaking clean technologies to market.[10]

Energy demand can also be managed with the use of big data technologies. Smart grids can increase energy distribution and production by allowing households with solar panels on their roofs to feed surplus energy back into the electricity grid. The real-time information provided by smart grids help utility companies better respond to demand, power supply, costs, and emissions as well as avert major power outages (UNCTAD, 2015). For instance, Zenatix, a Delhi-based start-up, deploys smart meters and temperature sensors to monitor energy meters and help households and offices reduce energy consumption through message-based alerts. One successful example of their impact is saving the Indraprastha Institute of Information Technology in New Delhi close to $ 30,000 annually in energy consumption (Dora, 2015).

D. Enabling economic diversification and transformation, productivity and competitiveness

For countries with requisite technological capabilities, frontier technologies may support structural transformation, improved living standards, increased productivity, reduced production costs and

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[8] Contribution from the Government of Germany.
[9] Contribution from the Government of Chile.
[10] Contribution from the Government of Canada.

prices, and raising real wages. Frontier technologies, including artificial intelligence, have the potential to promote new sources of employment and income and access new markets and opportunities previously out of reach.[11] New frontier technologies provide opportunities for technological leapfrogging and fundamentally restructuring their economies. For example, a few countries such as the Republic of Korea and Taiwan Province of China have achieved rapid economic growth by leapfrogging in some specific technology sectors such as semiconductors and other electronic goods. A few developing countries have made their mark as developers of renewable energy technologies, with Brazil as the second largest producer of liquid biofuels for transport and China as the global leader in the production of photovoltaic, wind and solar thermal heating technologies.

Renewable energy technologies and some 3D printing technologies hold potential promise for supporting manufacturing and industrial processes with minimal environmental costs. Frontier technologies enabling green industrialization could help developing countries leapfrog through investments in infrastructure and innovation that grow demand for modern energy services, create green jobs, and protect the environment. However, if developing countries seek to engage in long-term technological innovation through industrial development and manufacturing of leapfrogging technologies, it requires both hard and soft infrastructure as well as appropriate policy frameworks. An example of supportive policy framework is the Smart Manufacturing Systems Technology Roadmap coordinated by the Scientific and Technological Research Council of Turkey (TÜBİTAK) (see **Box 1**).

Box 1: Smart Manufacturing Systems Technology Roadmap in Turkey

In Turkey, the Smart Manufacturing Systems Technology Roadmap is based on different technology groups, interactions within the scope of smart manufacturing systems and factories of the future with 8 critical technologies and 29 critical products. A comprehensive participatory process included the definition of technology groups, technology-based strategic targets, the identification of critical technologies, the determination of research and development (R&D) projects and prioritized sectoral applications. This multi-layered roadmap approach helps to associate a critical technology to specific R&D projects and sector applications, which has been an effective way to support the new industrial revolution in Turkey.

Source: Contribution from the Government of Turkey.

E. Promoting social inclusion

Governments are using technologies to support inclusion. For example, a technology combining biometric and demographic data, called Aadhaar, enabled the financial inclusion of 1.2 billion people in India (see **Box 2**). Governments are also experimenting with blockchain technologies that may have wide-ranging applications in smart contracts, digital identity systems, land registration, and financial transactions.

Box 2: India's Aadhar program for social inclusion

The Aadhaar program in India is a government-led, technology-based financial inclusion system. It includes a unique identification number (based on biometric and demographic data) linked to a mobile phone number, a low-cost bank account, and an open mobile platform. The combination of

[11] Contribution from the Government of Mexico.

those elements enabled public and private banks to establish an open and interoperable low-cost payment system that is accessible to everyone with a bank account and a mobile phone. More than 338.6 million beneficiaries have now received direct benefit transfers, saving the Government $ 7.51 billion over three years.

Source: Contribution from the Economic and Social Commission for Asia and the Pacific (2018).

New technologies enable large segments of populations in developing countries to innovate, coordinate, and collaborate. Grass-roots innovation facilitates the involvement of grass-roots actors, such as social movements and networks of academics, activists and practitioners experimenting with alternative forms of knowledge-creation and innovation processes (see **Box 3**). For example, a fabrication laboratory established by the University of Nairobi has used 3D printing to develop a sanitation solution for slums and a vein-finder device to help administer injections in infants. New platforms provide innovative ways to coordinate by distributing work (e.g. gig economy and remote teams), building two-sided markets for the sharing economy (e.g. car and home sharing), developing open source software, and providing personalized digital learning within and outside established educational institutions (Van der Have and Rubalcaba, 2016). Digitally-enabled open and collaborative innovation enables knowledge and technology to be produced across a multiplicity of actors and institutions, drawing from a large pool of both formal and informal knowledge. As a result, crowdsourcing provides new abilities to harness the "wisdom of the crowd" to solve grand challenges, create open knowledge and data sources (e.g. online encyclopedias and volunteered geographic information), and crowdfund new businesses, projects, and philanthropic initiatives.[12]

Box 3: A platform for citizen legislative initiatives: ManaBlass.lv

Digital platforms can contribute to more inclusive policy making at the national level. In Latvia, for example, a platform called ManaBalss.lv ("My voice") helps to bring people's ideas to Parliament and put them on the agenda. ManaBalss is a civic initiative platform where every Latvian citizen who has attained the age of 16 can place an initiative and gather signatures for further submission to the Parliament. When the initiative reaches 10,000 signatures it is submitted to the Parliament for consideration. Initiatives that do not pass the threshold may be submitted to any of Latvia's municipalities, thus influencing policy implementation. As of 2017, over 70 per cent of Latvians have visited the platform. 42 initiatives have been submitted to the Parliament or municipality, and 15 of them have since became laws, law amendments or legislative acts. The initiative allows for a broader community involvement in the national decision-making process, ensuring the possibility to exert real impact on the decision making in a relatively short period of time. In addition, the platform informs the public about the needs of different groups of the society and involves the whole of society in addressing these needs.

Sources: Breidaks (2017); contribution from the Government of Latvia.

[12] For an in-depth discussion on innovative models to support sustainable development, see: UNCTAD (2017e). New innovation approaches to support the implementation of the sustainable development goals. United Nations publication. Sale No. UNCTAD/DTL/STICT/2017/4. New York and Geneva.

F. Confronting disease and improving health

Frontier technologies could address intractable challenges with respect to human health and agricultural productivity by more effectively distributing interventions, monitoring and assessing health-related indicators, and developing gene editing techniques. Countries are increasingly using geographic information systems and unmanned aerial systems to better connect citizens with existing health systems. For example, during a typhoid outbreak in Uganda, the Ministry of Health used data-mapping applications to allocate medicine and mobilize health teams (United Nations Global Pulse, 2015). In Rwanda, the government partnered with a robotics company, Zipline, to address maternal mortality by using drones to deliver blood to medical facilities, reducing the time to procure blood from four hours to fifteen minutes (Rosen, 2017). Vanuatu will soon embark on a world-first trial to deliver temperature-sensitive vaccines to remote villages via commercial drones (Ainge Roy, 2018).

Frontier technologies hold promise for making public health interventions more effective by using big data and digital simulations for “nowcasting” and forecasting. For example, the Hydrology, Entomology, and Malaria Transmission Simulator (HYDREMATS) is a spatial simulation model of malaria transmission and rainfall using satellite-derived vegetation and soil parameters. With the help of this model, scientists working in a Niger Sahel village targeted the application of a growth-inhibiting larvicide to a specific location in the village known to transmit malaria, decreasing the village adult mosquito abundance by 49 per cent (Hilbert, 2017). Recent research developments have explored the use of reinforcement learning – a specific branch of machine learning and artificial intelligence – to drive the development of interventional policy options for malaria control using digital simulation tools (Bent et al., 2017).

Digitization is enabling the novel manipulation of biological processes and atomic and molecular-scale matter. Advances in biotechnology allow very specific gene editing for human medicine, making personalized treatments possible for some conditions (Ledford, 2016). The large amounts of data gathered are “enabling scientists to identify key genetic predispositions to more than 5,000 of the inherited diseases resulting from mutations in a protein-encoding gene” and to target therapies based on the signatures of different mutations (Wadhwa with Salkever, 2017). Genome editing also allows disease-resistant genes from related wild plant species to be inserted in modern plants, and newly formed companies are using synthetic biology to develop biological nitrogen fixation to increase yields for African smallholders sustainably, by allowing crops to “fix” nitrogen from soil bacteria, reducing reliance on synthetic fertilizers (Engineering Nitrogen Symbiosis for Africa, 2018).

G. Scaling and personalizing education

New digital platforms, including massive open online courses (MOOCs), provide online courses that allow for open access and unlimited participation through the World Wide Web. MOOCs do not just involve online video lectures but also typically incorporate social sharing features (e.g. online discussion forum or wiki), interactive quizzes and assignments, supplementary resources (e.g. books, articles), community teaching assistants who moderate discussion forums and help answer student questions, as well as streaming office hour sessions with professors and staff. Key potential benefits include lower cost replication of high-quality teachers, content, and methods; self-paced learning; and data analytics for optimizing learning on the platform (Brynjolfsson and McAfee, 2014; Khan, 2013).

3D printing and open hardware and software platforms have the potential to enhance the educational experience in developed and developing countries. 3D printing is being used as a tool for education in primary, secondary, and post-secondary schools. In the United States of America, some 3D printing companies are training educators how to use the technology as part of afterschool programs at their schools (Council, 2015). In India, students are 3D printing historical artifacts, organ parts, city models, art projects, and dinosaurs to get hands-on experience about various subjects (Kohli, 2015). Hyderabad-based think3D is digitizing diagrams and educational images in Indian school textbooks for the visually impaired. In collaboration with the Devnar Foundation for The Blind, the 3D models of concepts can be "visualized" by touch in a cost-effective way (Dataquest, 2015).

