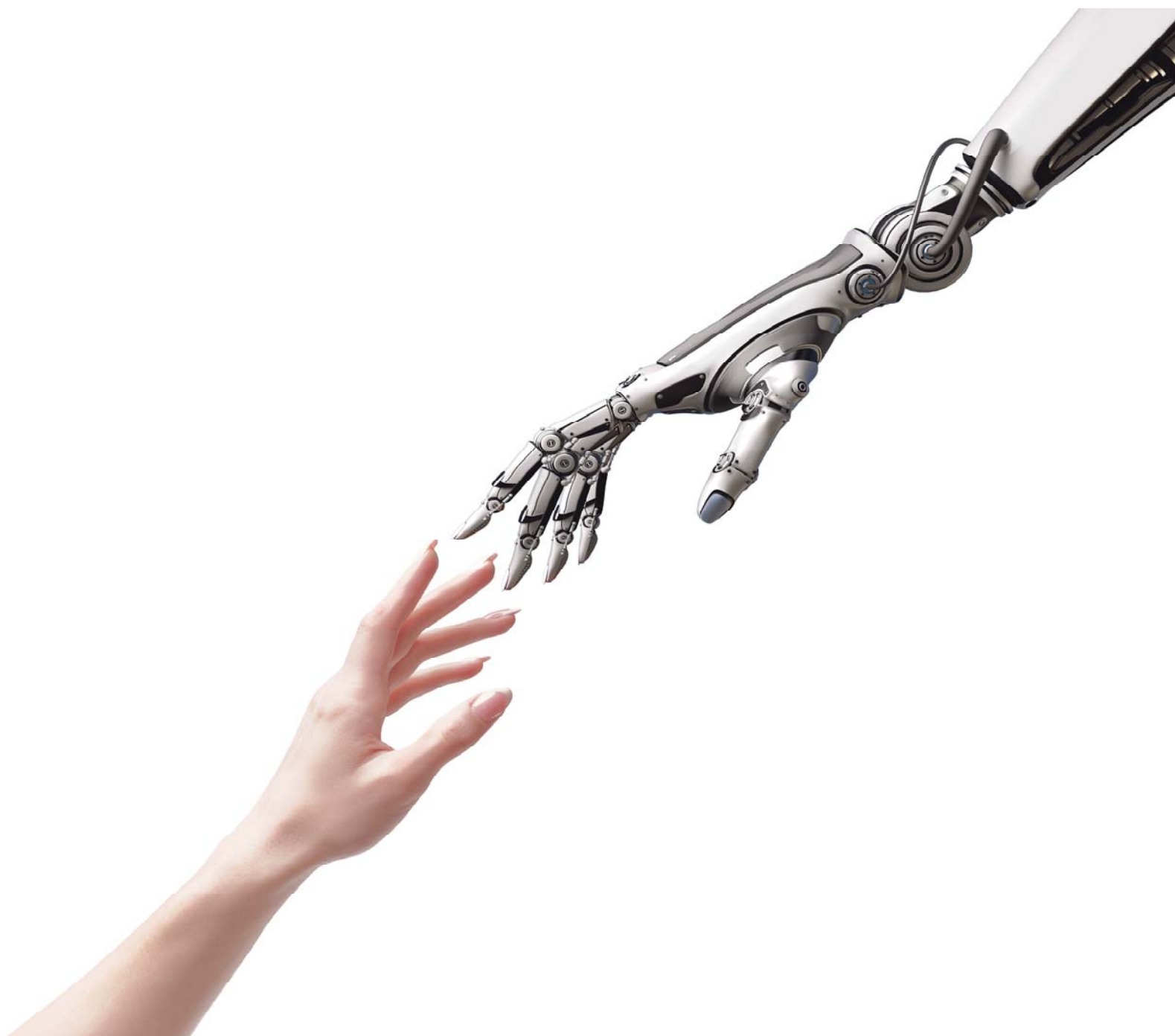
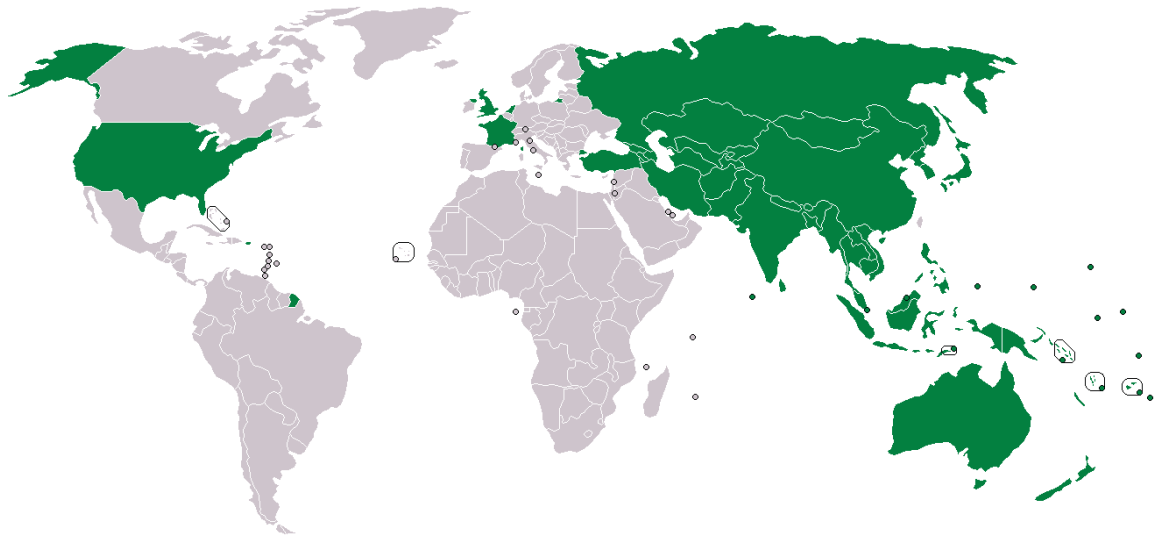


# FRONTIER TECHNOLOGIES

for sustainable development  
in Asia and the Pacific





*The shaded areas of the map indicate ESCAP members and associate members.*

The Economic and Social Commission for Asia and the Pacific (ESCAP) serves as the United Nations' regional hub promoting cooperation among countries to achieve inclusive and sustainable development. The largest regional intergovernmental platform with 53 member States and 9 associate members, ESCAP has emerged as a strong regional think-tank offering countries sound analytical products that shed insight into the evolving economic, social and environmental dynamics of the region. The Commission's strategic focus is to deliver on the 2030 Agenda for Sustainable Development, which it does by reinforcing and deepening regional cooperation and integration to advance connectivity, financial cooperation and market integration. ESCAP's research and analysis coupled with its policy advisory services, capacity building and technical assistance to governments aims to support countries' sustainable and inclusive development ambitions.



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## FOREWORD

Industrial revolutions, from the age of mechanization to mass production to the digital revolution, have spurred economic growth and prosperity. However, this was often at the cost to the environment and society. Carbon dioxide emissions dramatically increased in step with the industrial revolutions, and many people were left behind during the digital revolution fuelling a widening digital divide.

Now, as we enter the Fourth Industrial Revolution, a revolution defined by frontier technological breakthroughs such as AI, robotics, 3D printing, and the Internet of Things amongst others, it will be critical that these technologies work for society and the environment as well as the economy if we are to achieve the ambitions of the 2030 Agenda for Sustainable Development. In this regard we need to listen to historians, not just futurists. The disruptive nature of technology is nothing new. It will be critical to learn from the past as we shape the future of frontier technologies.

Frontier technologies offer a multitude of opportunities to re-imagine how our economies could serve better social and environmental needs. First, the adoption of technologies and innovation in production processes has the potential to enhance productivity. For example, embracing the Internet of Things in China's manufacturing chain could add up to \$736 billion to GDP by 2030.

Second, technologies have the potential to lift the sustainable development curve. For instance, improved application of frontier technologies to transportation and logistics could reduce carbon emissions by an estimated 4.5 billion tons by 2020. Image recognition has allowed researchers to scan more than 50,000 images of plants to identify crop diseases using smartphones with a success rate of over 99 per cent.

Third, innovative policy action to utilize technologies in the delivery of public services is gaining ground. E-government services, including in health and education sectors, are a great example of how governments are embracing technology.

Fourth, frontier technologies can help anticipate and respond to the effects of climate hazards and air pollution through the adoption of state-of-the-art technologies to address environmental impacts. In the Republic of Korea, the smart city of Songdo is built around the Internet of Things to reduce traffic pollution, save energy and water, and create a cleaner environment.

