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The impact of rapid technological change on sustainable development

Report of the Secretary-General

Executive summary

This report is a response to General Assembly resolution 72/242, in which the Commission on Science and Technology for Development is requested, through the Economic and Social Council, to give due consideration to the impact of key rapid technological changes on the achievement of the Sustainable Development Goals. The report contains analysis of the impact of rapid technological change on sustainable development, especially the consequences for the 2030 Agenda for Sustainable Development's central principle of "leaving no one behind". It presents the opportunities offered by rapid technological change regarding the achievement and monitoring of the Sustainable Development Goals across the various economic, social and environmental dimensions. It discusses the transformative and disruptive potential of rapid technological changes, including economic, social and normative considerations. In the report, it is highlighted that, without appropriate science, technology and innovation policies, technologies, be they old or new, are unlikely to deliver progress regarding global development. Such progress requires an environment that nurtures learning and innovation to build and manage effective innovation systems. In this context, the report presents examples of national strategies and policies for rapid technological change and takes stock of regional, international and multi-stakeholder cooperation. In addition to national and international policies, the report also calls for the international community to continue to discuss how international technology assessment and foresight, as well as consensus building on normative guidelines, can shape the developmental potential of rapid technological change. It concludes with suggestions for Member States and the international community.

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Introduction

1. At its twenty-first session in May 2018, in Geneva, the Commission on Science and Technology for Development selected The impact of rapid technological change on sustainable development as one of its priority themes for the 2018–2019 intersessional period.

2. The secretariat of the Commission convened an intersessional panel meeting from 15 to 17 January 2019, in Vienna, to improve understanding of this theme and to assist the Commission in its deliberations at its twenty-second session. This report is based on the issues paper prepared by the Commission secretariat,[1] the findings of the panel, country case studies contributed by Commission members, relevant literature and other sources.

3. This report is a response to General Assembly resolution 72/242, in which the Commission on Science and Technology for Development is requested, through the Economic and Social Council, to give due consideration to the impact of key rapid technological changes on the achievement of the Sustainable Development Goals. In 2018, the General Assembly also adopted a resolution on the impact of rapid technological change on the achievement of the Sustainable Development Goals and targets (A/73/L.20).

4. This report does not expressly define "rapid technological change." However, for the purposes of this report, the technologies associated with "rapid technological change" include (but are not limited to): big data; the Internet of things; machine learning; artificial intelligence; robotics; blockchain; three-dimensional printing; biotechnology; nanotechnology; virtual and augmented reality; renewable energy technologies; and satellite and drone technologies.

I. Opportunities offered by rapid technological change with regard to the Sustainable Development Goals

5. Given the diverse, multidimensional, ambitious and absolute nature of the Sustainable Development Goals, it will be practically impossible to achieve all of them by 2030 without the development and appropriate application of science, technology and innovation. This section will highlight the role of science, technology and innovation in key areas of the 2030 Agenda for Sustainable Development, including opportunities, key considerations and the requisite preconditions and policies needed for their effective application to sustainable development.

A. Accelerating and monitoring progress towards the Sustainable Development Goals

6. Rapid technological change can contribute to the faster achievement of the 2030 Agenda for Sustainable Development through several mechanisms by: improving real incomes (through increased productivity and reduced cost of goods and services); enabling faster and wider deployment of novel solutions to economic, social and environmental obstacles that operate as binding constraints on development; supporting more inclusive forms of participation in social and economic life; replacing environmentally costly modes of production with more sustainable ones; and giving policymakers powerful tools to design and plan development interventions. UNCTAD provides detailed examples of a wide range of applications of frontier technologies that are already demonstrating potential to accelerate progress towards the achievement of the Sustainable Development Goals.[2]

[1] The issues paper and all presentations and contributions to the intersessional panel cited in this report are available at https://unctad.org/en/pages/MeetingDetails.aspx?meetingid=2026 (accessed 21 February 2019).

[2] UNCTAD, 2018, *Technology and Innovation Report 2018: Harnessing Frontier Technologies for Sustainable Development* (United Nations publication, Sales No. E.18.II.D.3, New York and Geneva).

7. Frontier technologies, including big data and machine learning, can also be used to create, measure and develop and monitor more broadly the effectiveness of development programmes and progress towards the Sustainable Development Goals. Models based on both mobile telephone activity and airtime credit purchases have been shown to estimate multidimensional poverty indicators accurately,[3] while recent studies have validated the potential of satellite imagery and machine learning in estimating household consumption and assets, using publicly available and non-proprietary data.[4]

8. 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, over time, increasingly develop out of sync with the underlying socioeconomic or environmental reality over time.[5] Big data algorithms should not be taken at face value but rather critically examined, especially when used as part of complementary indicators for development efforts. This highlights the importance of human capabilities to assess and evaluate the accuracy of big data algorithms and understand when the results are useful or misleading.[6] In this respect, UNCTAD underlines the need for systematic efforts to invest in the physical infrastructure and nurture the innovation system and absorptive capacities that are necessary for frontier technologies to fulfil their potential.[7]

B. Improving food security, nutrition and agricultural development

9. About 795 million people (every ninth person in the world) are 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.

10. Big data, the Internet of things, remote sensing, drones and artificial intelligence may catalyse precision farming, reducing the number of agrochemical inputs for existing agricultural processes. Drones also represent a potential leapfrogging opportunity for Africa regarding precision agriculture, enabling more effective measurement of and response to variability in crop and animal production. Genetic sequencing, along with machine learning, is being used to detect soil quality and help increase crop quality. 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 yields. It is also being used with plant genomic and phenotypic data to predict the performance of new plant hybrids. Farming is becoming increasingly automated, with robots being used to carry out the ecological and economical weeding of row crops.

11. If rapid technological change is to be harnessed for the various dimensions of food security, then the food system itself must be made more innovative. This includes, among other things, defining a research agenda that focuses on smallholder farmers, investing in human capacity, enabling infrastructure for food systems, putting appropriate governance structures in place for agricultural innovation and strengthening farmer–scientist knowledge flows.[8]

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[3] Global Pulse, 2014, *2014 Annual Report: UN Global Pulse*, p. 8, available at www.unglobalpulse.org/sites/default/files/Annual%20Report_2014_FINAL-DIGITAL%20VIEW.pdf. .