Similarly, the Open Labware initiative, organized by TReND (Teaching and Research in Natural Sciences for Development in Africa), the Open Neuroscience initiative and the Baden Lab, is promoting the collaboration and construction of low cost, open scientific equipment for developing countries for educational and research purposes. The initiative includes designs and tutorials to 3D print tools such as optical fluorescence microscopes with optogenetics and temperature control, a motorized micromanipulator to handle very small biological samples (around 10 microns), and 3D printed micropipettes (Open Labware, 2018). The consortium´s article explaining the methods and uses of open hardware in lab equipment published in Plos Biology, has been downloaded more than 75,000 times (Baden et al., 2015).

III. Transformative and disruptive potential of rapid technological change

Rapid technological change will have transformative and disruptive effects that both advance and frustrate sustainable development. While the application of new and emerging technologies represents an opportunity to address the Sustainable Development Goals, they also pose new challenges for policy makers and society, as they can disrupt economic development, exacerbate social divides, and raise ethical questions.

A. Automation, labor markets, and jobs of the future

Automation from the convergence of artificial intelligence, machine learning, and big data could impact employment, productivity, globalization, and competition in unclear and potentially negative ways. While frontier technologies can be expected to create new jobs and markets, it also has the potential to disrupt existing labor markets and productive sectors. Ultimately, the impacts of automation will vary according to a range of factors, including levels of industrialization and development, skills and capacities (for a set of policies on skills in the European Union see **Box 4**), labor costs, export and production structures, technological capacities, infrastructure, demography, and policies encouraging or discouraging automation.[13]

Box 4: Skills Agenda for Europe

The countries of the European Union are advanced both in promoting rapid technological change and mitigating its potential negative effects. One example is the Skills Agenda for Europe, which aims (i) to improve the quality of training and the availability of lifelong learning and "re-tooling" programs; (ii) to make qualifications more comparable and hence more portable; and (iii) to promote "skills intelligence" by providing students and adults with relevant information about labor market conditions and trends so they can make better education and qualification choices. The Skills Agenda, on the one hand, enables rapid technological change by helping to develop a labor

[13] For a more detailed discussion, see Chapter 1, Section E.1 (pp. 21-25) of UNCTAD (2018).

force with the required skills. On the other hand, it contributes to risk mitigation by helping people to acquire flexible, portable skills and to adapt to changing labor market requirements induced by rapid technological change.

Source: Contribution from the Economic Commission for Europe.

The *Technology and Innovation Report 2018* (UNCTAD, 2018) reviews some of the recent estimations on the impact of automation on jobs. The results vary widely, depending on the assumptions made and the methodologies. Most of the studies only estimate job losses and do not consider job creation effects. For example, the World Bank estimates, that two-thirds of all jobs could be susceptible to automation in developing countries in coming decades. Estimates for the United States of America and Europe range between 50 and 60 percent of jobs. Further, digital automation may affect women and men differently. At the same time, it is worthwhile noting that machines and digital technologies are not perfect or even good substitutes for many tasks, at least not for the moment. Further, even if technologically feasible and economically reasonable, full automation of jobs takes time, even in developed countries (World Bank, 2016).

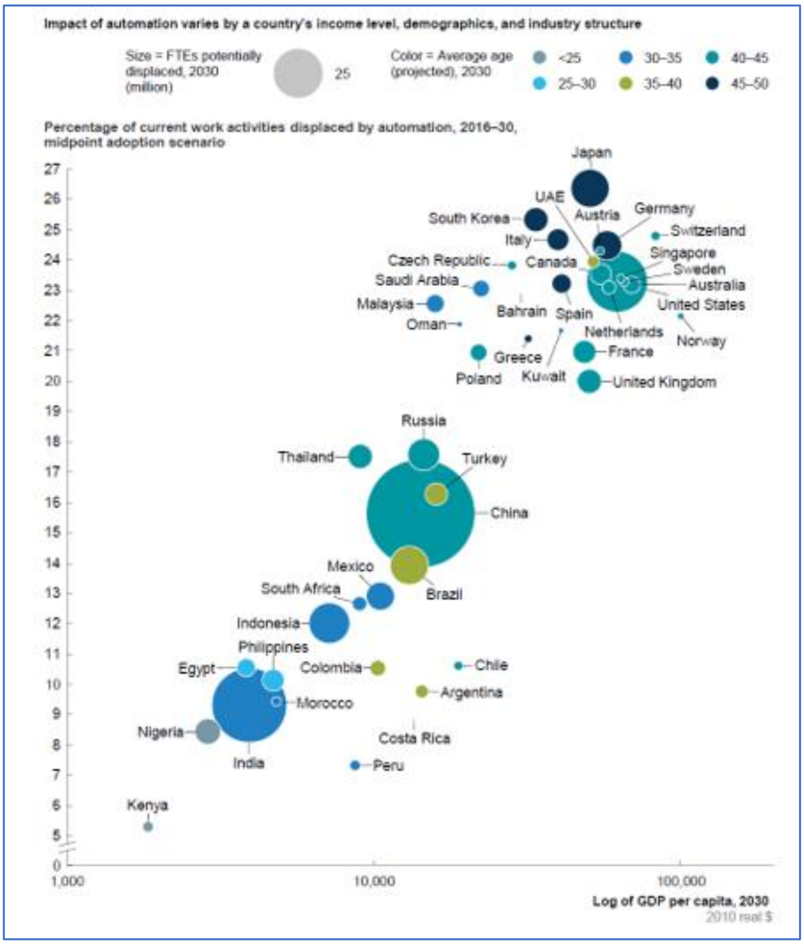
A recent study by the International Monetary Fund (Das and Hilgenstock, 2018) finds that although jobs in developing economies tend to be less exposed to automation, developed and developing countries have started to converge in this regard in the last decades. Consequently, automation can have important impacts on the economies of developing countries in the future, even if impacts may differ across countries.

According to the global management consulting firm McKinsey (McKinsey Global Institute, 2017), within affluent countries, a variety of cognitive tasks are susceptible to displacement. But very few jobs (5 per cent or less) are likely to be completely displaced. Many jobs are likely to be transformed, with up to 30 per cent being delegated to computer-based systems. The other 70 per cent is likely to be done in collaboration with the computer-based system. Complementarity is more likely than displacement. Based on this analysis, there may be more “hollowing out” of the income distribution, but work is not likely to disappear. Those working in the affected occupations in countries with lower Gross Domestic Product (GDP) per capita are less likely to be affected by these changes (see **Figure 1**). The reason is that the installation of artificial intelligence and robotic systems only makes sense where labor costs are high. Where labor costs are low, firms are likely to continue to choose labor-intensive production processes. As long as the quality and final cost of the product compete well with robot-based systems, labor-intensive processes are likely to continue.

UNCTAD (2017f) estimates that the use of industrial robots globally remains quite small and amounts to less than 2 million units. Robots are concentrated in the automotive, electrical and electronics industries, and in a small number of countries, such as Germany, Japan, the United States of America, China and the Republic of Korea. Routine tasks in manufacturing and service jobs are being replaced, but low-wage manufacturing jobs in areas such as clothing factories are left largely unaffected by automation.

As of today, new technologies have been substituting workers only in specific tasks, but they have not replaced entire occupations. Rather than eliminating occupations, technology changes how jobs are performed, and the number of humans needed to carry them out. According to a recent study by Bessen (2016), only one out of the 260 occupations listed in the 1950 US Census had been eliminated by 2010 due to automation, i.e., the elevator operator.

Figure 1: Impact of automation in relation to income, demographics and industry structure



Sources: World Bank, Oxford Economics, McKinsey Global Institute analysis.

While digital platforms may create opportunities for smaller businesses and entrepreneurs in developing countries, digitalization may also present certain development challenges. Platform-based economies tend to have winner-takes-all dynamics, where network effects benefit first movers and standard setters. Despite the new opportunities for trade and development, these platform dynamics could lead to widening income inequalities and increased polarization. The evolving digital economy has also been accompanied by online labor platforms that provide new income-generating activities for people in developing countries with the requisite skills and digital connectivity. However, an oversupply of job seekers on online labor platforms could lead to diminished bargaining power, resulting in a race to the bottom with respect to wages and working conditions. Further research and policy dialogue will be critical in ensuring that the expanding digital economy provides quality and decent jobs, particularly in developing countries (UNCTAD, 2017c) (see **Box 5**).

Box 5: A legal framework for workers of the platform economy

The digital economy creates new job opportunities and contributes to the outsourcing of different business processes through online platforms or applications. Graham and Woodcock (2018) notes however, that some of these practices can be harmful to digital workers (i.e. commercial content moderation), may undermine standard employment relationships, and workers can lose their bargaining power due to strong global competition. Lacking the power to collectively bargain, platform workers have little ability to negotiate wages and working conditions with their employers.

The Fairwork Foundation of the Oxford Internet Institute (OII) seeks to contribute to the welfare and job quality of digital workers. It highlights best and worst practices in the platform economy. Through consultation with several stakeholders including governments, platform operators, unions and workers the foundation has collaboratively developed five principles - on pay, conditions, contracts, governance, and representation - to establish a certification system for fair work on online platforms.

Sources: Contribution from the Government of Germany; Fairwork (2018); Graham and Woodcock (2018).