However, there are challenges. First, there are uncertainties about the future of work. In the coming decades, the jobs of 785 million workers, that's equivalent to over 50 per cent of total employment in the Asia-Pacific region could be automated.

Second, despite the rapid penetration of the internet the world over, several billion have been left behind. As ICT infrastructure is the backbone of many frontier technologies, there is a risk of its triggering a new frontier technology divide, compounding an already existing digital divide.

Third, frontier technologies pose trust and ethical questions. There are risks of calibrating AI algorithms based on biased data that may yield biased AI learning outcomes. Government-owned satellites, telecommunications multinationals, social media start-ups, all have real-time information at their fingertips. In this information and data revolution age, open and big data movements of varying quality, combined with advancements in computing, machine learning and behavioural economics, fuel the advancement of frontier technologies. Technology per se is not the problem, but there are ethical issues surrounding privacy, ownership and transparency.

In this context, this report reviews the status of frontier technologies in the Asia-Pacific region. The report stresses that while there are question marks over the scale and pace of the frontier technological transition, it would be prudent for governments to be prepared, and to put effective policies in place.

The policy framework for the next generation of technology and innovation should focus on creating an enabling environment for frontier technologies to positively impact economy, society, and environment; and to reduce inequalities. A few prerequisites for the development and application of frontier technologies are:

1. An inclusive ICT infrastructure.
2. A workforce fit for the emerging scale and speed of the technological revolution. In this context, there is a need to promote lifelong learning, reskilling and entrepreneurship development to develop a cadre of job creators.
3. A responsive and adaptive regulatory framework that doesn't stifle innovation.
4. A private sector that pursues responsible frontier technology development to tackle social and environment concerns; and to strengthen the quality and sustainability of growth by creating "shared value" through a focus on corporate sustainability.
5. A catalysing role of government in frontier technologies' evolution.

Cross-government cooperation; inter-governmental knowledge sharing and consensus building; and honest, open and regular discussion with civil society and the private sector, specifically technology developers; will be critical to ensure that frontier technologies have a positive impact on sustainable development.

The impacts of our technologically-driven future are far from pre-ordained. However, frontier technological breakthroughs require us to think differently about how we have traditionally formulated technology policy. I hope the ideas presented in this report stimulate thinking for the development of a next generation technology policy framework fit for the Fourth Industrial Revolution Future that we face.

A handwritten signature in black ink, appearing to read 'Shamshad Akhtar', with a stylized flourish at the end.

Shamshad Akhtar  
Under-Secretary-General of the United Nations  
and Executive Secretary, United Nations  
Economic and Social Commission for Asia and Pacific





## ACKNOWLEDGEMENTS

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## ABBREVIATIONS

AI	Artificial Intelligence
ASEAN	Association of Southeast Asian Nations
CAIIIA	China Artificial Intelligence Industry Innovation Alliance
CSR	Corporate social responsibility
DESA	United Nations Department of Economic and Social Affairs
ESCAP	Economic and Social Commission for Asia and the Pacific
FinTech	Financial technology
GDP	Gross domestic product
GPT	General-purpose technologies
ICT	Information and communications technology
IT	Information technology
IoT	Internet of Things
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
SDG	Sustainable Development Goal
SME	Small and Medium-sized Enterprise
STI	Science, Technology and Innovation
TFP	Total Factor Productivity
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
UK	United Kingdom
USA	United States of America





# 1. SETTING THE SCENE

## 1.1 Introduction

In 2015, when the world signed up to the most ambitious agenda ever agreed – the 2030 Agenda for Sustainable Development – technology was heralded as a key means of implementation for their achievement. Indeed, numerous innovations - such as pneumococcal vaccines, microfinance and green technologies - have been developed and spread around the world at an unrelenting pace over the last few decades; improving health, providing economic opportunities and addressing climate change. Digital technologies like mobile phones and the internet have created an era where ideas, knowledge and data flow more freely than ever before.

However, as we enter the Fourth Industrial Revolution - a revolution defined by frontier technological breakthroughs such as artificial intelligence (AI), robotics, 3D printing, and the Internet of Things amongst others - the wave of optimism surrounding the transformative potential of technology has been tempered by increasing concerns about the potential negative impacts of these new frontier technologies, key issues being the future of work and impact on jobs.

While the frontier technologies which are defining the Fourth Industrial Revolution offer a multitude of opportunities to re-imagine the economy, society and environment; there are also significant challenges which could fuel increased inequalities.

This report provides an overview of frontier technology development in Asia and the Pacific. It highlights key opportunities and challenges of frontier technologies across the three dimensions of sustainable

development - economic, social and environmental. The report also proposes some key policy priorities that could: 1) form the basis of a next generation technology policy framework for the Fourth Industrial Revolution future that we face, 2) ensure that frontier technologies more deliberately align to the ambitions of the Sustainable Development Goals (SDGs), and 3) ensure that no one is left behind.

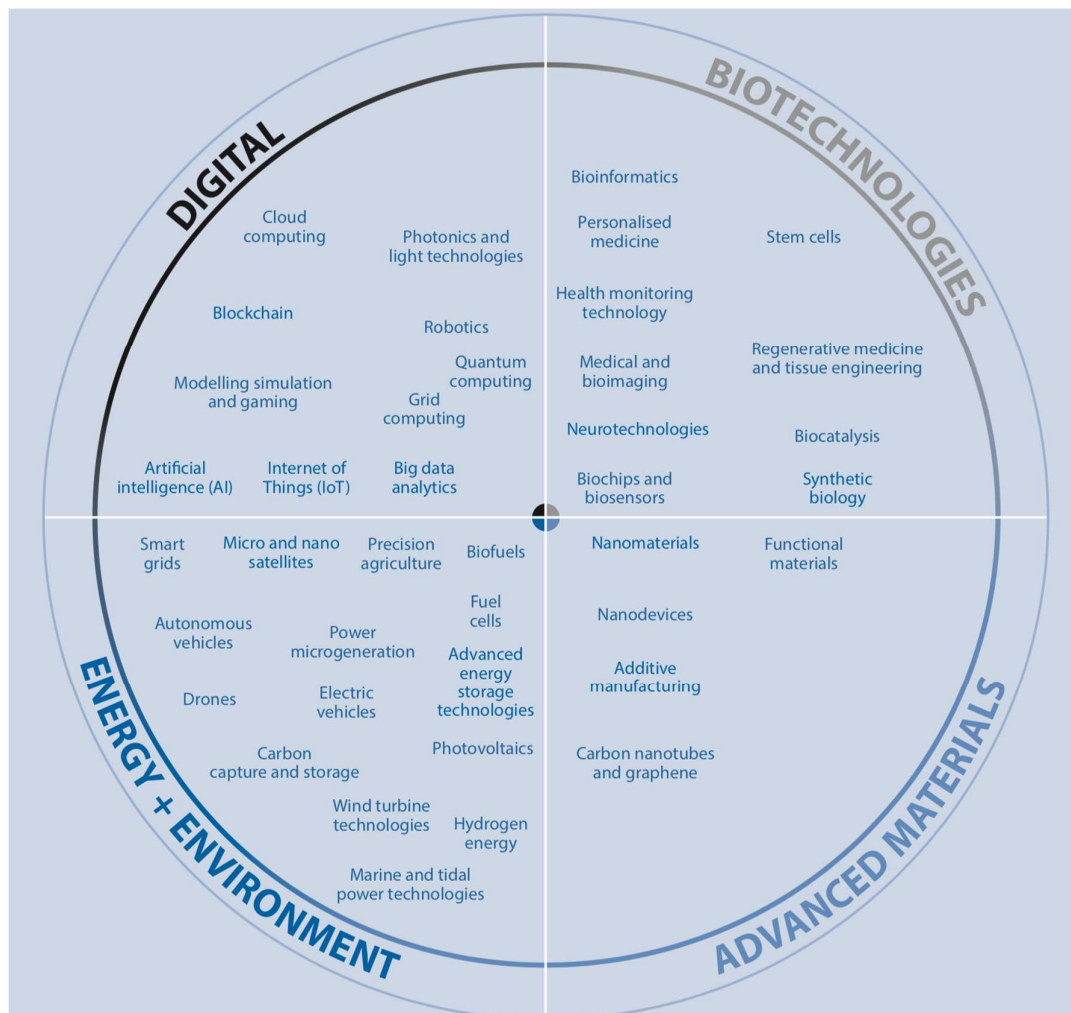
## 1.2 Classifying frontier technologies

There is no universally agreed definition of frontier technology. However, there is a recurring common feature across the different technological advances in that they all “have the potential to disrupt the status quo, alter the way people live and work, rearrange value pools, and lead to entirely new products and services”.<sup>1</sup>

Many frontier technologies can be classified as general-purpose technologies (GPT). While technological progress is often an incremental innovation in a specific sector or area, a GPT has the potential to re-shape the economy and boost productivity across all sectors and industries. Steam, electricity, internal combustion, and information technology (IT) are other examples of GPTs. More generally, it has been argued that a GPT has the following three characteristics:<sup>2</sup>

1. Pervasiveness – the GPT should spread to most sectors.
2. Improvement – the GPT should become more efficient and effective over time and keep lowering costs for users.
3. Innovation spawning – the GPT should enable the invention and development of new products or processes.