[4] Jean N, Burke M, Xie M, Davis WM, Lobell DB and Ermon S, 2016, Combining satellite imagery and machine learning to predict poverty, *Science*, 353(6301): 790-794.

[5] Lazer D, Kennedy R, King G and Vespignani A, 2014, The parable of Google flu: Traps in big data analysis, *Science*, 343(6176):1203–1205.

[6] Commission on Science and Technology for Development, 2016, Issues paper on foresight for digital development.

[7] UNCTAD, 2018, *Technology and Innovation Report 2018*.

[8] UNCTAD, 2017a, *The Role of Science, Technology and Innovation in Ensuring Food Security by 2030* (United Nations publication, New York and Geneva).

C. Promoting energy access and efficiency

12. The development of decentralized renewable energy systems could provide electricity in rural areas far from any grid system.[9] International prices for 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 modules by 80 per cent since 2009,[10] making both increasingly competitive with fossil fuel power generation.

13. Several countries have strategies to promote the development of renewable energy technologies. Chile is developing technologies to change the energy mix in the electricity sector through renewable energy, and is becoming a regional leader in the field of energy transition management.[11] The Government of Canada is also working to become a leader in the clean technology sector, by tackling the unique challenges that clean technology companies face relating to access to long-term capital and to domestic and international markets. This includes the recapitalization of Sustainable Development Technology Canada to help Canadian innovators bring their groundbreaking clean technologies to market.[12]

14. One example of the positive impact of the convergence of frontier technologies is the interaction in smart grids between renewable technologies and data and artificial intelligence technologies. For example, machine-learning algorithms can be used to predict the output of wind farms, allowing scheduled energy delivery to the grid.[13] Energy production and distribution are also improved by allowing households with solar panels to feed surplus energy back into the electricity grid. The real-time information provided by smart grids helps utility companies better respond to demand, power supply, costs and emissions and to avert major power outages.[14] Artificial intelligence, combined with innovative energy storage technologies, helps to address the intermittency of some forms of renewable energy through dynamic adjustment of supply and demand, thus facilitating the deployment of renewable energy technologies. Advances in battery and other technologies are also improving the performance of electric vehicles. When supported by proactive policies, such advances result in significant growth in market share. For example, the market share of electric passenger cars in China doubled between 2017 and 2018, rising from 2.1 to 4.2 per cent.[15]

15. According to a 2018 report of the Secretary-General, policy mixes and a systematic approach to innovation are necessary to increase the share of renewable energy in the global energy mix. This would include measures targeting both the demand for and supply of renewables, as well as a mix of supporting policies to stimulate research and development, build local skills, ensure affordability, and create a supporting regulatory environment. International cooperation, including North–South and South–South cooperation, can also facilitate knowledge sharing, policy learning, capacity building, technology development, and the deployment of interconnected grid infrastructures.[16]

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[9] UNCTAD, 2017b, *The Least Developed Countries Report 2017: Transformational Energy Access*, (United Nations publication, Sales No. E.17.II.D.6, New York and Geneva).

[10] International Renewable Energy Agency, 2016, *The Power to Change: Solar and Wind Cost Reduction Potential to 2025*.

[11] Contribution from the Government of Chile.

[12] Contribution from the Government of Canada.

[13] See www.theverge.com/2019/2/26/18241632/google-deepmind-wind-farm-ai-machine-learning-green-energy-efficiency (accessed 28 February 2019).

[14] UNCTAD, 2015, *Science, Technology and Innovation for Sustainable Urbanization*, UNCTAD Current Studies on Science, Technology, and Innovation no. 10 (United Nations publication, New York and Geneva), p. 23.

[15] See http://ev-sales.blogspot.com/2019/01/china-december-2018.html; and http://ev-sales.blogspot.com/2018/01/china-december-2017.html (accessed 28 February 2019).

[16] E/CN.16/2018/2.

D. Enabling economic diversification and transformation, productivity and competitiveness

16. For countries with the required technological capabilities, frontier technologies may support structural transformation, promote new sources of employment and income and enable access to new markets and opportunities.[17] In this regard, the rapid reduction in the costs of frontier technologies could provide developing countries with an opportunity to fast-track their progress from low-wage activities towards higher-wage and increasing return industries, and to benefit more from their participation in global value chains. For developing countries that lack domestic technological and policy capabilities related to frontier technologies, fulfilling their potential in this regard will require capacity development efforts and related resource support.

17. Historically, new technologies – along with science, technology and innovation policies, endogenous technological capacities and an enabling environment – have supported the productive upgrading of the economies of certain developing countries. For example, Taiwan Province of China achieved rapid economic growth by leapfrogging in specific technology sectors such as semiconductors and other electronic goods. Other countries have made their mark as developers of renewable energy technologies; for instance, Brazil has become the second largest producer of liquid biofuels for transport, and China is the global leader in the production of photovoltaic, wind and solar thermal heating technologies.

18. However, developing countries seeking to engage in long-term technological innovation through industrial development and manufacturing of leapfrogging technologies will need both hard and soft infrastructure and appropriate policy frameworks. One example of a supportive policy framework is the Smart Manufacturing Systems Technology Roadmap,[18] coordinated by the Scientific and Technological Research Council of Turkey. This multilayered road map approach helps to associate a critical technology with specific research and development projects and sector applications and has proved to be an effective way to support the new industrial revolution in Turkey.[19] Economic diversification and transformation can also be supported by policies involving smart specialization, platforms for economic discovery, incubators, accelerators and technology parks.[20]

E. Promoting social inclusion

19. Frontier technologies can also support inclusion. For example, a technology combining biometric and demographic data, called Aadhaar,[21] enabled the financial inclusion of 1.2 billion people in India. Governments are also experimenting with blockchain technologies that may have wide-ranging applications in smart contracts, digital identity systems, land registration and financial transactions.