B. Socioeconomic divides

Rapid technological change has the potential to perpetuate existing divides within and between countries as well as between women and men, rural and urban populations, and rich and poor communities (UNCTAD, 2018). As recent data shows, the share of Internet users in the total population of developed countries is more than four times as high as in least developed countries. This existing digital divide may exacerbate the economic divergence between countries at the frontier of rapid technological change and the least developed countries. Even if frontier technologies provide leapfrogging opportunities, countries below the technological frontier may leapfrog primarily through the adoption of technologies rather than through the development of new technologies. In this regard, successful as it has been in many respects, Africa's mobile revolution also demonstrates the limitations of leapfrogging by adopting technologies at the consumption rather than the production side. Despite spillover effects and significant potential welfare benefits, the economic impact of information and communication technologies (ICTs) in sub-Saharan Africa in recent years appears smaller than in other regions (World Economic Forum, 2016). This partly reflects the limitations of innovation policy in Africa to coevolve with the development of ICT, which has resulted in missing opportunities to build on the mobile revolution to foster innovation and development (Juma and Lee, 2005). The adoption of consumer ICT technologies, for example, cannot bring least developed economies close to the technological frontier, without appropriate technological capabilities in other sectors and an enabling innovation system.

The increasing rate of technological change may widen existing gender digital and science, technology, engineering, and mathematics (STEM) divides. Because women constitute low numbers in the science, technology, engineering, and mathematics job families, they may not be able to take advantage of the increased demand for workers with skills in frontier technologies. Additionally, automation can affect women and men differently, where women have been historically underrepresented in the science, technology, engineering, and mathematics job families that may benefit from the recent technological change involving automation. Women are 12 per cent less likely than men to make use of the Internet, and 33 per cent less likely to do so in the least developed countries, widening the existing gender digital divide, which persists in women's access to ICTs and opportunities to shape new and emerging technologies.

C. Ethical issues and considerations

While frontier technologies offer unprecedented opportunities to transform the practice, implementation, and monitoring of sustainable development, they also pose considerable ethical and bioethical concerns regarding the environment, privacy, security, data ownership and use, and safety. For example, smart energy meter technologies can use sophisticated statistical algorithms to determine sensitive household information like which appliances or devices a household might have and when it is operating. Data collected from health trackers and wearables and electronic health records that are disclosed to third-parties could potentially impact insurance policies or even future employment prospects.

Biased big data may produce unintended and sometimes discriminatory results. There is concern that biased data could scale discrimination in areas like predictive policing, access to financial services, and job recruiting. There is lack of transparency about how machine learning algorithms are devised and deployed. The increasing use of deep learning systems which produce predictions lacking interpretability and explanation pose great concern for application areas involving human health, public service delivery, and consumer advertising.

Beyond digital and artificial intelligence-related technologies, synthetic biology and CRISPR/Cas9-based genome editing raise various safety and ethical issues, including unintended effects of the technology (e.g. permanent DNA breaks at other, unintended sites in a genome), regulatory challenges involving labelling of modified crops (i.e. difficulty in identifying a modified organism once released), and intellectual property rights and their unclear implications for smallholder farmers. Policy makers need to consider the potential of these technologies to address the grand challenges in agriculture and medicine as well as the risks involved. Some experts note that recent developments in synthetic biology and the increasing pace of development create knowledge gaps and pose challenges for some countries to carry out risk assessments and understand the possible impacts on biodiversity and human health. Many developing countries - as well as indigenous people and local communities - require capacity development to stay abreast of new developments in synthetic biology (Convention on Biological Diversity, 2017).

There are critical questions about data ownership and access regarding agriculture, particularly in developing countries. Does data collected belong to the farmer, government, or third-party provider (private or non-governmental)? How do the privacy policies of private sector agricultural companies impact the livelihoods of smallholder farmers? Addressing these economic, social, and ethical concerns requires appropriate policies at the national and international levels to maximize benefits and minimize risks.

IV. Rapid technological change and leaving no one behind

When individuals experiment with new ways of meeting their needs and when communities organize themselves for larger and larger goals, they often improve technologies in the process. Businesses, however, survive and thrive on competitive advantage, and this need is often met in the industrial era through technological innovation. Innovations in the process of producing goods and services lower costs and increase productivity (Fagerberg et al., 2006). For example, mass production lowered the costs of many products. Power tools allow more construction in the same amount of time. Smart ride-hailing systems match riders and drivers more efficiently. Innovations in products themselves sometimes maintain or increase market share, and sometimes create whole new markets, as when the xerox machine replaced carbon paper copying or where mobile phones displace landlines.

This ongoing process of technological innovation takes place in a context of inequalities, among people, firms, regions, and nations. In practice, it often reinforces or widens those gaps (Cozzens, 2010). For example, firms tend to orient new products first to affluent consumers (Pavitt, 2005). Larger firms find it easier to maintain the technical capability that allows them take advantage of advances in both process and product innovations (Lazonick, 2005). Richer countries invest more in the creative environment that produces those advances (Nelson, 1993). Regions that attract innovators reap the benefits of those commercial efforts (Cooke et al., 1997). The more radical the innovation, the more likely it is that it will bring wealth to those who bring it to market, since they will have a temporary monopoly on its capabilities (Schumpeter, 1950). Technology-based wealth thus tends to pile up through a process of cumulative advantage, benefitting some people and places and not others.

However, new technologies also produce new opportunities. The computational revolution for example allowed Israel, Taiwan Province of China and Ireland to establish new niches in global production chains (Breznitz, 2011). Mobile phones and the Internet have made information available to people and places in ways that have improved health and financial security (Asongu and Nwachukwu, 2018; Burns, 2018).

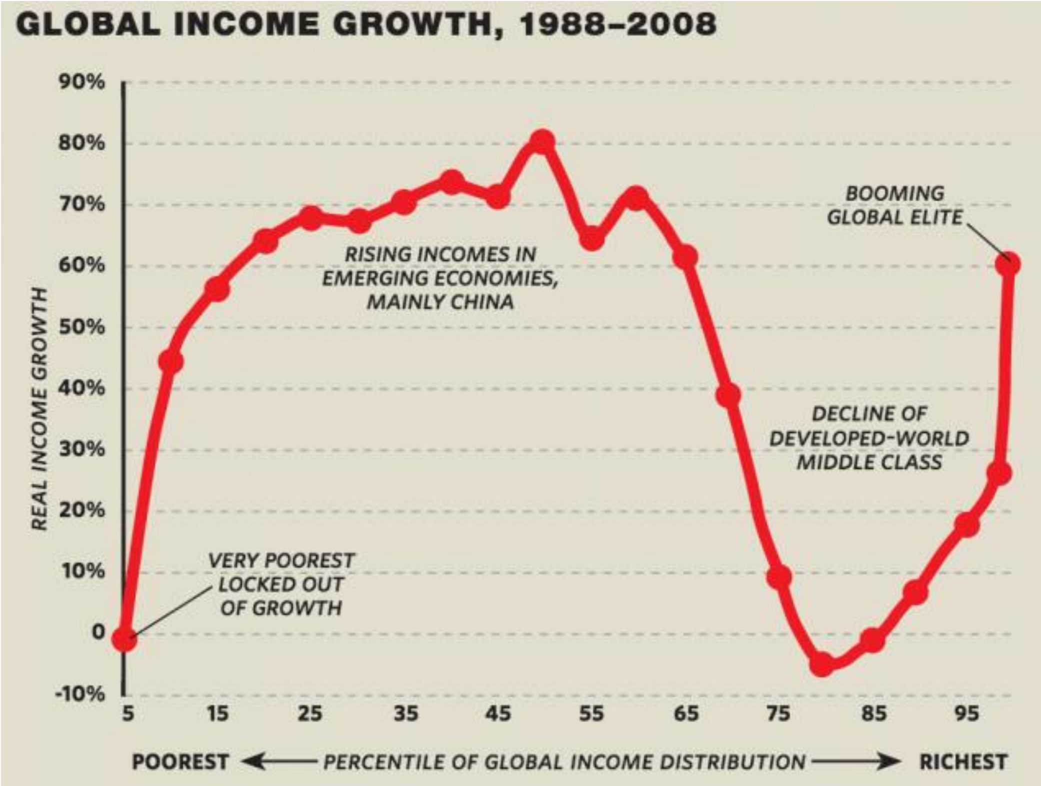
A. The impact of rapid technological change on gaps within countries

The process of globalization has the potential either to increase or decrease inequalities within countries. The latest wave of globalization has been characterized by the mutual exchange of manufactured goods between advanced and emerging economies, compared with the unequal exchange of raw materials for manufactured goods of earlier periods (Ghose, 2003). Establishing manufacturing capabilities often involves adopting production technologies that are new to the firm and sometimes new to the country (Binz and Anadon, 2018; Kuo et al., 2018). The growth of mid-wage manufacturing employment in emerging economies has allowed them to grow a new middle class, an inequality-reducing phenomenon, as Milanovic's "elephant graph" (**Figure 2**) shows (Milanovic, 2016).

Emerging technologies also have the potential to contribute to inequalities. Many economists see the main dynamic in high-income countries as "skill-biased technological change" (SBTC). As firms introduce new technologies into their production processes, demand rises for higher skills in the workforce. A wage premium develops for higher-skilled workers, and a gap opens between the earnings of lower-skilled and higher-skilled workers. Skill-biased technological change is most visible in the gap in earnings between college and high school graduates in the US and their equivalents in other countries. This gap has been increasing and accounts for about two thirds of the increase in income inequality in the US over the period since 1980 (Autor, 2014). Furthermore, empirical and theoretical studies have also demonstrated SBTC as contributing to wage inequality in developing countries (Goel 2017; Torres et al. 2017; Pi and Zhang, 2018).

Technological change may have different impact on different age groups as well as men and women. Older workers, for example, displaced by technological change will not qualify for jobs requiring skills they never acquired. Weak educational systems may not prepare young people for the emerging employment opportunities, and disadvantaged social groups, including women in many countries, often have fewer opportunities for formal education (Cozzens, 2010).