For these reasons, a multitude of different technologies have been identified as frontier. For example, OECD (2016)<sup>4</sup> listed 40 frontier technologies (figure 1) and mapped them into four quadrants that represent broad technological areas: biotechnologies, advanced materials, digital technologies, and energy and



Source: OECD, 2016b.

Table 1 shows technologies defined as frontier by several organizations and studies. It shows that the following technologies have been most commonly identified as frontier: 3D printing, the Internet of Things, AI, and robotics. Given

the absence of a universally agreed definition of frontier technology and the multitude of technologies that have been defined as frontier; to provide focus, this report mainly covers these four technologies.

**Table 1. Frontier technologies identified by different organizations**

OECD	World Bank	World Economic Forum	McKinsey Global Institute	Institute of Development Studies	MIT Technology Review 2018
Internet of Things	Fifth-generation (5G) mobile phones	Artificial intelligence	Mobile internet	3D printing	3D Metal Printing
Big data analytics	Artificial intelligence	Robotics	Automation of knowledge work	Collaborative economy tools	Artificial Embryos
Artificial intelligence	Robotics	Internet of Things	Internet of Things	Alternative internet delivery	Sensing City
Neuro technologies	Autonomous vehicles	Autonomous vehicles	Cloud technology	Internet of Things	Artificial intelligence for Everybody
Nano/micro satellites	Internet of Things	3D printing	Advanced robotics	Unmanned aerial vehicles/drones	Dueling Neural Networks
Nanomaterials	3D printing	Nanotechnology	Autonomous and near-autonomous vehicles	Airships	Babel-Fish Earbuds
3D printing (additive manufacturing)		Biotechnology	Next-generation genomics	Solar desalination	Zero-Carbon Natural Gas
Advanced energy storage technologies		Materials science	Energy storage	Atmospheric water condensers	Perfect Online Privacy
Synthetic biology		Energy storage	3D printing	Household-scale batteries	Genetic fortune-telling
Blockchain		Quantum computing	Advanced materials	Smog-reducing technologies	Materials' Quantum Leap
			Advanced oil and gas exploration		
			Renewable energy		

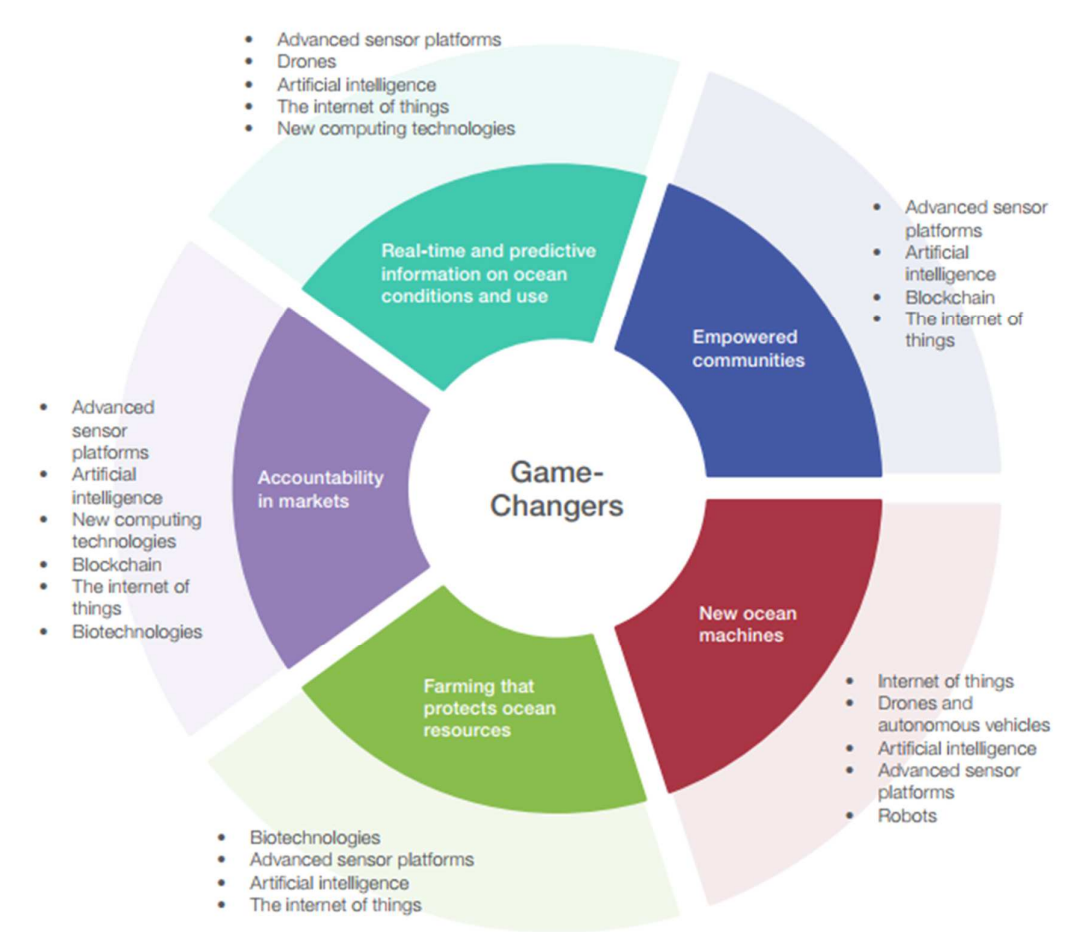
Source: prepared by the ESCAP team based on OECD, 2016b; World Bank, 2016; World Economic Forum, 2016; McKinsey Global Institute, 2013; Institute of Development Studies, 2016; and MIT Technology Review, 2018

**Note:** While Financial Times (2017) does not produce a list like in table 1, it argues that advanced robotics, 3D printing and the Internet of Things are the technologies that are expected to transform manufacturing over the next couple of decades.

While the technologies may be different and have unique functionalities, they are often inextricably linked with increasingly blurred boundaries. For example, big data is an essential component of many other technologies such as blockchains and the Internet of Things, while the development of blockchains and Internet of Things would

further strengthen big data. Also, several technologies can be used together to solve challenges. Figure 2 shows that frontier technologies such as advanced sensors, Internet of Things, AI, drones, blockchain, biotechnologies, autonomous vehicles, and robots can be utilized to address the challenges related to oceans' sustainability.

Figure 2. The Fourth Industrial Revolution is game-changers for oceans



Source: World Economic Forum, 2016a.

## ENDNOTES

- <sup>1</sup> McKinsey Global Institute, 2013.
- <sup>2</sup> Bresnahan and Trajtenberg, 1996.
- <sup>3</sup> Institute of Development studies, 2016.
- <sup>4</sup> OECD, 2016b.

## 2. OVERVIEW OF SELECTED FRONTIER TECHNOLOGIES IN THE REGION

The Asia-Pacific is a leading region in the development of frontier technologies and is forecast to be a prominent market of the future. Measured by venture-capital investment, several countries in the region - including Australia, China, Japan and Singapore - are in a leading group of countries investing in frontier technologies<sup>1</sup> (figure 3).

Similarly, figure 4 shows that China, Japan and Republic of Korea have been among the global leaders in 3D printing, robotics and nanotechnology. However, the figure also shows that the patenting activity has been geographically concentrated in developed countries worldwide (except China).

### 2.1 Artificial intelligence

The term AI has been around since the 1950s. It generally refers to computer systems that can perform tasks that normally require human intelligence. In most cases, AI should be regarded as narrow AI (or weak AI), in that it is designed to perform a narrow task (e.g. playing chess, facial recognition, internet searches, or driving a car). General AI (strong AI) with cognitive capacity like humans is not available. There are debates as to whether or how soon general AI will outperform humans in the future (box 1).