20. New technologies can enable communities and individuals to coordinate and collaborate in novel forms of innovation. 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. Successful examples include the Indian Aadhaar programme for financial inclusion and the Latvian ManaBalss.lv platform, which helps to bring people's ideas to Parliament and put them on the agenda.[22]

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[17] Contribution from the Government of Mexico.

[18] Contribution from the Government of Turkey.

[19] Ibid.

[20] UNCTAD, 2018, *Technology and Innovation Report 2018*0.

[21] Contribution from the Economic and Social Commission for Asia and the Pacific (ESCAP).

[22] Contribution from the Government of Latvia; ESCAP, 2018, Frontier technologies for sustainable development in Asia and the Pacific. Available at www.unescap.org/sites/default/files/publications/Frontier%20tech%20for%20SDG.pdf; Breidaks I, 2017, Citizen initiatives platform: MyVoice, presented at Civil Society Days 2017, Brussels. Available at: www.eesc.europa.eu/resources/docs/csdays2017---workshop-4---imants-breidaks---citizen-initiatives-platform-my-voice.pdf.

21. Pro-poor, inclusive and frugal innovations can incorporate marginalized and under-represented communities as producers and beneficiaries of innovation processes in new production models that address social needs, stimulate pro-poor entrepreneurship and facilitate solidarity across groups. However, new models of innovation that support social inclusion should be underpinned by science, technology and innovation policies that consider the direction, distribution and diversity of innovation pathways.[23]

F. Confronting disease and improving health

22. 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. Egypt transformed a pilot telemedicine project into a national initiative, using a comprehensive information and communications technology solution to provide medical services by connecting health physicians with professional doctors and experts.[24] Latvia is pioneering the use of artificial intelligence in individualized treatments for metastatic melanoma.[25] The Food and Drug Administration of the United States of America is studying emerging technologies such as blockchain as a data-exchange mechanism for immediately accessing information on patients, supplies and crisis response during a public health emergency.[26]

23. Digitization is also enabling the novel manipulation of biological processes. Advances in biotechnology enable very specific gene editing for human medicine, making personalized treatments possible for some conditions.[27] Gene drives have also been identified as a potential complementary intervention for the control and elimination of malaria in Africa.[28] Emerging technologies for health require strategic policies for implementation, including research, infrastructures, education, regulation, entrepreneurship, communication awareness and the proactive engagement of Governments, development partners and the private sector. Weak cooperation and governance are of particular concern, given the potential health risks for citizens and legal liabilities for businesses posed by some frontier biotechnologies.

G. Improving access to educational learning and resources

24. New digital platforms, including massive open online courses, provide online courses that allow for open access and unlimited participation through the Internet. Key potential benefits include the following: lower-cost replication of high-quality teaching, content and methods; self-paced learning; and data analytics for optimizing learning on the platform.[29]

25. Three-dimensional printing and open hardware and software platforms have the potential to enhance the educational experience in developing countries, where they are being used as a tool for education in primary, secondary and post-secondary schools. Similarly, the Open Labware initiative, organized by Teaching and Research in Natural Sciences for Development in Africa, the Open Neuroscience initiative and Badenlab are promoting collaboration regarding, and the production of, low-cost, open scientific equipment for

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[23] UNCTAD, 2017c, *New Innovation Approaches to Support the Implementation of the Sustainable Development Goals* (United Nations publication, New York and Geneva), p. 28.

[24] Contribution from the Government of Egypt.

[25] Contribution from the Government of Latvia.

[26] Contribution from the Government of the United States of America.

[27] Ledford H, 2016, [Clustered regularly interspaced short palindromic repeats] CRISPR: Gene editing is just the beginning, *Nature*, 7 March. Available at www.nature.com/news/crispr-gene-editing-is-just-the-beginning-1.19510 (accessed 22 February 2019).

[28] New Partnership for Africa's Development, 2018, Gene drives for malaria control and elimination in Africa. Available at https://nepad.org/publication/gene-drives-malaria-control-and-elimination-africa-0 (accessed 22 February 2019).

[29] Brynjolfsson E and McAfee A, 2014, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*, WW Norton and Company; and Khan S, 2012, *The One World Schoolhouse: Education Reimagined*, Twelve, New York.

developing countries for educational and research purposes.[30] However, integrating digital learning mechanisms, three-dimensional printers and open platforms into education also requires the upgrading of teachers' capacities and assessment of the suitability of such technologies regarding existing learning strategies.

II. Transformative and disruptive potential of rapid technological change

26. Rapid technological change will have transformative and disruptive effects that may both advance and frustrate sustainable development. While the application of new and emerging technologies represents an opportunity for faster progress towards the Sustainable Development Goals, rapid technological change can also disrupt markets and economies, exacerbate social divides and raise normative questions. Consideration of the direction, distribution and diversity of innovation pathways in the context of the Sustainable Development Goals could provide opportunities for policymakers to support new forms of innovation that avoid the economic, social and environmental challenges that arose during past technological eras.

A. Automation, labour markets and employment

27. Automation based on the convergence of artificial intelligence, machine learning and big data could have an impact on trade, competition, growth and employment in ambiguous and potentially negative ways. While frontier technologies can be expected to create new jobs and markets in the aggregate and in the long-term, their effects on specific markets and productive sectors can be profoundly disruptive. Ultimately, the impacts of automation will vary according to a range of factors, including the following: levels of industrialization and development; skills and capacities; labour costs; export and production structures; technological capacities; infrastructure; demography; and policies encouraging or discouraging automation.[31]

28. UNCTAD has reviewed a number of recent studies estimating the impact of automation on jobs.[32] The results vary widely, depending on the assumptions made and the methodologies used. Most of the studies only estimate job losses and do not consider job creation effects. Further, digital automation may affect women and men differently. Given that women hold jobs that are at high risk of automation and are underrepresented in the science, technology, engineering and mathematics job families, all of which will benefit from increasing demand on the job market, current gender dynamics in the labour force could be amplified. Moreover, jobs at lower risk of automation occupied by women typically pay less than "low-risk" male-dominated jobs.[33]

29. Moreover, 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. Furthermore, even if technologically feasible and economically reasonable, full automation of jobs takes time, even in developed countries.[34]