Figure 2: **Global Income Growth (1988-2008), based on Milanovic (2016)**



Source: Corak (2016) based on Milanovic (2016)

High technology development strategies may increase inequalities, and the dynamic is more exaggerated in lower income countries (Cozzens, 2006). New technology-based firms generate high-skill, high wage jobs, but relatively few of them. As the high-wage workers spend their earnings in the local economy, lower-wage services jobs are generated. In countries with generally high education levels, many people have the right levels of skills for the jobs, and compensation goes up gradually. In countries with generally low education levels, however, where only a few people have the right skills, the people who get these jobs may also receive hyper-wages, raising the top end of the income distribution dramatically. The more global the industry, the more likely this is to occur. When combined with high unemployment levels that keep service wages down, the spending by the high-end individuals will not bring much prosperity to the poorest.

Countries that are benefitting from globalization through new manufacturing or service employment are likely to experience growing inequality between urban and rural areas and between core and peripheral regions. China illustrates this pattern. Its level of inequality is about the same as the US. But differences between regions explain much more of the inequality in China rather than difference between individuals as in the US (Milanovic, 2005). Technological innovation is almost always and everywhere an urban phenomenon, particularly where the local network of expertise accelerates the process, as for example in Bangalore, India (Pal and Ghosh, 2007).

B. The impact of rapid technological change on gaps between countries

Technology-related inequalities between countries develop both in industry and trade and in quality of life for citizens. The very wide differences in household income across the globe are shaped profoundly by differences in national income levels (Milanovic, 2016). The higher educational levels achieved in richer countries make better jobs available. Even poor households in high-income countries may have access to good transportation systems, quality health care, and housing that would be available only at middle incomes in less affluent countries. Technological change in the global economy carries both opportunities and threats for national economies.

Middle income countries can use incremental innovation to their advantage with the necessary concentration of expertise and an active effort to apply it to strategic industries. An active approach is often the key to using incremental innovation for competitiveness, whether through targeted research and development, standards or public procurement. The GSM industry in the Nordic countries, for example, was aided significantly by national champion firms and public procurement policies (Edquist et al., 2015). Nokia, for example, become a global force in an industry that was already emerging elsewhere. In less affluent environments, national firms often prefer importing the technologies they need to modernize production, to increase productivity quickly and remain competitive. Importing technology can be a first step towards technological learning and upgrading. However, the import of technologies does not automatically lead to the building of local skills because much of the knowledge embedded in such technologies is tacit knowledge and is not easily transferable (UNCTAD, 2014b). Finding the resources to invest in scientific and technical expertise is a difficult task, and weak educational systems undermine the effort to develop higher level achievements.

Another opportunity that globalization has created comes from the growing middle classes in emerging economies. Rising household incomes in emerging economies (e.g. China, India, and Brazil) create new markets for low-cost products that are designed for the infrastructural conditions of those countries (for example, uneven or limited electricity) (Kaplinsky et al., 2009; Kaplinsky, 2011). Firms located in conditions like these are more likely to capture these markets than those that design for the infrastructural conditions of affluent countries. Since there are more people living in non-affluent than affluent countries, spreading these products beyond the national market can produce a new competitive base. While these firms are innovating for the classical reasons, they are producing benefits for a set of people who might not necessarily be the targets of high-technology firms in the global North. This kind of innovation has the potential to change the distributional dynamics of the global economy by shifting both market and production power outwards from the core.

Disruptive technological change brings both opportunities and threats. The information technology revolution, starting in the 1970s, called for rapid expansion of new manufacturing capacity. The "Asian tigers" moved into this opportunity space and occupied the new niche. Taiwan Province of China, for example, became a major site for semiconductor manufacturing (Breznitz, 2011). On the other hand, many fear that the Fourth Industrial Revolution will eliminate many of the new jobs created in low and middle income countries in the past few decades as manufacturing and service jobs are brought back into affluent countries, with much smaller workforces requiring higher skill levels (Dubhashi and Lappin, 2017; Makridakis, 2017).

Whether technological change improves the quality of life for citizens in a country often depends on regulatory environments, absorptive capacity and prices. For example, anti-retrovirals for the treatment of HIV/AIDS remained out of reach for many years in lower-income countries because of cost, at least for people of modest income who depended on public health services to provide them.

But assertive uses of patent law provisions and an international humanitarian movement brought the prices down (Butler, 2007). As another example, lack of facilities and trained people kept small farmers in Mozambique from benefitting from plant tissue culture until the past decade, although it had been widely adopted in other countries. A modest international grant and training outside the country resulted in the development of technology research, development, and diffusion capacities (Brito et al., 2012). Likewise, competition policies were instrumental in the availability of pre-paid mobile phones, which enabled mobile phone technology to reach low-income families and provided a pathway for such widely beneficial innovations as mobile banking (Thakur et al., 2014) In short, policy can help spread the benefits of new technologies if they keep disadvantaged groups in view.

C. Potential of rapid technological change to "leave no one behind"

The threats and opportunities of rapid technological change are well illustrated in the emergence of the Fourth Industrial Revolution, the convergence of digitally-enabled technologies that may be ushering in a new techno-economic paradigm. Some of the links between Industry 4.0 and inequalities are likely to be similar to those experienced during earlier technoeconomic revolutions, and others are likely to be particular to this convergence. The dynamics described in this chapter draw attention to both.

First, emerging technological regimes tend to appear threatening at first (Weart, 2012). This is particularly true during the period when technological visionaries are painting the future in the starkest terms. Many of the most drastic changes never come about or have been tamed in their consequences by the time they do, and other profound transformations affect aspects of socioeconomic organization that were not anticipated in the first stage (Kriechbaum et al., 2018).

Second, based on the experience of past emerging technologies, Industry 4.0 will expand, evolve, and spread in unexpected ways as the innovations diffuse. New entrepreneurs will find new uses, in either product or process form, to reach a variety of goals (Bortagaray et al., 2014). The more disruptive the pathway the technoeconomic paradigm follows, the more unpredictable the applications. Regarding Industry 4.0, disruptive effects have already appeared in several sectors, including retailing (e.g. Amazon) and transportation (e.g. Uber). Furthermore, there is little evidence that the hybrid jobs that have appeared, dependent both on personal services and digital connections, are being compensated highly (for evidence among ride-hailing drivers, see Berger et al., 2018 and Zwick, 2018).

Third, there are likely to be differential effects by gender. Several occupations identified as less vulnerable to displacement by robotics are those in which women predominate, such as day care and social work. It is probably premature, however, to declare that men will become the disadvantaged group of the future, especially considering the gender divides created by the underrepresentation of women in STEM job families. Likewise, the informal economy is not a likely place for robotics and artificial intelligence to affect jobs; perhaps it will even grow if the expensive new technologies raise prices in the formal economy. In terms of urban, rural and regional distributions, some applications are rather place-based (such as robotic systems in manufacturing) while others take place in cyberspace (such as data-based marketing). The latter might lead to growing spatial decentralization rather than centralization.

Finally, as in previous technoeconomic revolutions, new institutions will be needed to counter inequality and restore social cohesion. Just as the physical concentration of workers in the industrial revolution facilitated organizing and unionization, social media may make organizing possible in distributed workforces (Glenn, 2015; Alang, 2016). Public social safety nets may be implemented through universal basic income schemes (Perkio, 2015; Reich, 2018). Corporations transformed by activist investors may make social responsibility a central function. As new centripetal forces increase polarization, new unifying ones may well emerge.

V. National strategies and policies

The rapid reduction in the costs of some new and emerging technologies could provide an opportunity for developing countries to fast track structural transformation and stimulate sustainable economic growth. Moreover, new and emerging technologies could facilitate new pathways to sustainable development that also consider its social and environmental dimensions. However, without appropriate STI policies, technologies – new or old – are unlikely to deliver progress on the global development agenda. Such progress requires an environment that nurtures learning and innovation to build and manage effective innovation systems. This chapter investigates national science, technology and innovation policies that could facilitate harnessing frontier technologies for sustainable development.

A. Addressing the education-employment nexus of rapid technological change

As discussed in the previous chapter, the dynamics of innovation globally tend to increase inequality, by giving an advantage to firms, countries, and regions that have innovation capabilities already. The dominant, market-led pattern is not oriented towards meeting the needs of the poor, achieving gender equality, nor closing economic gaps within or between countries, all central elements of the Sustainable Development Goals. Policies, however, can create counter-currents in this pattern by focusing on investments that spread capabilities more broadly and stimulate innovation with and for groups at the margins.

Strengthening national educational systems is a common recommendation for effective response to rapid technological change (Romer, 1990). Knowledge production is treated as a key factor of production in New Growth Theory, the object of the most recent Nobel Prize in economics. That theory makes rising skill and educational levels central to economic growth, along with scientific research and technological innovation. These are clearly long-term investments, which do not in and of themselves change the structure of employment opportunity. Galbraith provides a vivid image of the possible disconnect (Galbraith, 1998). The employment structure is like a building, he points out, with a certain number of floors and offices; specific educational credentials are needed to rise from floor to floor and occupy each office, but the structure is not shaped by the availability of skills. When those who are qualified to occupy the upper floors are scarce, their occupants are paid more and inequality increases. But raising overall educational levels without changing the structure of the building can result in more available talent for some floors than they need, leading to "bumping down," that is, people taking jobs below their skill levels. Raising educational levels in the overall population, then, is always a good thing, but does not necessarily solve employment challenges.