#### Box 1. Homo Deus: A Brief History of Tomorrow

Homo Deus: A Brief History of Tomorrow, a book written by Yuval Noah Harari, was first published in Hebrew in 2015. The book describes mankind's current abilities and achievements and attempts to paint an image of the future. Many philosophical issues are discussed such as the human experience, individualism, human emotion and consciousness.

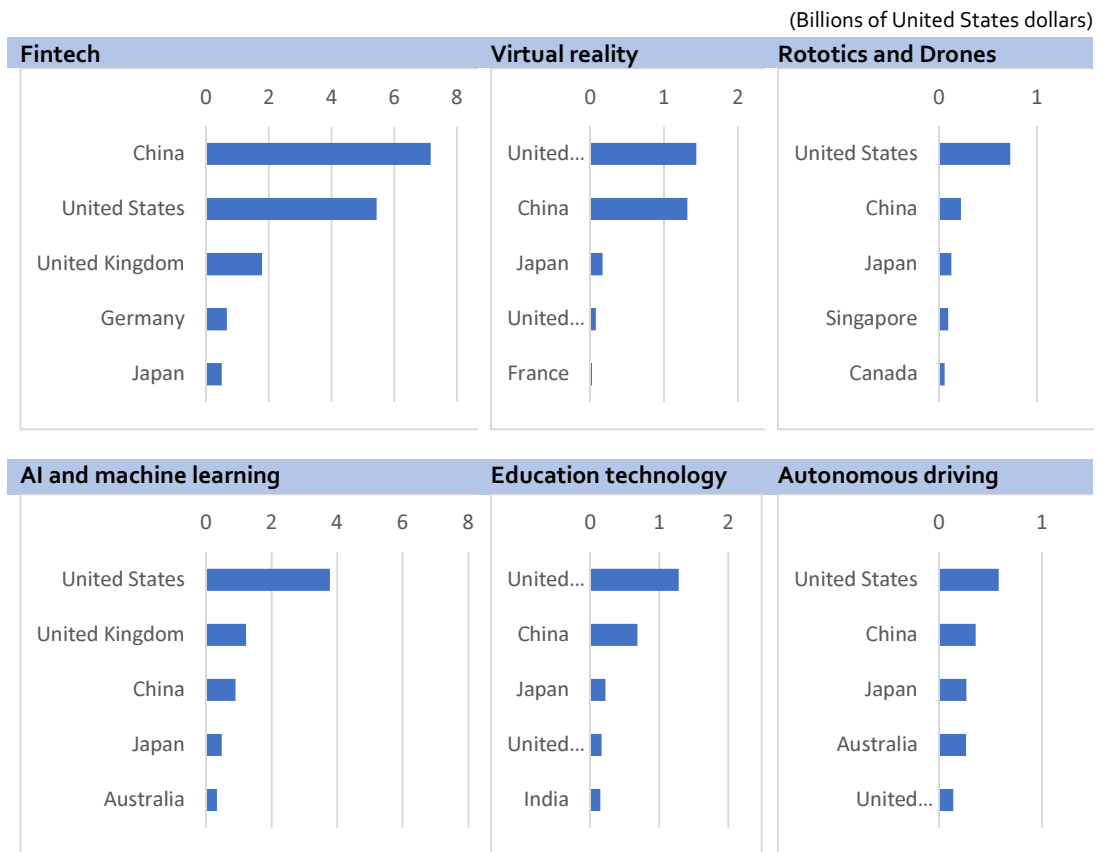
The last chapter suggests a possibility that humans are algorithms, and as such *homo sapiens* may not be dominant in a universe where big data becomes a paradigm. The book closes with the following question: "What will happen to society, politics and daily life when non-conscious but highly intelligent algorithms know us better than we know ourselves?"

Source: <https://www.worldcat.org/title/homo-deus/oclc/953597984>

According to OECD,<sup>2</sup> AI is defined as the ability of machines and systems to acquire and apply knowledge, and to carry out intelligent behaviour. This includes a variety of cognitive tasks (e.g. sensing, processing oral language, reasoning, learning, making

decisions) and demonstrating an ability to move and manipulate objects accordingly. Intelligent systems use a combination of big data analytics, cloud computing, machine-to-machine communication and the Internet of Things to operate and learn.

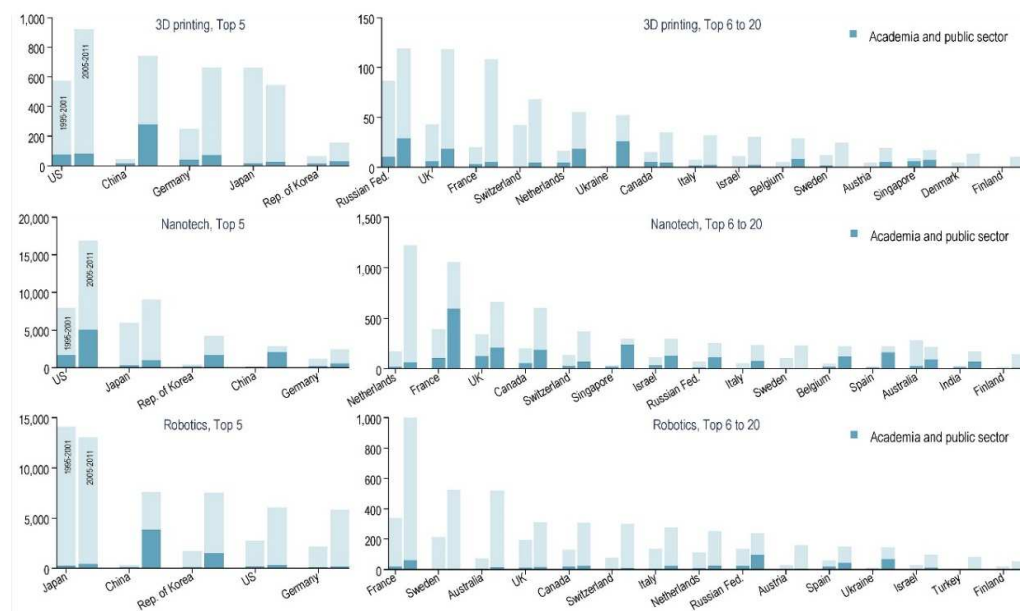
Figure 3. Venture-capital investment by technology



Source: McKinsey Global Institute, 2017.

Figure 4. Countries drive patenting in 3D printing, nanotechnology and robotics

(Numbers of first patent filings)



Source: World Intellectual Property Organization, 2015.

AI is a software and generally algorithm-based although its functions (e.g. talking or playing a game) need to be reflected through physical substance (such as a

robot). In this sense, AI is like a human brain. To date, AI development has been generally focused on a selection of specific domains (table 2).

**Table 2. Major artificial intelligence domains**

<i>Major AI domains</i>	<i>Description</i>
<b>Large-scale Machine Learning</b>	Design of learning algorithms, as well as scaling existing algorithms, to work with large data sets.
<b>Deep Learning</b>	Model composed of inputs such as image or audio and several hidden layers of sub-models that serve as input for the next layer and ultimately an output of activation function.
<b>Natural Language Processing</b>	Algorithms that process human language input and convert it into understandable representations.
<b>Collaborative Systems</b>	Models and algorithms to help develop autonomous systems that can work collaboratively with other systems and with humans.
<b>Computer Vision (Image Analytics)</b>	The process of pulling relevant information from an image or sets of images for advanced classification and analysis.
<b>Algorithmic Game Theory and Computational Social Choice</b>	Systems that address the economic and social computing dimensions of AI, such as how systems can handle potentially misaligned incentives, including self-interested human participants or firms, and the automated AI-based agents representing them.
<b>Soft Robotics (Robotic Process Automation)</b>	Automation of repetitive tasks and common processes such as customer servicing and sales without the need to transform existing IT system maps.