30. Beyond artificial intelligence and robotics, platform-based economies tend to display 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. Digital labour platforms often fail to provide reasonable compensation, predictable income streams and standard labour

[30] Baden T, Chagas AM, Gage GJ, Marzullo TC, Prieto-Godino LL and Euler T, 2015, Correction: Open labware: Three-D printing your own lab equipment, *PLoS Biology*, 13(5).
[31] For a more detailed discussion, see UNCTAD, 2018, *Technology and Innovation Report 2018*, p. 23.
[32] Ibid., p. 25.
[33] Ibid., p. 22.
[34] International Bank for Reconstruction and Development and World Bank, 2016, *World Development Report 2016: Digital Dividends*, Washington, D.C., p. 126.

protections.[35] An oversupply of job seekers on online labour platforms could also lead to diminished bargaining power, resulting in a race to the bottom regarding wages and working conditions. Further research and policy dialogue will be critical in ensuring that the expanding digital economy provides quality and decent jobs.[36]

31. The countries of the European Union have moved forward in promoting rapid technological change and in mitigating its potential negative effects. One example in this regard is the New Skills Agenda for Europe, which is designed to: (a) improve the quality of training and the availability of lifelong learning and "retooling" programmes; (b) make qualifications more comparable and hence more portable; and (c) promote "skills intelligence" by providing students and adults with relevant information about labour market conditions and trends so that they can make better education and qualification choices.[37]

32. It is essential to address the potential social costs of the disruptive effects of rapid technological change, particularly on labour markets, over the short and medium term. This highlights the importance of lifelong learning, for skills updating as well as skills upgrading, which will require active policy support. Strengthened social protection is also important in offsetting negative impacts on employment and protecting those unable to adapt to rapidly changing skills requirements. This calls for the development of a new social compact that includes novel approaches to social safety nets to help people deal with the disruption created by technological transitions. Policy experimentation (such as the 2017–2018 Finnish partial universal basic income pilot scheme) is needed to better understand the social and economic implications, particularly for developing countries.[38]

B. Socioeconomic divides

33. Rapid technological change has the potential to perpetuate existing divides within and between countries, women and men, rural and urban populations and rich and poor communities.[39] As recent data show, the share of Internet users in the total population of developed countries is more than four times higher than in that of least developed countries. This existing digital divide may exacerbate economic divergence between countries at the frontier of rapid technological change and the least developed countries.

34. Countries wishing to cross the technological frontier may leapfrog primarily through the adoption of technologies, rather than through the development of new technologies. However, innovation policies can help developing countries to foster and facilitate the deployment of frontier technologies and their adaptation to meet their needs and promote sustainable development.

35. The increasing rate of technological change may widen existing gender digital and science, technology, engineering and mathematics divides. Only 12 per cent of leading machine-learning researchers are women,[40] and only a third of entry-level positions in technology companies are being filled by women.[41] There is evidence that some applications of artificial intelligence or big data may be subject to bias, including gender bias. Because the number of women working in the fields of science, technology, engineering and mathematics is low, they may not be able to take advantage of the increased demand for

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[35] Berg J, Furrer M, Harmon E, Rani U and Silberman MS, 2018, *Digital Labour Platforms and the Future of Work: Towards Decent Work in the Online World* (International Labour Organization, Geneva), p. xviii.

[36] UNCTAD, 2017c, *Information Economy Report 2017: Digitalization, Trade and Development* (United Nations publication, Sales No. E.17.II.D.8, Geneva and New York), p. xiv.

[37] Contribution from the Economic Commission for Europe.

[38] UNCTAD, 2018, *Technology and Innovation Report 2018*, pp. 75–76.

[39] Ibid.

[40] Simonite T, 2018, AI is the future-but where are the women? *Wired*, 17 August, available at www.wired.com/story/artificial-intelligence-researchers-gender-imbalance/ (accessed 22 February 2019).

[41] Krivkovich A, Kutcher E and Yee L, 2016, Breaking down the gender challenge, *McKinsey Quarterly*, March. Available at www.mckinsey.com/business-functions/organization/our-insights/breaking-down-the-gender-challenge (accessed 22 February 2019).

workers with skills in frontier technologies, or significantly shape rapid technological change.

C. Normative considerations

36. While frontier technologies offer unprecedented opportunities to transform the practice, implementation and monitoring of sustainable development, they also pose profound questions regarding how legal, social, ethical and cultural norms could be affected in aspects ranging from the integrity of human life to the safety of the natural environment and from the respect for personal privacy, security and safety to the prevention of any form of discrimination.

37. Genetic engineering techniques, for example, may confront the global community with foundational questions involving the key values attached to human, animal and plant life and its manipulation. Synthetic biology and [clustered regularly interspaced short palindromic repeats]CRISPR/Cas9-based genome editing raise questions about possible unintended effects (for example, permanent DNA breaks at other unintended sites in a genome), regulatory challenges involving the labelling of modified crops (i.e. difficulty in identifying a modified organism once it has been released) and intellectual property rights and their unclear implications for smallholder farmers.[42]

38. As well as bringing increased convenience and personalization to digital platforms, digital and artificial intelligence-related technologies may introduce the possibility of scaling bias, discrimination and inequality in unprecedented ways. Biased big data may produce unintended and sometimes discriminatory results. There is concern that biased data introduce or amplify discrimination in areas such as predictive policing, access to financial services and recruitment. There is a lack of transparency surrounding the issue of how machine-learning algorithms are devised and deployed. The increasing use of deep-learning systems, which produce predictions lacking interpretability and explanation, is a matter of great concern regarding application areas involving human health, public service delivery and consumer advertising.

39. Furthermore, automated algorithms could threaten consumer protection, particularly regarding privacy and security. Smart meter technologies can use sophisticated statistical algorithms to determine sensitive household information, such as which appliances or devices a household might possess and when they are operating. Data collected from health trackers and wearables and electronic health records that are disclosed to third parties could potentially have an impact on insurance policies or even on future employment prospects.