This observation is particularly true when the number of jobs shifts suddenly, as can happen when automation arrives (Brynjolfsson and McAfee, 2014). At such moments, displaced workers need temporary income support and targeted retraining (Centre for the New Economy and Society, 2018). In addition, the economy must be dynamic enough that new floors and offices are available for them to occupy. In the long-term, most economists expect that as technological revolutions eliminate old jobs, and innovation creates new industries and employment (Autor, 2015). National innovation-supporting strategies facilitate these. Individuals who are prepared to step into these new opportunities will move forward rather than being left behind.

B. Strengthening national innovation systems for rapid technological change

The flexibility of an occupational structure within a country is strongly influenced by its national innovation system, that is, the interaction and alignment of a variety of institutions, public and private, to support adoption and adaptation of new products and processes in private and public organizations. The challenge for developing countries to reap the benefits from existing, new and frontier technologies, is to learn, adopt and disseminate knowledge and technologies. To do this, countries need to boost their efforts to strengthen the effectiveness of their innovation systems, which tend to be weaker and more prone to systematic failures and structural deficiencies (Chaminade and Padilla-Pérez, 2017). Firms are at the core of innovation systems, which also encompass research and education systems, government, civil society and consumers.

1. Building capabilities, connections and the enabling environment

The key aspects that policy makers might want to focus on are the capabilities of the various actors, the connections among them that facilitate exchanges and collaborations, and the enabling environment for innovation that is created (UNCTAD, 2018). In developing countries with nascent innovation systems, building endogenous innovation potential involves developing a basic capacity to learn how to adopt, assimilate, adapt and diffuse existing knowledge and technologies. These capabilities are required to benefit from technology transfers, which should supplement efforts to build domestic innovation potentials.

The connections among actors are equally essential for facilitating learning, technology adoption and the development of new technologies. This requires networking and collaboration capabilities among all actors. In countries with an underdeveloped knowledge base, government and non-government actors can step in to develop capacities, domestic links and facilitate relations with foreign firms and research centers. National governments can encourage the development of such linkages. Very few countries try to develop such systems generically, covering all disciplines and technological areas. Most work on developing the connections takes place within sectors that are chosen strategically, either because of their connection to public goals, like those reflected in the SDGs, or in business sectors where the country has strengths. These actions form “sectoral” innovation systems (Malerba, 2004).

For example, in the water and sanitation sector (Goal 6), where most households worldwide receive their water from public utilities, to form a water sector innovation system, national governments can:

- support training programs that supply local water systems with appropriate experts;
- link personnel in public systems to professional associations outside the country, to draw on international best standards and raise awareness of technological options;
- recognize and reward upgrading in water system practices to international levels; and
- where private firms from outside the country are selected to provide water and sanitation services, make sure that the contracts include transfer of know-how and skill to local actors.

Furthermore, an effective innovation system requires attention to key elements of an enabling environment. STI policy makers could consider addressing the following issues:

- Developing infrastructure, with a specific emphasis on providing access to electricity and connectivity, ensuring affordable access to ICTs, and overcoming gender, generational, and digital divides.
- Ensuring a regulatory and policy framework that provides a stable and predictable environment to facilitate long-term planning by firms and other innovation actors.

- Creating an institutional setting and governance structure that incentivizes actors to invest in productive activities and support other relevant institutions, NGOs and grass-roots movements that promote new forms of innovation.
- Supporting an entrepreneurial ecosystem that provides flexible access to finance through appropriate and readily accessible financial instruments, organizational capabilities and managerial competencies.
- Developing human capital, both technical and soft skills, through an inclusive and strong technical and vocational education system.
- Financing R&D, technology and innovation as well as providing the appropriate levels of intellectual property protection.

The examples below show that several CSTD member States have initiatives addressing these issues. Chile and Peru, for example, have both launched ambitious projects to develop fiber optic networks covering the whole of the country (see **Box 6**). Egypt has taken several steps to provide a strong legislative environment to keep pace with rapid technological change (see **Box 7**). Latvia is supporting demand for sustainable technologies through green public procurement (see **Box 8**), while South Africa, has several initiatives to support technological innovation in small, medium and micro enterprises (see **Box 9**).

Box 6: Public-private partnerships in Chile and Peru to develop digital infrastructure

In 2016 Chile has launched a large optical fiber project called Fibra Óptica Austral, that will bring fiber optic Internet all across Chile, from the Northern town of Puerto Montt to Puerto Williams in the South. The project is implemented in a public-private partnership from 2017 to 2020 and includes 3 land-based and one submarine section (Subsecretaría de Telecomunicaciones de Chile, 2018).

The connectivity policy promoted by Peru's Government aims to reduce the Internet connectivity gap experienced by large groups of citizens in the country. The National Fiber Optic Network project consists of the design, deployment and operation of a fiber optic network through public-private partnerships. It will develop a network of more than 13,000 kilometers connecting Lima with 22 regional capitals and 180 provincial capitals.

Sources: Contribution from the Governments of Chile and Peru; Subsecretaría de Telecomunicaciones de Chile (2018).

Box 7: Providing strong legislative environment to keep pace with the needs of the ICT sector in Egypt

Egypt's Ministry of Communications and Information Technology is looking beyond the uses of ICT-based networks to the institutional, regulatory, financial, political and cultural conditions that frame them. Therefore, attention has been paid to providing a strong legislative environment to keep pace with the needs of the ICT sector. Proposals were finalized to amend several telecommunications laws, e-signature and public-private partnership in infrastructure projects. The country is also concluding proposals for the freedom of information law. The e-Commerce law is one of the key initiatives that the country worked on, in cooperation with the UNCTAD. The e-Commerce Strategy contributes to increasing internal trade in Egypt, enhancing the country's exports and creating jobs for youth while promoting their creativity and entrepreneurship skills.

Source: Contribution from the Government of Egypt.

Box 8: Green public procurement in Latvia to support sustainable technologies

Green public procurement promotes the use of environmentally-friendly, innovative and sustainable technologies in the manufacturing of goods. In Latvia, green public procurement is encouraged by a regulatory framework, namely the Public Procurement Law and, in particular, the Cabinet of Ministers Regulation on Requirements for Green Public Procurement and Procedures for Application that establish requirements and criteria to certain groups of products and services, based on innovative and environmentally-friendly technological solutions and approaches. The application of these principles is aimed at all the societal groups. The greatest challenge for the introduction of green procurement principles in public procurement is the concerns raised by procurement agents about the increased complexity and expenses. However, in this context it is essential to evaluate the product life cycle costs in their entirety.

Source: Contribution from the Government of Latvia.

Box 9: Supporting technological innovation in the entrepreneurial ecosystem in South Africa

South Africa is making investments in a range of programs that strengthen and leverage science, technology and innovation as a key enabler of economic development. This includes programs to support small and medium enterprises, improve the competitiveness of existing industrial sectors, enhance localization opportunities, and help to build the industries as a future. To illustrate, investments in Technology Stations support more than 3000 small, medium and micro enterprises through providing access to world-class infrastructure and expertise that would otherwise not be available to stakeholders to enable them to engage in technology innovation.

The country also has sector-specific initiatives, such as the Biorefinery Industry Development Facility that focuses on the development and testing of biorefinery technologies, or the Mandela Mining Precinct to support local innovation in South Africa's mining industry.

To support innovators in getting access to finance, the Technology Innovation Agency (TIA) is managing various funding instruments to develop and commercialize promising technologies. This includes the Seed Fund, the Technology Development Fund, the Commercialization Support Fund, as well as a special fund targeted at youth innovators, called the Youth Technology Innovation.

Source: Contribution from the Government of South Africa

To be effective, STI policies need to be internally consistent and aligned with national priorities and development plans. The former can be promoted through the design and deployment of strategies and policy instruments at the most appropriate level, while the latter requires a "whole-of-government" perspective, facilitating cooperation across ministries and other public bodies in different fields of policy. Coherence is needed between STI policies and policy areas such as industrial policies, trade, foreign direct investment (as knowledge and technology are often being transferred through trade and foreign direct investment), education and competition.

2. Promoting sustainable innovation policies

Countries seeking to orient STI policies towards sustainable development need to integrate societal challenges to their cores (UNCTAD, 2018). Stark and growing differences between industrialized urban areas and agricultural regions, with steep gaps in income, health, and education, have led some national governments to work to reduce regional inequalities through their investment in science, technology, and innovation (Djeflat and Cummings, 2015). Colombia has set the conditions for more regional development of innovation capabilities with its General System of Royalties (OECD, 2014). Regional and local governments themselves are trying to use the power of interaction through innovation systems to grow their place-based economic opportunities. Local systems of innovation and production can contribute to regional prosperity (Matos et al., 2016).

Gender-inclusive innovation policies may be directed to women's participation as innovators or entrepreneurs; women as decision makers in technological systems; or the impact of new technologies in women's lives. For the first goal, policies and practices need to be consciously designed to make women feel welcome in technological spaces. Jimenez found, for example, in innovation hubs in the United Kingdom and Zambia, that women experienced gender discrimination intersecting with other identities (Jiménez, 2018). She recommends that such spaces be designed deliberately to avoid hierarchy and foster equal relationships. Technical and vocational training may be a means of empowering women to play roles in new technological sectors (Hemson and Peek, 2017). Involving women in how new technologies are implemented affects their eventual impact as positive or negative in women's lives (Hansda, 2017).

Youth-oriented policies can also be helpful in making technological change inclusive. Some countries have developed special school programs to increase interest in new technologies, particularly focused on entrepreneurship (du Toit and Gaotlhobogwek 2018; Wensing et al., 2018). Some initiatives are focused on unleashing creativity (Muraveva et al., 2017) while museums are often used as venues for inspiring youth to pursue technology careers and exposing them to role models (Marx, 2017). Special efforts must be made to reach young people who are neither in school nor working (Ospina, 2018).