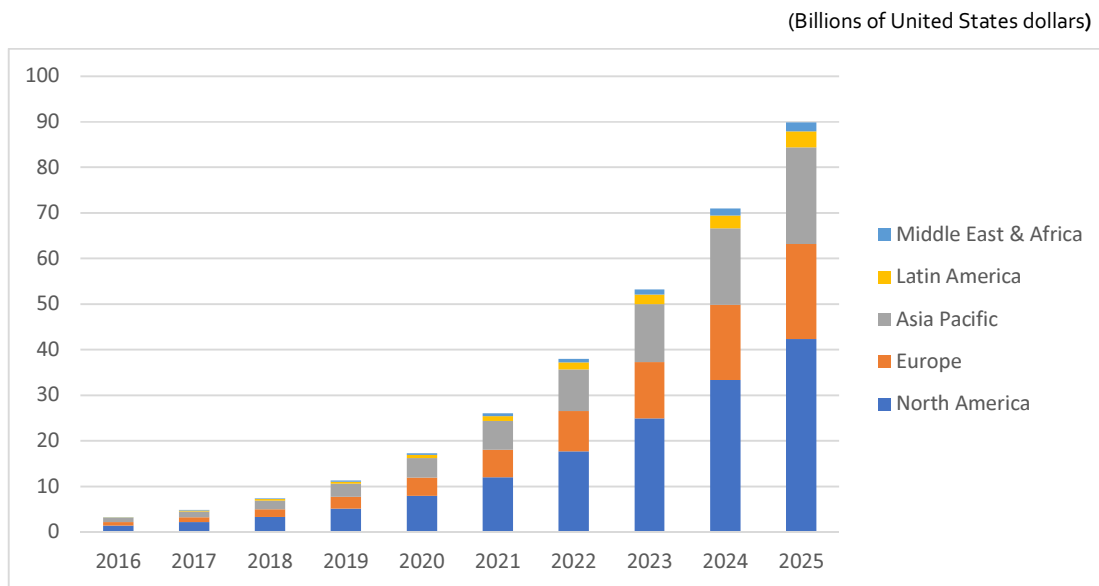
Source: PricewaterhouseCoopers, 2017.

Data on the level of investment of AI in the region is limited. According to McKinsey, corporations invested between \$20 billion and \$30 billion globally in 2016. Tech giants such as Alibaba, Amazon, Baidu, Facebook and Google account for more than three quarters of total AI investment to date. From 2011 through to February 2017, these companies were behind 29 of 55 major merger and acquisition deals in the United States of America (USA) and 9 of 10 major deals in China.<sup>3</sup>

Globally, revenue generated from the direct and indirect application of AI software are projected to grow from \$3.2 billion in 2016 to nearly \$89.8 billion by 2025<sup>4</sup> (figure 5). While any forecasted data should be viewed with caveats given the uncertainties with regards to the economic impact of frontier technologies, it nevertheless shows the AI market will grow exponentially.<sup>5</sup>



**Figure 5. Artificial intelligence software revenue, world markets, 2016-2025**



Source: Tractica, 2017.

Estimates suggest that China's total investment in AI enterprises reached \$2.6 billion in 2016.<sup>6</sup> China's State Council has recently issued guidelines on AI development wherein it is aiming to become a global innovation centre in the field by 2030, with an estimated total output value of the AI industry projected at \$147 billion.<sup>7</sup> China Artificial Intelligence Industry Innovation Alliance was set up in 2017, with targets to incubate 50 AI-enabled products and 40 firms, launch 20 pilot projects, and set up a technology platform within three years.<sup>8</sup>

Singapore recently announced plans to invest over \$100 million in AI over the next five years.<sup>9</sup> In the Republic of Korea, SK Telecom announced in early 2017 that it will invest \$4.2 billion in AI.<sup>10</sup>

Measured by patents filed, from 2010-14, the USA led AI-related patent applications submitting 15,317 applications. China was second submitting 8,410. During this period,

Japan and Republic of Korea submitted 2,071 and 1,533 respectively. India was also among the top 10 countries globally in terms of numbers of patents submitted. In addition, China and India are among the top 10 countries in terms of the number of AI companies.<sup>11</sup>

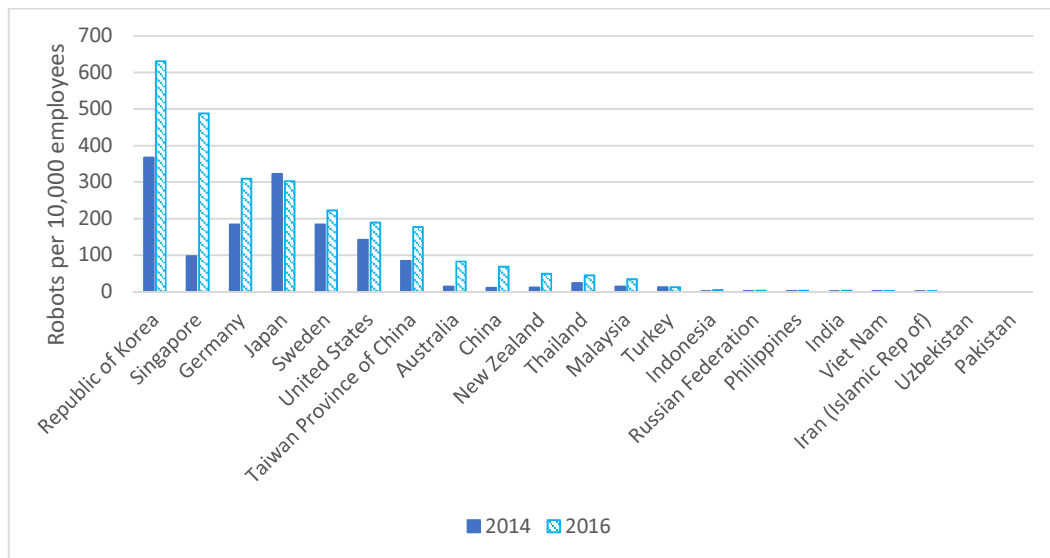
## 2.2 Robotics

A robot is a mechanical device that can be programmed to perform a variety of human tasks. According to the International Organization for Standardization, a robot is an actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks. Robots are classified as "industrial" (automotive, chemical, rubber, plastics, and food industries) and "service" (logistics, medicine, assisting the elderly, agriculture, floor-cleaning, civil construction, and exoskeletons).<sup>12</sup>

The automation of production is accelerating around the world. Robot density rose from 66 robot units per 10,000 employees in 2015 to 74 robot units per 10,000 employees in 2016. By region, the average robot density in Europe is 99 units, in the Americas 84 and in Asia 63.

Worldwide, since 2010, the Republic of Korea has by far the highest robot density in the manufacturing industry. Its robot density increased from 367 in 2014 to 631 in 2016. Singapore was ranked second in the world in 2016, with a rate of 488 robots per 10,000 employees (figure 6).

**Figure 6. Estimated robot density in manufacturing, 2014 and 2016**



Source: data of year 2014 were taken from UNCTAD, Trade and Development Report 2017, data of year 2016 were taken from International Federation of Robotics (<https://ifr.org/ifr-press-releases/news/robot-density-rises-globally>).

**Note:** 2016 data for Turkey and Viet Nam were missing, as reflected in the figure.

Japan ranked fourth in the world. In 2016, 303 robots were installed per 10,000 employees in manufacturing. In addition, Japan is the world's predominant industrial robot manufacturer. The production capacity of Japanese suppliers reached 153,000 units in 2016 – the highest level ever recorded. Today, Japan's manufacturers deliver 52 per cent of the global supply. The development of robot density in China is the most dynamic in the world. Due to the significant growth of robot installations, particularly between 2013 and 2016, the density rate rose from 25 units in 2013 to 68 units in 2016.<sup>13,14</sup> Robot density in

manufacturing in other developing countries in the region remains generally low and, at times, at a negligible level.

### 2.3 The Internet of Things

Internet of Things represents a concept in which network devices can collect and sense data, and then share that data across the internet where that data can be utilized and processed for various purposes.

The term goes beyond devices traditionally connected to the internet, such as laptops and smartphones, by including all kinds of objects and sensors that permeate the

public space, the workplace and homes, and that gather data and exchange these with one another and with humans. The Internet of Things is closely related to big data analytics and cloud computing. While the Internet of Things collects data and takes action based on specific rules, cloud computing offers the capacity for the data to be stored, and big data analytics empowers data processing and decision-making. In combination, these technologies can empower intelligent systems and autonomous machines.