40. A number of academic, civic, industrial and government initiatives are underway at various levels to develop answers to questions such as those set out above. Educational institutions may wish to consider offering courses and dialogues on the ethics and governance of rapid technological change. However, the normative dimensions of rapid technological change have clear supranational implications, pointing to the need for an evolving, inclusive global discourse on how to steer the development of frontier technologies in ways consistent with the 2030 Agenda for Sustainable Development and, more generally, with the universally accepted principles underpinning the international system.

III. Key policy considerations

41. New and emerging technologies could facilitate new pathways towards sustainable development that also take into consideration its economic, social and environmental dimensions. This section investigates how national science, technology and innovation policies, regional and international cooperation and multi-stakeholder engagement could facilitate the harnessing of frontier technologies for sustainable development.

[42] UNCTAD, 2017, *The Role of Science, Technology and Innovation in Ensuring Food Security by 2030* (United Nations publication, New York and Geneva), pp. 21–22.

A. Back to basics: Strengthening national innovation systems

42. Without appropriate science, technology and innovation policies, technologies, be they old or new, 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. National innovation systems involve the interaction and alignment of a variety of institutions, both public and private, to support the adoption and adaptation of new products and processes by private and public organizations. Firms are at the core of innovation systems, which also encompass research and education systems, Government, civil society and consumers.

43. Policymakers might wish to focus on the following key aspects: the capabilities of the various actors; the connections between them that facilitate exchanges and collaboration; and the enabling environment for innovation that is created.[43] 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.

44. National science, technology and innovation policies can promote the use of key technologies, build small and medium-sized enterprises' capacities, provide financial support for research and development, and connect actors within the innovation system. Several countries use policy instruments to support key technologies. In Latvia, green public procurement is encouraged by the Public Procurement Law, while South Africa has sector-specific initiatives, including the Biorefinery Industry Development Facility and the Mandela Mining Precinct, which supports local innovation in the mining industry.[44]

45. To be effective, science, technology and innovation policies need to be internally consistent and aligned with national priorities and development plans. Consistency may be promoted through the design and deployment of strategies and policy instruments at the most appropriate level. Alignment, however, requires a "Whole-of-Government" perspective, facilitating cooperation across ministries and other public bodies in different fields of policy.

46. Countries seeking to orient science, technology and innovation policies towards sustainable development should also consider integrating societal challenges into their cores.[45] Gender-inclusive innovation policies may be directed towards women's participation as innovators or entrepreneurs, while youth-oriented policies can also be helpful in making technological change inclusive. Innovation in informal settings is also getting attention as a source of livelihoods (Sustainable Development Goal 8),[46] given that 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.[47]

47. Countries may also consider developing science, technology and innovation policies that focus on specific technologies that advance their national economic and development agendas (see box 1). It is important to note, however, that even if countries develop national science, technology and innovation or more technology-specific strategies, translating these strategies and policies into programmes with a tangible impact on pressing developmental challenges is a critical issue.[48]

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[43] UNCTAD, 2018, *Technology and Innovation Report 2018*, pp. 54–57.

[44] Contributions from the Governments of Latvia and of South Africa.

[45] UNCTAD, 2018, *Technology and Innovation Report 2018*, p. 66.

[46] Cozzens S and Sutz J, 2014, Innovation in informal settings: Reflections and proposals for a research agenda, *Innovation and Development* 4(1): 5-31; Kraemer-Mbula E and Wunsch-Vincent S, eds., 2016, The informal economy in developing nations: Hidden engine of innovation? Cambridge University Press, Cambridge.

[47] Müller J, 2010, Befit for change: Social construction of endogenous technology in the South, paper presented at the Association of Development Researchers Conference, Gjerrild, Denmark, March.

[48] Contribution from the Economic and Social Commission for Western Asia.

Box 1
Selected examples of sector-specific strategies for rapid technological change

Chile hosts around 50 per cent of the world's installed capacity in terms of astronomical observatories, and is exploring opportunities to use that privileged position to develop big data analysis and artificial intelligence capacities. Latvia has developed the "Data-Driven Nation Concept", which has three pillars: (a) data democracy (promoting access and uptake of data); (b) data-enabled citizen engagement in public administration processes; and (c) data and technology-driven innovation development and commercialization.

Several countries of the Asia–Pacific region have 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 road maps, plans and standards for the Internet of things.

Most Arab countries already have science, technology and innovation strategies (i.e. Egypt, Jordan, Morocco, Saudi Arabia and the United Arab Emirates). In addition, Morocco and Tunisia have developed more specialized digital strategies, Qatar and the Sudan have smart strategies, the United Arab Emirates has 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).

Sources: Contributions from the Governments of Chile and Latvia, the Economic and Social Commission for Western Asia and the Economic and Social Commission for Asia and the Pacific (ESCAP).

B. Closing digital divides by building infrastructure and digital competencies

48. Digitalization and connectivity are key features of frontier technologies. It is therefore critical that digital policies should be calibrated according to countries' readiness to engage with and benefit from the digital economy.[49] The 2018 report of the Secretary-General on building digital competencies to benefit from existing and emerging technologies, with a special focus on gender and youth dimensions, makes it clear that digital competencies include technical skills, but also generic and complementary skills that enable people to understand media, search for information, be critical about what is retrieved and communicate with a variety of digital tools and applications.[50]

49. Different types of digital skills are needed to adapt to new technologies, including skills required to adopt, use and creatively adapt existing technologies and to create entirely new technologies.[51] Education and training programmes on digital skills should be inclusive and accessible to everyone; examples in this regard include the Canadian CanCode and Digital Literacy Exchange programmes and the Secondary Transition to Employment Programme–United States Geological Survey Partnership.[52]

50. Information and communications technology is now considered to be part of a country's critical physical infrastructure, which, as an enabling technology, creates synergies with other key technologies such as biotechnology, nanotechnology and advanced manufacturing. Taking advantage of this potential requires investment in basic information and communications technology infrastructure, a reliable energy supply and telecommunication infrastructure, and regulation that ensures a competitive marketplace

[49] UNCTAD, 2017c, *Information Economy Report 2017*.
[50] E/CN.16/2018/3, para. 10.
[51] Ibid., paras. 13–16.
[52] Contributions from the Governments of Canada and of the United States of America.

providing quality, affordability and accessibility.[53] For example, in 2016, Chile launched a large-scale project that will spread fibre optic Internet across Chile.[54] Peru is planning to develop a national fibre optic network more than 13,000 km long, connecting Lima with 22 regional capitals and 180 provincial capitals.[55]

C. Promoting regional, international and multi-stakeholder cooperation

51. Including through regional, international and multi-stakeholder cooperation, the international community can support efforts to harness rapid technological change for sustainable development and prevent it from leading to widening divides, greater socioeconomic inequalities and environmental degradation.