Innovation in informal settings is also getting attention as a source of livelihoods (Goal 8) (Cozzens and Sutz, 2014; Kraemer-Mbula and Wunsch-Vincent, 2016). Small, informal crafts-based businesses can play a major role in adapting external innovations to local conditions and filling the gap when production systems change (Muller, 2010). Indigenous medicine carries knowledge informally that can be turned into competitive advantage on international markets. In this context, communities are working to capture some of that benefit for themselves. See for example the efforts of the Australian national government to recognize and protect the intellectual property rights of indigenous communities (Australian Government, 2018). National policies can make room for informal innovators even though they are often operating outside standard regulations and to protect their new ideas from exploitation (Kraemer-Mbula and Wunsch-Vincent, 2016). Universities can expand their technical capabilities to these enterprises through extension services (Mytelka and Farinelli, 2000).

Other policies may include regulations and standards on environment or health; economic and financial instruments such as feed-in tariffs or removal of subsidies for unsustainable activities; demand support through public procurement; education and training policies supporting inclusiveness and life-long learning; or capacity building and information sharing both locally and internationally (UNCTAD, 2018). The United States of America, for example, applies a "light-touch" approach to emerging technologies (see **Box 10**).

Box 10: The approach of the United States of America to emerging technologies

The policy approach of the United States of America to emerging technologies has several sides. First, assess the adequacy of existing regulations and policies before establishing new ones, and avoid any *ex ante* regulatory approaches that could stifle innovation or stigmatize new technologies. Second, encourage multi-stakeholder participation in technology development and incorporate input from non-governmental (e.g. private sector) stakeholders. Third, seek to bolster American science and technology research and development (R&D), in part through international cooperation, and to remove barriers to innovation, in large part by sharing initiatives, best practices, and norms. In addition, the country supports public-private partnerships that accelerate technology transfer on voluntary and mutually agreed terms and create value for its citizens.

The country takes a holistic approach to innovation, providing multiple forms of support. For example, the National Science Foundation (NSF) supports Industry-University Cooperative Research Centers that help build long-term partnerships among industry, academia, and government. The country also supports small businesses developing next-generation technologies through the Small Business Innovation Research and Small Business Technology Transfer programs. These programs provide funding for early-stage R&D across a variety of mission areas, from health to agriculture to energy, fueling the commercialization of federal investments in R&D.

The government is exploring opportunities to apply frontier technologies on several fields of public services. The Food and Drug Administration (FDA) is studying emerging technologies such as blockchain as a data exchange mechanism to immediately access information on patients, supplies, and crisis response during a public health emergency. In partnership with the private sector, the Department of State is seeking blockchain solutions to worker rights challenges. The General Services Administration's (GSA) Emerging Citizen Technology Office, launched in 2016, is dedicated to working collaboratively across government, industry, and academia to help programs take advantage of emerging technology innovations to improve public services today. Focal technologies for the GSA include artificial intelligence, robotics, blockchain, social media, and virtual and augmented reality.

Source: Contribution from the Government of the United States of America.

3. Developing technology-specific strategies

Countries may also consider developing STI policies that focus on specific technologies that advance their national economic and development agendas. As **Box 11** shows, Chile has used its comparative advantage in astronomical observations to develop endogenous capacities, including both human and physical capital. Building on the existing capacities in astronomy, the country is now exploring opportunities to develop capacities for big data analysis and artificial intelligence. Several countries of the Asia-Pacific region developed policies for specific frontier technologies. China, Japan and the Republic of Korea have developed strategies on artificial intelligence, and the Republic of Korea was the first country in the world to develop a tax on robots. Countries including Australia, India, Japan, Malaysia, New Zealand, the Republic of Korea, and Singapore are developing roadmaps, plans and standards for the Internet of Things (Economic and Social Commission for Asia and the Pacific, 2018).

Box 11: Developing capacities in frontier technologies based on existing capacities in astronomy in Chile

Chile launched several policy initiatives to take advantage of rapid technological change. The aim of these programs is to build endogenous capacities to address national development priorities such as climate change, aging population and getting prepared for the ongoing technological revolution. Accordingly, the country is exploring opportunities to use its privileged position in astronomy to develop capacities in big data analysis and artificial intelligence. Due to its unique atmospheric conditions, Chile is hosting around 50 per cent of the installed capacity in astronomical observatories in the world (the figure is expected to reach 75 per cent by the beginning of next decade). The facilities produce a massive amount of data, the management and analysis of which requires interdisciplinary skills, including skills in mathematical models and algorithms. The Government of Chile sees an opportunity in the astronomic observatory facilities to build capacities for big data analysis and create a privileged space to promote artificial intelligence. On the other hand, as many of Chile's observatories are operated by international partners such as European countries, Canada, Japan and the United States of America, significant international collaboration and scientific diplomacy in astronomy is taking place in the country (Rodríguez García-Huidobro, 2017).

Sources: Contribution from the Government of Chile; Rodríguez García-Huidobro (2017).

It is important to note, however, that even if countries develop national STI or more technology specific strategies, translating these strategies and policies into programs of tangible impacts on pressing developmental challenges is a critical issue (see **Box 12**).

Box 12: Challenges in translating strategies into impact in some Arab countries

Most Arab countries already have STI strategies (i.e. Egypt, Jordan, Morocco, Saudi Arabia, United Arab Emirates). In addition, Morocco and Tunisia have developed more specialized digital strategies, Qatar and Sudan have smart strategies, the United Arab Emirates have an artificial intelligence strategy, and several countries in the region have launched open data initiatives (Bahrain, Jordan, Morocco, Oman, Qatar, Saudi Arabia, Tunisia and the United Arab Emirates). However, according to the Economic and Social Commission for Western Asia, countries are facing challenges in implementing these strategies, due to lack of absorptive capacity; inadequate financial and non-financial resources, high levels of bureaucracy; limited Infrastructure and a lack of advanced equipment; lack of proper intellectual property infrastructure and governing policies and legislations; brain drain; low levels of foreign direct investment due to many reasons including political instability; weak private sector engagement in STI (i.e. limited resource funds, venture capitals, angel investors); legislations related to confidentiality, privacy and integrity of data; and ethical issues related to the use of artificial intelligence.

Source: Contribution from the Economic and Social Commission for Western Asia.

C. Building digital competencies to close digital divides

Digitalization and connectivity are key features of frontier technologies. It is therefore critical that digital policies be calibrated according to countries' readiness to engage and benefit from the digital economy (UNCTAD, 2017c). With the rapid development of ICTs and other frontier technologies, digital capabilities are particularly important, not only in the context of jobs, but also for social and civic participation in current and future societies (communication, financial inclusion, identification, etc.). Digital competencies include technical skills, but also generic and complementary skills to be able to understand media, search for information, be critical about what is retrieved, and communicate with a variety of digital tools and applications (UNCTAD, 2018b).

Different types of digital skills are needed to adapt to new technologies. We can differentiate four levels of digital skills needed during the adoption, use and domestication of technologies. We can distinguish skills required to adopt technologies (involves basic education, literacy and familiarity with technology devices), those needed in the basic use of technologies (involves understanding of new technologies, knowledge of digital rights, privacy and security, ability to use digital technologies to collaborate and create), those necessary for the creative use and adaptation of technologies (involves basic computing skills and familiarity with algorithms), and those essential for the creation of new technologies (sophisticated programming skills and knowledge of complex algorithms) (UNCTAD, 2018b).

As many frontier technologies are designed to be used in contexts with developed infrastructure and abundant natural and social resources, developing countries need to have appropriate skills to introduce modifications to new technologies (Huang and Palvia, 2001). Education and training programs that focus on digital skills for all should be inclusive and accessible to everyone (see some best practices in **Box 13** and **Box 14)**. Other types of competencies vary across sectors, countries and industrial development. In countries where technology development remains in its early stages, basic technical skills and generic skills are the most required. Countries where the manufacturing sector dominates economic growth will require a workforce with specialized skills in robotics, automation and the Internet of Things. Digital policies should also support cross-sectoral collaboration both within government and with other stakeholders to address a wide spectrum of policy areas.

Box 13: Inclusive policies in Canada and the United States of America to develop digital skills

In Canada, the Innovation and Skills Plan is one of the components of the government's efforts to leverage the opportunities of frontier technologies. Launched in 2017, the strategy provides a series of new client-centric measures to support innovation in a digital age and strengthen Canada's innovation ecosystem. Delivered in partnership with the private sector, research and postsecondary institutions, and others, the Plan focuses on skills; research, technology and commercialization; program simplification; and the investment and scale-up of companies. Plan initiatives such as "Connect to Innovate" and "Connecting Families" ensure that high-speed Internet is available and affordable for more citizens. "CanCode" and the "Digital Literacy Exchange" provide digital training with an emphasis on traditionally underrepresented Canadians. "Computers for Schools" and "Accessible Technology Development" foster inclusivity in access to technology that enables participation in the digital economy. In addition, Canada's National Digital and Data Consultations launched in June 2018 are the next steps of the Innovation and Skills Plan to further promote an inclusive digital economy. The consultations seek ideas and recommendations from citizens in three key areas: the future of work, unleashing innovation, and trust and privacy. Furthermore, the Pan-Canadian Artificial Intelligence Strategy is developing global thought leadership on the economic, ethical, policy and legal implications of advances in artificial intelligence.

A good example of providing science, technology, engineering and mathematics (STEM) education for underrepresented groups is the United States Geological Survey (USGS) Secondary Transition to Employment Program. The initiative connects USGS scientists with young adults with cognitive and other disabilities (ages between 18 and 22) who are enrolled in workforce training programs. These young adults particularly enjoy and excel at repetitive and routine tasks that are data- and detail-oriented. They have analyzed 49,000 images for the iCoast project, transcribed over 27,000 handwritten bird phenology cards from 19th and early 20th centuries, recorded over 90,000 wildlife time-lapse images, and scanned over 500,000 bird banding lab sheets.