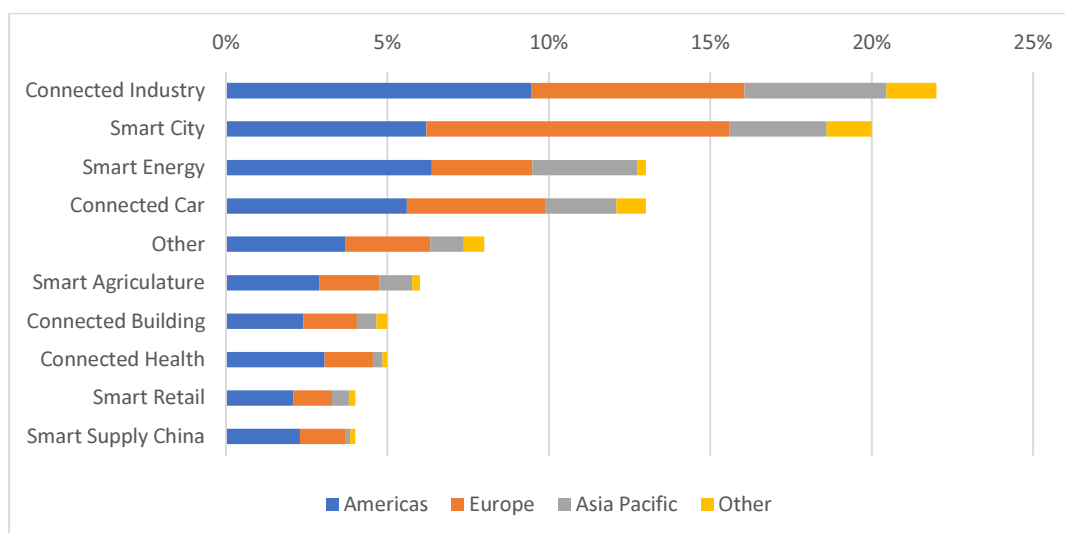
The Internet of Things is spreading rapidly. Ericsson (2015) notes that there are already 230 million cellular Machine-to-Machine subscriptions for Internet of Things applications, and it projects up to 26 billion connected devices by 2020.<sup>15</sup>

Internet of Things is expected to have the greatest impact in healthcare, manufacturing, energy systems, transport systems, smart cities and urban infrastructure, and smart government (OECD, 2015). IoT Analytics, a consultancy company, analysed 640 actual projects

related to Internet of Things.<sup>16</sup> According to available data, most projects identified were in industrial settings (141 projects), followed by smart cities (128) and smart energy (83). The Americas make up most of those projects (44 per cent), followed by Europe (34 per cent). There are large differences in terms of individual project segments and regions. The Americas and particularly Northern America is active in connected health (61 per cent) and smart retail (52 per cent), while the majority of smart city projects are located in Europe (47 per cent). The Asia-Pacific region is particularly active in the area of smart energy projects (25 per cent) (figure 7). 75 per cent of these projects concentrate on five SDGs:

- #9 Industry, innovation, and infrastructure (25 per cent)
- #11 Smart cities and communities (19 per cent)
- #7 Affordable and clean energy (19 per cent)
- #3 Good health and well-being (7 per cent)
- #12 Responsible production and consumption (5 per cent)

**Figure 7. Implementation of Internet of Things related projects**



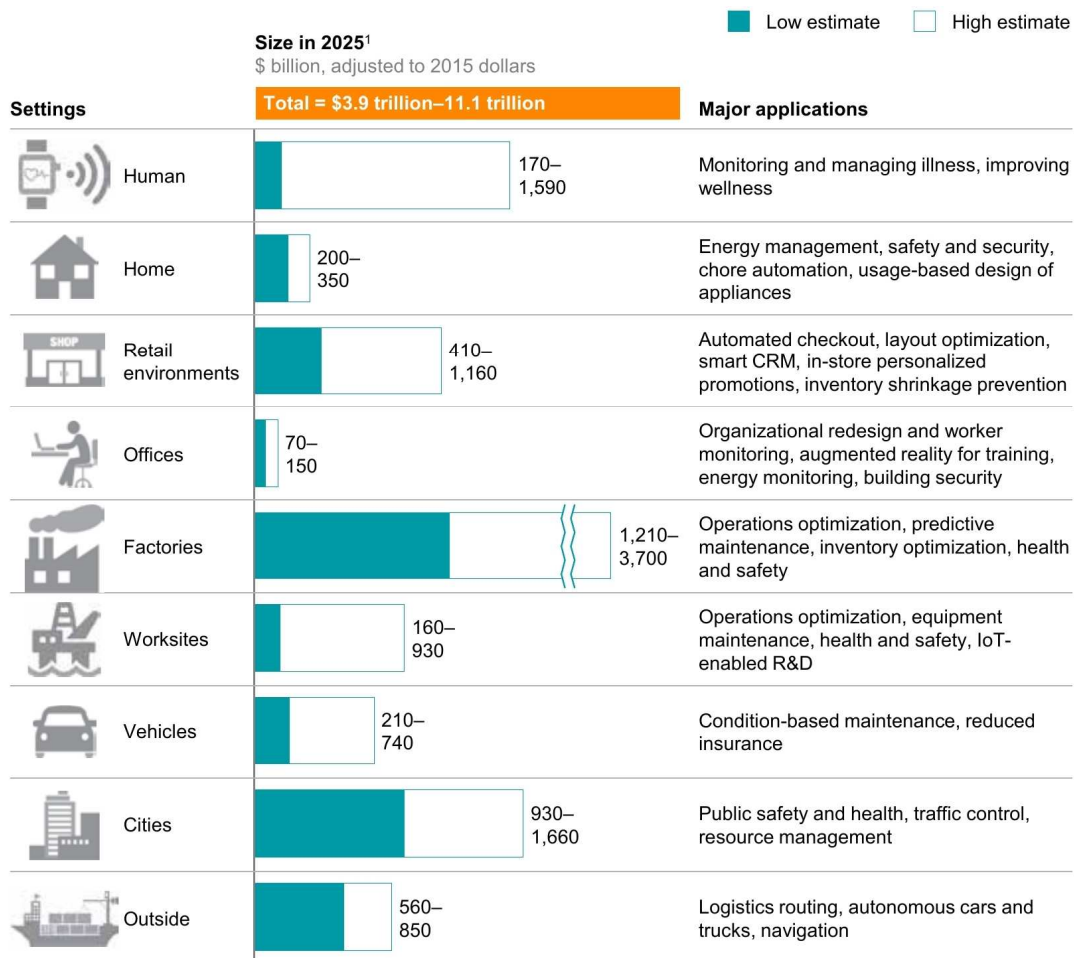
Source: IoT Analytics, 2016.

**Note:** data do not include consumer IoT projects

According to the Boston Consulting Group, by 2020, companies will be spending an estimated €250 billion a year on the Internet of Things, with half of the spending coming from the manufacturing, transport and

utility industries.<sup>17</sup> McKinsey estimates that Internet of Things will add around \$11 trillion of market value globally by 2025, roughly divided equally between high-income and developing economies (figure 8).<sup>18</sup>

**Figure 8. Potential economic impact of Internet of Things in 2025**



<sup>1</sup> Includes sized applications only.  
NOTE: Numbers may not sum due to rounding.

Source: McKinsey Global Institute, 2015.

**Note:** Potential economic impact of Internet of Things in 2025, including consumer surplus, is \$3.9 trillion to \$11.1 trillion.

## 2.4 3D printing

3D printing (also referred to as additive manufacturing), refers to a set of manufacturing technologies where 3D objects are created by adding successive layers of material on top of one another,

aided by specialized computer programs for both process control and object design.

Since it first became commercially available, 3D printing has had an impact on production

processes in various industries and sectors. It first found application as a rapid prototyping process. Engineers and industrial designers used it to accelerate their design and prototyping operations, saving both time and money. Gradually, as newer 3D printing methods were introduced using new raw materials, it found application in the production of components or even finished products in several industrial sectors, including aerospace and aviation, automobiles, construction, industrial design, medical products and defence. It has even been applied to create consumer products such as fashion, footwear, jewellery, glasses and food.<sup>19</sup>

3D printing, in contrast with the concept of economies of scale, can be used to produce

tailor-made products of small quantity. It can turn out one-off items with the same equipment and materials needed to make thousands, thus altering the nature of traditional manufacturing.

The industrial 3D printing market is mainly comprised of small and medium-sized enterprises (SMEs), but two large system manufacturers dominate the industry, Stratasys and 3D Systems, both based in the USA. Three Japanese companies are among the global leading 3D printing companies (table 3).