52. Such support will need to be increased to prevent the evolving digital economy from leading to widening digital divides and greater income equalities. For example, the share of information and communications technology in total Aid for Trade declined from 3 per cent during the period 2002−2005 to only 1.2 per cent in 2015. [56]

53. Global collaboration in scientific research has grown considerably over recent decades, opening up new opportunities for combining the most advanced scientific capabilities with detailed local knowledge in key areas of sustainable development. The capacities of many developing countries to participate in such collaboration have increased considerably. To direct such networks firmly towards achievement of the Sustainable Development Goals, Governments need to move beyond simply funding and managing research and development to influencing networks. This requires an understanding of networks' formation, organization, norms, dynamics, motivations and internal control mechanisms.[57]

54. Recently, there have been several examples of successful regional and international collaboration in scientific research and capacity-building for frontier technologies. [58] International collaboration, including North–South, South–South and triangular collaboration, to address rapid technological change can include knowledge and data sharing, capacity building and collaboration in research and technology development, foresight exercises and science, technology and innovation policy (see box 2).

Box 2

Examples of regional and international collaboration

Regional and international collaboration in frontier technologies can take many forms, including collaborative technology development, capacity building and policy research. International collaboration can support efforts to share data and develop technologies. The European Union European Earth Observation Programme (also known as "Copernicus") provides full, free and open data and contributes to regional and international efforts to identify and respond to global challenges. Germany has recently launched the Green Peoples' Energy for Africa initiative, which supports partner countries in developing decentralized, renewables-based energy systems. QualiREG is a scientific and technical network of Indian Ocean agrifood actors that promotes research, development and innovation for agrifood chain quality.

Training and participation in international exchanges also help to spread scientific and technical expertise across countries. For example, the National Institutes of Health of the United States of America sponsors international collaborative projects through the Fogarty

[53] UNCTAD, 2018, *Technology and Innovation Report 2018*, p. 57.

[54] Chile, Subsecretariat for Telecommunications, Proyecto Fibra Óptica Austral 2017, available at https://foa.subtel.gob.cl/proyecto-fibra-optica-austral-2/ (in Spanish) (accessed 16 November 2018).

[55] Contribution from the Government of Peru.

[56] Organization for Economic Cooperation and Development (OECD) and World Trade Organization (WTO), 2017, *Aid for Trade at a Glance 2017: Promoting Trade, Inclusiveness and Connectivity for Sustainable Development*, Geneva and Paris, pp. 306–307.

[57] UNCTAD, 2018, *Technology and Innovation Report 2018*, p. 104.

[58] Ibid.

International Centre, and the European Union welcomes "third countries" into most of its research programmes.

Regional and international collaboration on technology foresight and policy research can strengthen the capacities of national policymakers to respond to rapid technological change. A Canadian-supported ESCAP project entitled Catalysing Women's Entrepreneurship – Creating a Gender-Responsive Entrepreneurial Ecosystem supports the development of gender-responsive policies and programmes by policymakers and provides training for women entrepreneurs.

Sources: Contributions from the Governments of Austria and Germany; Contribution from the High-Level African Panel on Emerging Technologies; United Nations Office for Outer Space Affairs, 2018, *European Global Navigation Satellite System and Copernicus: Supporting the Sustainable Development Goals. Building Blocks towards the 2030 Agenda* (United Nations publication, Vienna); Government of Canada, 2018, Catalysing Women's Entrepreneurship - Creating a Gender-Responsive Entrepreneurial Ecosystem. Available at http://w05.international.gc.ca/projectbrowser-banqueprojets/project-projet/details/D004857001 (accessed 12 November 2018); and Abdus Salam International Centre for Theoretical Physics, 2018, New Internet of Things doctoral programme: [International Centre for Theoretical Physics] ICTP supports [the African Centre of Excellence in Internet of Things] ACE IoT in Rwanda. Available at www.ictp.it/about-ictp/media-centre/news/2018/5/iot-phds.aspx (accessed 16 November 2018).

55. At the global level, the Secretary-General's High-level Panel on Digital Cooperation is considering potential mechanisms and models to improve international cooperation on new and emerging technologies. Multi-stakeholder initiatives can also leverage their participants' resources to raise awareness about major challenges, such as gender digital divides (for example, the Equals Global Partnership and the World Wide Web Foundation Rights, Education, Access, Content, Targets initiative) and advocate for actions to address these challenges.[59] Countries may also wish to consider developing collaborative research and development partnerships involving leading technology companies and domestic science and technology talent to address their most critical problems.[60]

IV. Directing rapid technological change to support sustainable development

56. In this report, note is taken of how rapid technological change offers unprecedented opportunities for addressing the social, economic and environmental challenges of the twenty-first century. A number of risks are identified regarding social and economic disruption that have implications for the resilience of our social, cultural and political institutions, as well as possible unintended consequences for the future of humanity and the planet.

57. In a globalized economy and an increasingly digitalized world, where products, services, information and knowledge are moving ever faster, responses to those challenges can only come from coordinated undertakings, based on international cooperation, inclusive multilateralism and a multi-stakeholder approach.

58. In particular, the international community needs to advance its collective understanding of how to steer new and emerging technologies in ways that leave no one behind. Progress is needed in: (a) conceptualizing international technology assessment and

[59] Contribution from the Government of Canada; Equals, 2018, available at https://www.equals.org (accessed 16 November 2018); Human Rights Council, 2018, Report of the Special Rapporteur on violence against women, its causes and consequences on online violence against women and girls from a human rights perspective, 12 June, A/HRC/38/47; World Wide Web Foundation, 2017, [Rights, Education, Access, Content, Targets] REACT with gender-responsive information and communications technology policy: The key to connecting the next 4 billion. Available at http://webfoundation.org/docs/2017/09/REACT-with-Gender-Responsive-ICT-Policy.pdf (accessed 12 November 2018).