Sources: Contribution from the Government of Canada and the United States of America.

Box 14: Policies for an empowering digital environment for women and girls

The World Wide Web Foundation provides a policy framework with a list of policy steps needed to close the digital gender gap and ensure full digital inclusion. The initiative called REACT focuses on rights, education, access, content, and targets to close the gender digital divide (World Wide Web

Foundation, 2017). It recommends policy makers to protect and enhance rights online; to equip everyone, especially women with adequate skills to effectively use the Internet; to provide affordable access to the Internet; to ensure that relevant content for women is available and used; and to set and measure tangible gender-equity targets.

While digital technologies have the potential to be used in transformative ways to empower women and girls and advance gender equality, they have also enabled new forms of violence against women and girls. Although there is no comprehensive data, in a recent survey in the European Union, 11 per cent of women have reported having experienced some sort of online harassment since the age of 15 (European Union Agency for Fundamental Rights, 2014). Women are also disproportionately targeted by online violence and suffer disproportionately serious consequences as a result (Human Rights Council, 2018). To address cyber violence against and abuse of women and girls, Canada developed a Playbook for Gender Equality in the Digital Age. This playbook outlines a set of best practices for a multi-stakeholder approach to ensure a positive and empowering digital environment for all. It covers four broad areas including access, culture, education and an international framework.

Sources: Contribution from the Government of Canada; Human Rights Council (2018); World Wide Web Foundation (2017).

D. Strengthening capacity for technology foresight and assessment

If societies are to cope better with the accelerated pace and broadened scope of technological change, policymakers will need to develop plans based on technological foresight and assessment of potentially disruptive effects of technology over years and even decades. Foresight involves bringing together key agents of change and sources of knowledge, to develop strategic visions and intelligence to shape the future. Developing capacity in technology foresight (e.g. horizon scanning and ex ante impact assessments) can enable countries to identify and exploit the potential of frontier technologies for sustainable development, identify priority technologies in the short, medium and longer term, and assess the potential effects of emerging technologies. There are also important implications for the methodologies and types of evidence needed to support policy and implementation, for example combining methodologies and data for technological, economic, social and environmental impacts in assessment of the environmental impacts of innovation.

United Nations Member States are increasingly recognizing the importance of foresight activities to enable societies and policymakers to adapt to the changes created by the proliferation of new technologies. The Economic and Social Council recognized that technology and assessment exercises could help policymakers and stakeholders in the implementation of the 2030 Agenda through the identification of challenges and opportunities that can be addressed strategically (E/2017/22). In its most recent resolution on STI for development (E/RES/2018/29) the Council encouraged Governments to undertake systemic research for foresight exercises, on new trends in STI in ICTs in their impact on development, particularly in the context of the 2030 Agenda for Sustainable Development and to consider undertaking strategic foresight initiatives on global and regional challenges at regular intervals and cooperate towards the establishment of a mapping system to review and share technology foresight outcomes. At the same time, the latest General Assembly resolutions on STI for development (A/RES/72/228) and on the impact of rapid technological change on the achievement of the SDGs (A/RES/72/242) encourage Member States to continue considering the impact of rapid technological change and to conduct technology assessment and foresight activities to evaluate their development potential and mitigate potential negative effects. Countries could explore ways and means of conducting national, regional, and international technology assessments and foresight exercises.

An international capability to monitor such developments and draw out their implications for low- and middle-income countries would significantly affect the capability of national decision-makers to respond. International efforts to support national responses, however, need to draw on a deeper base of concepts and information than international organizations themselves can provide. Several interdisciplinary, international research communities are devoted to analyzing the trends and identifying options for action thrives in Europe, North America, and affluent Asia, including the Global Network on the Economics of Learning, Innovation and Competence-Building Systems (GLOBELICS), the European Forum for Studies of Policies for Research and Innovation (EU-SPRI), the Society for the Studies of New and Emerging Technologies (S.NET), and the European Union program on Responsible Research and Innovation. International and national organizations can help develop this monitoring capability inside low- and middle-income countries with support to a wider range of researchers, both for collaborative research projects and travel to meet their professional peers. Ph.D. schools are a particularly cost-effective way of deepening expertise in both the short and long term. For such research to be useful, connections to policymakers is key and convening policy or research exchanges on a regular basis would help insure that knowledge is relevant, useful, and accessible.

VI. Regional, international, and multi-stakeholder cooperation

Intergovernmental and multi-stakeholder efforts to strengthen digital capabilities can provide avenues for refocusing and strengthening international cooperation for innovation in frontier technologies. However, support by the international community, including regional and international cooperation, will need to expand to prevent the evolving digital economy from leading to widening digital divides and greater income equalities. According to OECD, the annual baseline average official development assistance for ICT was around USD 500 million globally. Between 2006 and 2015 this amount has been between USD 650 million and USD 700 million, representing a small share in total aid efforts. The share of ICT in total aid for trade, declined from 3 per cent baseline average in 2002-2005 to only 1.2 per cent in 2015 (OECD and WTO, 2017).

A. Regional and international cooperation

International collaboration, including North-South and South-South collaboration, to address rapid technological change can be manifold. It can include knowledge and data sharing, capacity building, collaboration in research and technology development, collaboration in foresight exercises, and collaboration in STI policy (see **Box 15** and **Box 16**). International organizations and bodies like the CSTD have an important role to play to support or provide a forum for such collaboration.

Box 15: International collaboration in space technologies

One example of international collaboration in the use of space technologies is through the European Union's space infrastructure, namely the Galileo satellite navigation program and the Copernicus Earth observation program. Galileo is the European Union's own global navigation satellite system (GNSS), currently under deployment, providing a highly accurate, global positioning services. The Copernicus satellite program is the world's largest single Earth observation (EO) program, that provides vast amounts of data feeding into a range of information services on the environment, humanitarian needs and in support of policy-making. By providing full, free and open data, Copernicus is contributing to regional and international efforts to identify and respond to global challenges such as climate change, land and water management, or pollution. A recent study conducted by the United Nations Office for Outer Space Affairs showed that the programs can directly contribute to 13 out of the 17 Sustainable Development Goals, both through monitoring and in the achievement of some of the targets. Both technologies can enable several applications, including forecasting natural disasters, optimizing crop productivity, air and water quality monitoring, meteorological forecasting, disaster management, support of search and rescue operations, nature monitoring (United Nations Office for Outer Space Affairs, 2018).

Sources: Contribution of the Government of Austria; United Nations Office for Outer Space Affairs (2018).

The United States Agency for International Development (USAID), for example, is actively exploring how emerging technologies, such as blockchain (Nelson, 2018) and artificial intelligence (Paul, 2018), impact development, in both positive and negative ways. USAID is partnering with the Massachusetts Institute of Technology and others to further research how to mitigate issues of bias and unfairness that arise in low and middle-income country contexts.

Training international research students and participating in international exchanges also helps to spread scientific and technical expertise across countries. The United States National Institutes of Health, for example, sponsors international collaborative projects through the Fogarty International Center, and the European Union welcomes “third countries” into most of its research programs.

Another good example for international collaboration in research on frontier technologies is the work of the High-Level African Panel on Emerging Technologies (APET). The panel was appointed in 2016 by the African Union Commission to give recommendations on how Africa should harness emerging technologies. The panel has recently published three reports on three key technologies, including gene drives (for malaria control an elimination), drones (to transform Africa’s agriculture), and micro-grids (to empower communities and enable transformation).

Box 16: International collaboration in renewable energy technologies

International collaboration has an essential role in the area of renewable energy technologies (UNCTAD, 2017d). For example, Germany has recently launched the initiative called “Green Peoples’ Energy for Africa”. The program aims to support partner countries in the development of decentralized, renewables-based energy systems. The program will develop decentralized energy structures in rural regions with the assistance of municipalities, cooperatives and private-sector investments, and build local capacity of African municipalities to provide affordable, reliable and sustainable energy. Whilst the initiative addresses African communities as a whole, the Energy Training Initiative is targeting young adults.

Sources: Contribution of the Government of Germany; UNCTAD (2017d).

An example for collaboration on policy is a project of the United Nations Economic and Social Commission of Asia and the Pacific, supported by Canada.[14] The project called Catalyzing Women’s Entrepreneurship – Creating a Gender-Responsive Entrepreneurial Ecosystem aims to address the challenges of women entrepreneurs in the Asia-Pacific region in accessing finance and new

[14] Contribution from the Government of Canada.

technologies. The project supports the development of gender-responsive policies and programs by policy makers, and provides training for women entrepreneurs (Government of Canada, 2018).

B. Multi-stakeholder initiatives

Science and engineering in affluent and emerging economies are deeply embedded in the commercial dynamics that exacerbate inequalities within and between countries. At the same time as scientists and engineers respond to these programs in their own regions and countries, they also belong to international communities that are oriented ultimately to public benefit. Some of them live in societies that recognize that fulfilling their international development obligations is good for the world economy and thus for theirs. For the scientific and technical communities of affluent countries to support efforts to mitigate inequalities, more of their work needs to be oriented towards the needs of the those at the margins. Individuals and institutions make commitments to this goal in a variety of ways.