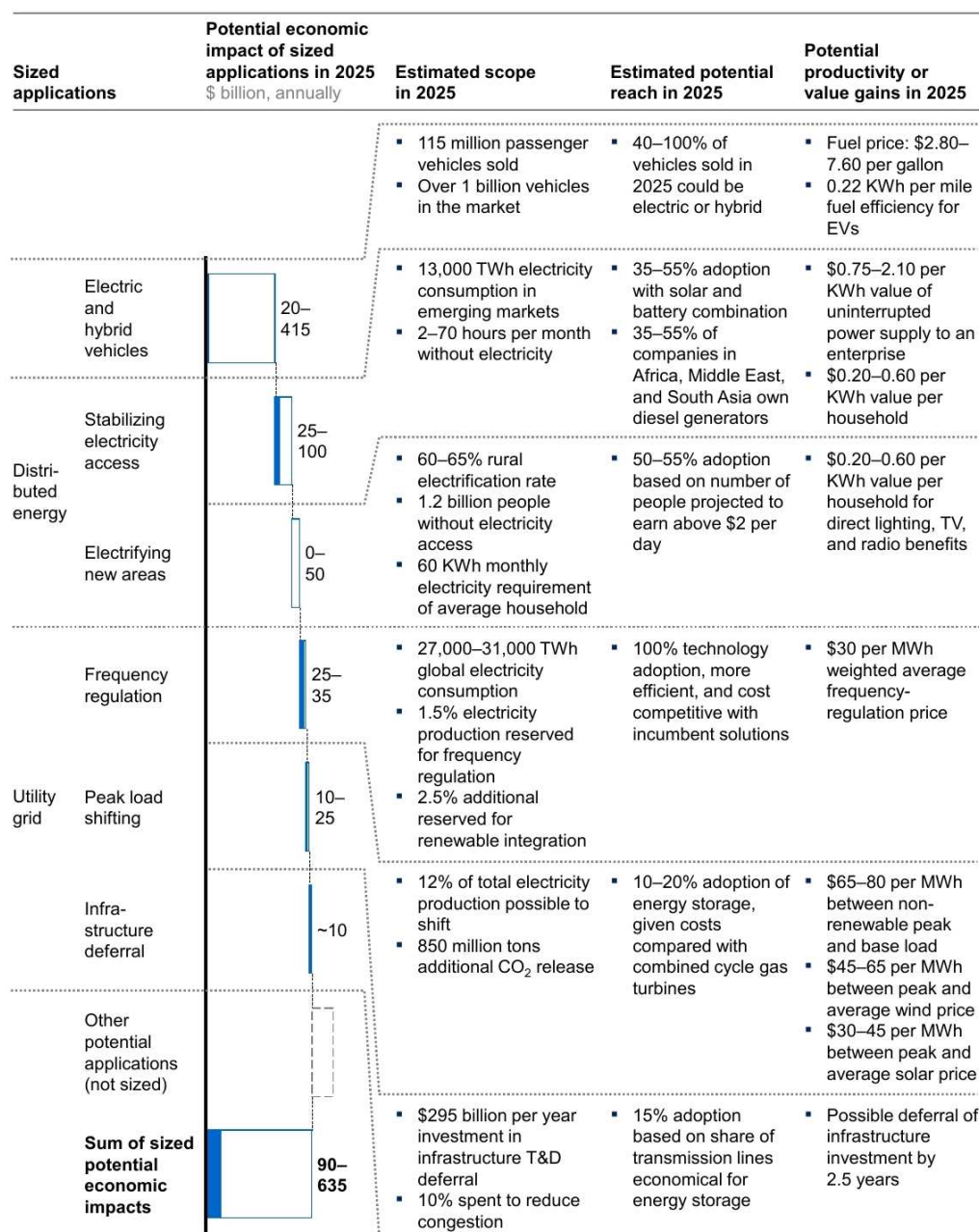
McKinsey estimates that the application of 3D printing could have a direct economic impact of \$230 billion to \$550 billion per year in 2025 globally (figure 9).

**Table 3. Top ten firms filing for patents on 3D printing, since 1995**

Company name	Country where the firm is headquartered	Number of first patent filings
<b>3D Systems</b>	USA	200
<b>Stratasys</b>	USA	200
<b>Siemens</b>	Germany	145
<b>General Electric</b>	USA	131
<b>Mitsubishi Heavy Industries Ltd</b>	Japan	120
<b>Hitachi</b>	Japan	117
<b>MTU Aero Engines</b>	Germany	104
<b>Toshiba</b>	Japan	103
<b>EOS</b>	Germany	102
<b>United Technologies</b>	USA	101

Source: World Intellectual Property Organization, 2015.

Figure 9. Direct economic impact of 3D printing



Source: McKinsey Global Institute, 2013.

**Note:** Estimates of potential economic impact are for some applications only and are not comprehensive estimates of total potential. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact. Possible surplus shifts among companies and industries or between companies and consumers are not sized. These estimates are not risk or probability-adjusted. Numbers may not sum due to rounding.

## ENDNOTES

- <sup>1</sup> McKinsey Global Institute, 2017c.
- <sup>2</sup> OECD, 2016b.
- <sup>3</sup> McKinsey Global Institute, 2017a.
- <sup>4</sup> Tractica, 2017.
- <sup>5</sup> For example, see McKinsey Global Institute, 2017a and PricewaterhouseCoopers, 2017.
- <sup>6</sup> See Bajpai, 2017.
- <sup>7</sup> State Council, 2017.
- <sup>8</sup> China Daily, 2017a.
- <sup>9</sup> See <https://www.cnbc.com/2017/05/03/singapores-national-research-foundation-to-invest-150-million-dollars-in-ai.html>
- <sup>10</sup> Colquhoun, 2017.
- <sup>11</sup> See Nikkei Asian Review, 2017 and The Economist, 2017.
- <sup>12</sup> See <https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en:term:2.4>.
- <sup>13</sup> International Federation of Robotics, 2018.
- <sup>14</sup> As discussed extensively in UNCTAD (2017), different studies show different numbers in China.
- <sup>15</sup> See Ericsson (2015) and OECD (2015b).
- <sup>16</sup> IoT Analytics, 2016.
- <sup>17</sup> Boston Consulting Group, 2017.
- <sup>18</sup> McKinsey Global Institute, 2015.
- <sup>19</sup> Internet Society, 2017.

### 3. OPPORTUNITIES FOR HARNESSING FRONTIER TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT

Frontier technologies are already demonstrating their potential application for sustainable development (box 2). This section discusses the potential economic, social and environmental benefits of frontier technologies in the context of the 2030 Agenda for Sustainable Development.

#### 3.1 Economic development

Technologies and, more broadly, innovation are central to long-term growth. The adoption of technologies and innovation in production processes increases overall productivity and expands production possibilities. Technological capabilities - comprising the ability and effort of mastering new technologies, adapting them to local conditions, improving upon them, diffusing them within the economy and exploiting them overseas by manufactured export growth and diversification, and by exporting technologies themselves; are fundamental to maintain broad economic growth.<sup>1</sup>

From an economic perspective, a nation's competitiveness depends on the capacity of its industry to innovate and upgrade.<sup>2</sup> As shown in figure 10, national competitiveness is highly correlated with national innovation capability. In this figure, two global indicators - Global Competitiveness Index and Global Innovation Index - are used to illustrate the point. Developed by the World Economic Forum, the Global Competitiveness Index is a tool that measures the economic foundations of national competitiveness. "Competitiveness" is defined as the set of institutions, policies, and factors

that determine the level of productivity of a country, covering 12 pillars, namely, institutions, infrastructure, macroeconomic environment, health and primary education, higher education and training, goods market efficiency, labor market efficiency, financial market development, technological readiness, market size, business sophistication, and innovation.

The Global Innovation Index is built upon two sub-indices namely the Innovation Input Sub-Index and the Innovation Output Sub-Index. The former comprises 5 input pillars capturing elements of the national economy that enable innovative activities. The latter reflects the results of innovative activities within the economy and includes 2 pillars. Each pillar is divided into three sub-pillars. A total of 81 indicators were included for calculating the Global Innovation Index in 2017.

Figure 10 shows that the large or advanced economies in the region including Singapore, Japan, Republic of Korea, Australia, New Zealand and China score well in terms of both national competitiveness and innovation (see top right corner of the figure).

However, technological progress has not always been reflected in traditional economic indicators (figure 11). As economist Robert Solow stated, "You can see the computer age everywhere but in the productivity statistics". Other researchers point out that the traditional indicators such as Gross Domestic Product (GDP) are not adequate to measure the benefits from internet and modern technologies. For



instance, the internet provides rich information on almost every aspect of life, while most information is free of charge

and is not counted as GDP (or productivity) (box 3).