[60] Contribution from the Institute for Transformative Technologies.

foresight and (b) developing an inclusive global discourse, from a developmental perspective, about the normative aspects of rapid technological change.

A. Global technology foresight and assessment for rapid technological change

59. Developing capacity in technology assessment and foresight (for example, horizon scanning and ex ante impact assessments) can enable countries to: identify and exploit the potential of frontier technologies for sustainable development; assess the potential effects and risks of emerging technologies; and determine the most likely mid and long-term technological developments.

60. Technology foresight and assessment are formal processes for informing the governance of innovation and research. Technology foresight and technology assessment are typically defined respectively as: "systematic and explicit attempts to identify areas of strategic research and emerging generic technologies likely to yield the greatest economic and social benefits" and "anticipation of impacts and feedbacks in order to reduce the human and social costs of learning how to handle technology in society by trial and error".[61]

61. Member States increasingly recognize the importance of technology assessment and foresight activities in enabling societies and policymakers to adapt to the changes brought about by the proliferation of new technologies. The Economic and Social Council has recognized that technology assessment exercises could help policymakers and stakeholders in implementing the 2030 Agenda for Sustainable Development through the identification of challenges and opportunities that can be addressed strategically (E/RES/2017/22).[62]

62. Member States could explore ways and means of conducting national, regional and international technology assessments and foresight exercises. An international capability to monitor such developments and outline their implications for low and middle-income countries would significantly enhance the capability of national decision-makers to respond.

63. Although foresight activities are rarely conducted at the international level, there have been calls for international foresight activities as a mechanism for framing and articulating development needs and bringing these to bear on innovation actors.[63] Moreover, there is a need for a global initiative that can systematically convene experts from across disciplines to address scientific, technical and innovative developments and their potential impacts for the economy, society and the environment. Such a global initiative should ideally involve both technology assessment and foresight to evaluate the immediate and long-term impacts of new technologies.

B. An inclusive discourse on the normative dimension of rapid technological change

64. Global technology assessment and foresight should be guided by norms, principles and values that direct the development and application of rapid technological change in ways that uphold core United Nations values and principles, including human rights and advance sustainable development.

65. Growing awareness of the key ethical and normative issues involved in the emergence, deployment, use and development of frontier technologies has led to the emergence of many voluntary initiatives to develop principles to guide rapid technological change to be fair, transparent, accountable and inclusive. For example, in the area of artificial

[61] Van Zwanenberg P, Ely A and Stirling A, 2009, *Innovation, Sustainability, Development A New Manifesto. Emerging Technologies and Opportunities for International Science and Technology Foresight*, Social, Technology and Environmental Pathways to Sustainability Centre, Working Paper 30, Brighton, p. 4.

[62] Related United Nations resolutions recommending the use of technology assessment and foresight exercises include: E/RES/2018/29; A/RES/72/228; and A/RES/72/242.

[63] Van Zwanenberg P et al., 2009, *Innovation, Sustainability, Development A New Manifesto*.

intelligence, over 30 principles have been developed by academics, non-governmental organizations,[64] Governments and supranational bodies[65] and industry.[66]

66. The World Commission on the Ethics of Scientific Knowledge and Technology recently addressed the issue of robotics ethics.[67] The Secretary-General of the United Nations recently published a strategy on new technologies,[68] and the High-level Panel on Digital Cooperation was established to raise awareness about the transformative impact of digital technologies and to contribute to the broader public debate.[69]

67. The wealth of diverse initiatives in response to the normative challenges of artificial intelligence specifically reveals different and sometimes conflicting emphases and priorities, pointing to a need for a more comprehensive and coherent framework.[70] Beyond artificial intelligence, normative and ethical considerations are being discussed and deliberated

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[64] For example: Asilomar [Artificial Intelligence] AI Principles; General Principles in Ethically Aligned Design, version 2, by the Institute of Electrical and Electronics Engineers; Principles for Algorithmic Transparency and Accountability, by the Association for Computing Machinery; Japanese Society for Artificial Intelligence Ethical Guidelines; Montreal Declaration for a Responsible Development of Artificial Intelligence; Three ideas from the Stanford Human-Centred AI Initiative; Three rules for artificial intelligence systems, Chief Executive Officer, Allen Institute for Artificial Intelligence; Harmonious Artificial Intelligence Principles; Universal Guidelines for Artificial Intelligence, by The Public Voice; Principles for the Governance of AI, by The Future Society; Tenets, by Partnership on AI; Top 10 Principles For Ethical Artificial Intelligence, by UNI Global Union, 2017; AI Policy Principles, by the Information Technology Industry Council, 2017; Toronto Declaration: Protecting the rights to equality and non-discrimination in machine learning systems; 10 principles for public sector use of algorithmic decision making, by Nesta. Sources: Zeng Y, Lu E and Huangfu C, 2018, Linking artificial intelligence principles, presented at the Association for the Advancement of Artificial Intelligence Workshop on Artificial Intelligence Safety, 2019, Cornell University; www.accessnow.org/cms/assets/uploads/2018/08/The-Toronto-Declaration_ENG_08-2018.pdf; and www.nesta.org.uk/blog/10-principles-for-public-sector-use-of-algorithmic-decision-making/.