Academic research groups adopt this orientation on their own, with research support from private foundations. For example, the University of California, Berkeley houses an Alliance for Global Health, which includes both student exchanges and joint research projects that link its campus to partners in Brazil, China, India, Mexico, Nicaragua, South Africa, and Uganda. It is particularly focused on infectious diseases.[15] The MIT CoLab (Community Innovators Laboratory) focuses on "innovation from the margins," serving as "a research and development hub which harness the depth of wisdom in marginalized communities to address issues of inequality."[16]

Regarding capacity building, there are several international activities involving the Internet of Things and artificial intelligence. For example, an Internet of Things Doctoral Program has been created as part of a collaboration between the African Center of Excellence in Internet of Things (ACEIoT) at the University of Rwanda, College of Science and Technology and the Abdus Salam International Centre for Theoretical Physics (ICTP) in Italy (Abdus Salam International Centre for Theoretical Physics, 2018). The online education platform Fast.ai offers free classes on deep learning with the aim of increasing diversity in AI. The platform has launched diversity and international fellowships for deep learning, providing an opportunity for participants to receive state of the art practical education in AI (Fast.ai, 2018).

Frontier technologies may also help vulnerable groups through applications targeted to address their special needs. Machine learning can help drive toward greater financial inclusion via alternative credit scoring algorithms. USAID-funded partners like Apollo Agriculture and FarmDrive have leveraged machine learning to deliver agronomic advice to smallholder farmers and help increase access to financial services in the agricultural sector in Kenya. Machine learning can also help in match-making to address youth unemployment. Harambee Youth Employment Accelerator, for example, is a social enterprise in South Africa that is integrating machine learning to better match traditionally excluded low-income youth with jobs in the formal economy.[17]

Multi-stakeholder initiatives can also leverage their member's resources to raise awareness about major challenges, such as gender digital divides (see **Box 17**) and advocate for actions to address these challenges.

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[15] For more information, see: http://globalhealth.berkeley.edu/.
[16] For more information, see: https://www.colab.mit.edu/.
[17] Contribution from the Government of the United States of America.

Box 17: Multi-stakeholder initiatives to address gender digital divides

A few multi-stakeholder initiatives have been launched in recent years to address gender digital divides and support women's participation in the digital world. EQUALS, for example, is a global partnership founded in 2016 by 2016 by the ITU, UN Women, the International Trade Centre, GSMA and the United Nations University. Through a partnership with private sector leaders, governments, civil society, communities and individuals around the world, EQUALS aims to achieve digital gender equality by raising awareness, building political commitment, leveraging resources and knowledge, and harnessing the capacities of partners. It does this through four main workstreams on access, skills, leadership, and research (EQUALS, 2018).

The G20 launched the #eSkills4Girls initiative in 2017 to support efforts to address gender digital divide in low income and developing countries. It is a joint project of G20 countries, and it provides a platform to share information and knowledge on the issue, to showcase current initiatives, good practices, as well as policy recommendations to different stakeholders.

Sources: Contribution from the Government of Germany; EQUALS (2018).

C. United Nations and the CSTD

In recent years, there has been growing interest by Member States to examine the impact of rapid technological change on sustainable development within the United Nations System. Discussions have been taking place in several fora. In 2017, the United Nations General Assembly (GA) passed a Resolution on the "Impact of rapid technological change on the achievement of the Sustainable Development Goals" (A/RES/72/242), and recently in 2018, a Resolution on the "Impact of rapid technological change on the achievement of the Sustainable Development Goals and targets" (A/73/L.20). In response to this, the United Nations Commission on Science and Technology for Development (CSTD) and the Multi-stakeholder Forum on Science, Technology and Innovation for the Sustainable Development Goals (STI Forum) held dedicated sessions on the impact of rapid technological change in 2018. Other initiatives include two expert group meetings in Mexico (in 2016 on exponential technological change, automation, and their policy implications for sustainable development[18], and in 2018 on rapid technological change, artificial intelligence, automation, and policy implications[19]). Regional commissions are also contributing to better understand the impact of rapid technological change through expert meetings (such as the recent meeting on fourth industrial revolution organized by the Economic Commission for Europe[20]) and analytical work on the regional applications and best practices in supporting frontier technologies (Economic and Social Commission for Asia and the Pacific, 2017 and 2018; Economic and Social Commission for Western Asia, 2018). Furthermore, the United Nations Secretary General António Guterres has recently published a UN-

[18] The outcome document of this Expert Group Meeting is available at: https://sustainabledevelopment.un.org/content/documents/15295Meeting_report_final.pdf (accessed 12 November 2018).
[19] The outcome document of this Expert Group Meeting is available at: https://sustainabledevelopment.un.org/content/documents/19330EGM_MexicoConclusions_and_Recommen Recomme.pdf (accessed 12 November 2018).
[20] Contribution from the Economic Commission for Europe.

wide Strategy on New Technologies[21] and established a High-level Panel on Digital Cooperation to raise awareness about the transformative impact of digital technologies and contribute to the broader public debate[22]. Across the United Nations system, agencies, forums, and initiatives can support Member States through capacity-building activities, technology foresight and assessment, and norm-setting and building consensus.

1. Capacity-building

Developing countries could also benefit from the various STI policy capacity-building initiatives of the United Nations. These include trainings and workshops facilitated by the United Nations Interagency Task Team on Science, Technology and Innovation for the SDGs (IATT) of the Technology Facilitation Mechanism. The Technology Bank for Least Developed Countries is a long-standing priority of the LDCs confirmed in the 2015 Addis Ababa Action Agenda and in Sustainable Development Goal 17 (in target 17.8). Developing countries could engage with the recently inaugurated Bank whose aim is to improve the utilization of scientific and technological solutions in the world's poorest countries and promote the integration of least developed countries into the global knowledge-based economy. Furthermore, CSTD could launch capacity-building workshops to help developing country Member States improve STI capacities in relation to the achievement of the SDGs.[23]

2. Technology foresight and assessment

There is need for technology foresight and assessment to better understand the impact of frontier technologies and to identify approaches that can leverage them to accelerate the achievement of the SDGs in all countries and leave no one behind. Platforms such as the CSTD and the STI Forum, as well as initiatives such as the Secretary-General's High-level Panel on Digital Cooperation, contribute to the broader public debate on how to ensure a safe and inclusive digital future for all. The CSTD can also support and showcase good examples of international, regional and national technology foresight exercises and assessments.

3. Norm-setting and consensus building

The United Nations could encourage agreement on a global framework of norms and standards rooted in the values of the United Nations system to frame and guide technological innovation, especially in areas like artificial intelligence, bio- and nano-technology, robotics, machine learning and big data, where the potential ramifications are very large. The globalization, convergence, and impacts of these technologies have supranational implications requiring international coordination. Global consensus ensures that new technologies are compatible with the Sustainable Development Goals, particularly regarding their social and environmental implications. Despite their considerable potential, frontier technologies alone will not suffice to address the challenges of sustainable development. Governments and other stakeholders need to be proactive in putting in place policies that minimize

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[21] The United Nation Secretary General's Strategy on New Technologies is available at http://www.un.org/en/newtechnologies/images/pdf/SGs-Strategy-on-New-Technologies.pdf (accessed 12 November 2018).

[22] More information about the High-level Panel on Digital Cooperation is available at http://www.un.org/en/digital-cooperation-panel/ (accessed 12 November 2018).

[23] CSTD, in collaboration with the Government of China, convened STI capacity-building training workshops on "Science, Technology and Innovation Policy and Management for Sustainable Development" and "High-Tech Park and Incubator Development Program" in September 2018.

their risks and ensure the equitable distribution within and across countries of the benefits of technologies.

For example, international standards for health and safety support targeted development of national capability in areas of rapid technological change. For nanotechnology, concerns about the occupational and environmental risks of nanoscale particles posed a challenge to early development of applications. International organizations stepped into the information gap and began to collate and evaluate the available data for specific product groups.[24] Because of the ongoing dialogue at the international level, countries such as South Africa did not need to mount their own testing programs, nor depend entirely on expertise from specific countries, but they could address potentially unequal risks through international best practices.

Furthermore, global consensus could identify a set of technological innovations that will be most critical for achieving health, sanitation and environment related goals of the 2030 Agenda and facilitate the access to and use of these technologies by all countries and all communities. Targeting research funding towards SDG-related projects, mapping existing scientific knowledge and current research against local needs, and building technological capabilities at national and international efforts can ensure that these mission-critical innovations serve the 2030 Agenda.

VII. Key messages

Rapid technological change offers a significant opportunity to achieve the 2030 Agenda for Sustainable Development and the Sustainable Development Goals. New and emerging technologies can support poverty eradication efforts, monitor sustainable development targets and indicators, improve food security, promote energy access and efficiency, enable structural economic transformation, support social inclusion, combat disease, and enable access to quality education.

Rapid technological change also poses new challenges for policy-making, threatening to outpace the capacity of governments and society to adapt to the changes that new technologies bring about. Automation could impact employment, productivity, globalization, and competition in unclear and potentially negative ways. Rapid technological change also has the potential to perpetuate existing divides among and between countries and raise ethical issues involving privacy, security, data stewardship, and safety.

Although the global dynamics of technological change have potential to increase socioeconomic divides, policies can support investments that spread capabilities more broadly and stimulate innovation with and for groups at the margins.

National strategies harnessing rapid technological change for sustainable development involve building and managing effective innovation systems. Key policy considerations include addressing the education-employment nexus, building endogenous innovation capacities, developing digital competences to bridge digital divides, and strengthening the capacity for technology foresight.

Intergovernmental and multi-stakeholder efforts to strengthen digital capabilities can provide avenues for refocusing and strengthening international cooperation for innovation in frontier technologies. North-South, South-South, and triangular cooperation, initiatives by academic,

[24] See the OECD's publications in the Series on the Safety of Manufactured Nanomaterials: http://www.oecd.org/science/nanosafety/publications-series-safety-manufactured-nanomaterials.htm.

technical, business, and civil society communities, and UN system-wide efforts can play a role in ensuring that rapid technological change leaves no one behind.

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