[65] For example: Japan, Ministry of Internal Affairs and Communications, AI Research and Development Principles and draft AI Utilization Principles; United Kingdom of Great Britain and Northern Ireland, House of Lords AI Code; Ethical principles and democratic prerequisites, by the European Group on Ethics in Science and New Technologies; European Commission draft Ethics Guidelines for Trustworthy AI; Council of Europe Ethical framework for the use of artificial intelligence in judicial systems; Singapore Model Governance Framework for AI; and Canada-France Statement on Artificial Intelligence. Sources: Zeng et al., 2018, Linking artificial intelligence principles; https://ec.europa.eu/futurium/en/system/files/ged/ai_hleg_draft_ethics_guidelines_18_december.pdf; https://www.coe.int/en/web/artificial-intelligence/-/31st-plenary-meeting-of-the-cepej-adoption-of-the-first-european-text-defining-the-ethical-framework-for-the-use-of-artificial-intelligence-in-judicia (accessed 27 February 2019); https://international.gc.ca/world-monde/international_relations-relations_internationales/europe/2018-06-07-france_ai-ia_france.aspx?lang=eng (accessed 27 February 2019); and https://channels.theinnovationenterprise.com/articles/singapore-releases-model-governance-for-ai-at-wef (accessed 27 February 2019).

[66] For example: DeepMind Ethics and Society Principles; OpenAI Charter; AI at Google: Our principles; Microsoft AI principles; IBM’s principles for the cognitive era and principles for trust and transparency; Developing AI for Business with Five Core Principles, by Sage; SAP’s Guiding Principles for Artificial Intelligence; Sony Group AI Ethics Guidelines; Unity’s Guiding Principles for Ethical AI; and Telefónica AI Principles. Sources: Zeng et al., 2018, Linking artificial intelligence principles; https://blogs.unity3d.com/2018/11/28/introducing-unitys-guiding-principles-for-ethical-ai/ (accessed 27 February 2019); and www.telefonica.com/en/web/responsible-business/our-commitments/ai-principles (accessed 27 February 2019).

[67] World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), 2017, Report of COMEST on robotics ethics, 14 September. Available at https://unesdoc.unesco.org/ark:/48223/pf0000253952 (accessed 25 February 2019).

[68] United Nations, 2018, United Nations Secretary-General’s strategy on new technologies, September. Available at www.un.org/en/newtechnologies/images/pdf/SGs-Strategy-on-New-Technologies.pdf.

[69] United Nations, 2018, Secretary-General’s High-level Panel on Digital Cooperation, available at www.un.org/en/digital-cooperation-panel/ (accessed 12 November 2018).

[70] Whittlestone J, Nyrup R, Alexandrova A and Cave S, 2019, The role and limits of principles in [artificial intelligence] AI ethics: Towards a focus on tensions, University of Cambridge; and Zeng Y et al., 2018, Linking artificial intelligence principles.

regarding a range of frontier technologies, including synthetic biology, the Internet of things, nanotechnology, drones and neurotechnologies.

68. As a result of the abovementioned ethical and normative questions, the issue arises of how to develop a global discourse on this matter that respects diversity, global inclusiveness, multi-stakeholder involvement, coherence between multiple initiatives and their consistence with the international community's development agenda. Governments and other stakeholders might wish to begin exploring the high-level characteristics, elements and directions that could define a useful global response to this challenge. Developing countries, especially least developed countries, not engaged in the development of frontier technologies but likely to be affected by their consequences, need to be part of this global discourse.

V. Suggestions for consideration by member States and the Commission on Science and Technology for Development at its twenty-second session

69. Rapid technological change has potential regarding the implementation of the 2030 Agenda for Sustainable Development and the achievement of the Sustainable Development Goals. However, such change poses new challenges for policymaking, threatening to outpace the capacity of Governments and society to adapt to shifts brought about by new technologies. Although the global dynamics of technological change have the potential to increase socioeconomic divides, policies can support investments that spread capabilities more broadly and stimulate innovation with and for groups at the margins of society. National strategies harnessing rapid technological change for sustainable development involve the building and management of effective innovation systems. North–South, South–South and triangular cooperation, initiatives by academic, technical, business and civil society communities and United Nations system-wide efforts can also play a role in ensuring that rapid technological change leaves no one behind. The international community is encouraged to advance its collective understanding of how to navigate and shape new and emerging technologies in ways that "leave no one behind." This should involve discussions on international technology assessment and foresight and consensus building on normative and ethical guidelines to shape the developmental potential of rapid technological change.

70. Member States may wish to consider the following suggestions:

(a) Increase national support for research and development activities regarding rapid technological change, and bring together Government, academia, the private sector and civil society to take part in these activities, from basic research to implementation;

(b) Ensure coherence between science, technology and innovation policies and strategies on rapid technological change and the broader national development agenda;

(c) Recognize and consider the social and cultural contexts of local groups, especially women, and support innovation, scaling and deployment of rapid technological change in such contexts;

(d) Promote North–South, South–South and triangular partnerships on rapid technological change and investigate collaborative research and development mechanisms that might be effective for technology facilitation;

(e) Conduct technology assessment and foresight exercises in order to encourage structured debate among all stakeholders towards creating a shared understanding of the implications of rapid technological change;

(f) Apply a gender lens in science, technology and innovation policies, including by promoting and leveraging science and technology to support women's development in key sectors involving rapid technological change. Policies should also promote gender equality in science and technology-related education, careers and leadership, as well as encourage and support the role of women in innovation.

71. The international community may wish to consider the following suggestions:

(a) Work toward defining an international technology assessment and foresight mechanism that would help developing countries assess the immediate and long-term implications of technological change;

(b) Explore how the normative challenges raised by rapid technological change can be considered in an inclusive global discourse consistent with the 2030 Agenda for Sustainable Development;

(c) Encourage international science, technology and innovation collaboration in rapid technological change;

(d) Foster closer collaboration among different international organizations and with civil society organizations regarding initiatives designed to build skills for rapid technological change;

(e) Promote the use of digital methods, such as online platforms, for international knowledge sharing and capacity building.

72. The Commission is encouraged to:

(a) Support multi-stakeholder collaboration in policy learning, capacity building and technology development;

(b) Improve coordination among stakeholders and enable partnerships in rapid technological change that harness the specific expertise and interest of stakeholders;

(c) Encourage the sharing of lessons between countries and regions, while recognizing that policies and policy mixes cannot be simply transplanted from one context to another;

(d) Compile and share examples of good practice and lessons learned in mainstreaming a gender perspective into science, technology and innovation policies and programmes, with a view to replicating and scaling up successes, and increase collaboration with the Commission on the Status of Women.