### Box 2. How frontier technologies could support the Sustainable Development Goals

The 2030 Agenda for Sustainable Development contains 17 Sustainable Development Goals. Goal 17 identifies technology as one of the key the means of implementation. This box provides a few examples of how frontier technologies could support specific Sustainable Development Goals.<sup>3</sup>

- End poverty (Goal 1): In many developed nations, household surveys and census data can be used to identify poor neighbourhoods. But this information is not always readily available in developing countries. What's more, gathering this kind of data on the ground can be slow, difficult, and prohibitively costly. In this respect, researchers and scientist are applying AI to identify poverty.<sup>4</sup>
- Agriculture (Sustainable Development Goals 1, 2, 5, 8, 10 and 12): An area where AI has potential for developing countries is in increasing agricultural efficiency. For example, recent advances in image recognition allowed researchers to scan more than 50,000 photos of plants to help identify crop diseases at sites using smartphones with a success rate of over 99 per cent.<sup>5</sup>
- Healthcare (Goal 3): Developing countries are endemically short of medical workers.<sup>6</sup> AI applications have the potential to fill this gap. In the case of the Ebola virus, machine learning enabled the identification of species that harboured the virus.<sup>7</sup> More recently, AI applications have been developed that substitute and complement highly educated and expensive expertise by analysing medical images.<sup>8</sup> For example, an experiment that tested an AI algorithm for detecting cancer against 21 trained oncologists performed just as well as the doctors.<sup>9</sup> Other frontier technologies could also revolutionize healthcare. For instance, 3D printing can produce precise anatomies of patients which could enable doctors to practice procedures prior to complex surgeries. It can also produce patient specific prosthetics, orthotic braces and customized medical implants.
- Education (Goal 4): Quality education is a key development challenge for many developing countries. A study of the United Nations Educational, Scientific and Cultural Organization (UNESCO) shows that 27.3 million primary school teachers will need to be recruited worldwide, and remarked that trained teachers are in short supply in many countries.<sup>9</sup> While there are currently few applications of AI for education, it could potentially provide customized teaching<sup>10</sup> and automated assessment of essays.<sup>11</sup>
- Gender equality (Goal 5): Information and communications technology (ICT) and the internet have provided women and girls with useful information on health and nutrition. Electronic commerce has enabled women to participate in trade. Google's Internet Saathi project supports women ambassadors to train and educate women across 300,000 Indian villages on the benefits of the internet in their day-to-day life.<sup>12</sup>
- Water (Goal 6): A 3D printed filter can remove water impurities and block popular microbes that infect water in developing countries. This water purification system has the potential to save the lives of many people in developing countries where clean water is not readily available.<sup>13</sup>
- Energy (Goal 7): Faced with an increasing demand for renewable energy, countries in the region may benefit from AI in hybrid energy system optimization.<sup>14</sup>

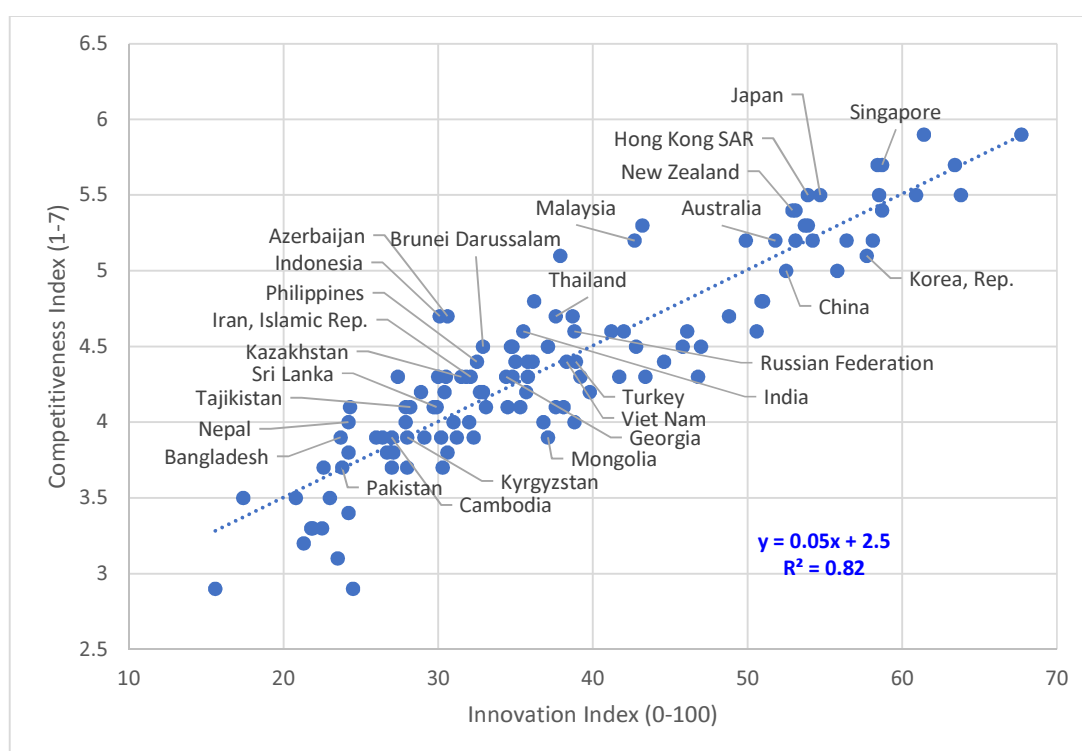
## Box 2. How frontier technologies could support the Sustainable Development Goals

(continued)

- Decent work (Goal 8): AI-powered automation may replace some repetitive jobs but create new jobs that we have not yet imagined.
- Cities and energy (Goal 11 and Goal 7). Internet of Things is being used to build smart cities. Singapore and Songdo, Republic of Korea have been well identified to be global leaders in developing smart cities. Noting that energy consumption in cities is often enormous, smart cities carry huge potential to be energy efficient.<sup>15</sup>
- Environment and climate (Goal 13): AI and deep learning can help climate researchers and innovators test out their theories and solutions as to how to reduce air pollution. One example of this is the Green Horizon Project from IBM that analyses environmental data and predicts pollution as well as testing “what-if” scenarios that involve pollution-reducing tactics. By using the information provided by machine learning algorithms, Google was able to cut the amount of energy it used at its data centres by 15 per cent. Similar insights can help other companies reduce their carbon footprint.<sup>16</sup>
- Oceans (Goal 14). Ocean-going drones can cruise the ocean in a cost-effective and efficient manner. They can help assess fish stocks and patrol remote areas. Real-time reporting allows dynamic management of fishing.

Source: Prepared by the ESCAP study team.

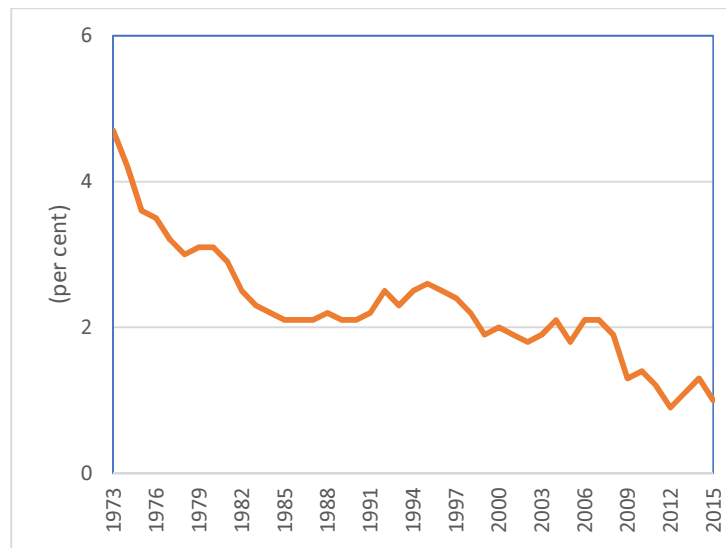
Figure 10. National competitiveness and innovation capability



Source: Prepared by the ESCAP study team. Data are derived from the Global Competitiveness Report 2016–2017 (<https://www.weforum.org/reports/the-global-competitiveness-report-2016-2017-1>) and Global Innovation Index 2017 (<https://www.globalinnovationindex.org/>). Sample covers 120 countries worldwide. The scores of countries in Asia and the Pacific covered in the samples are labelled.

**Note:** Global Competitiveness Index uses a 1–7 scale while Global Innovation Index uses a 0–100 scale (higher average score means higher degree of competitiveness or innovation).

**Figure 11. Growth of labour productivity per hour worked**



Source: World Bank, 2016.

**Note:** Five-year moving average of median growth of labour productivity per hour worked, in percent, in 87 countries

### Box 3. Debate on impacts of innovation and technology

The book “The Rise and Fall of American Growth” has drawn wide attention. “Whether or not you end up agreeing with Gordon’s thesis, ...this book will challenge your views about the future; it will definitely transform how you see the past.” wrote economist Paul Krugman in The New York Times.

In this book, the author Robert Gordon, argued that the age of great American productivity is over and predicts that the future would not live up to the past in terms of economic growth.

Among the readers of the book, Bill Gates, found “his historical analysis, which makes up the bulk of the book, utterly fascinating”. However, Bill Gates disagreed with the analysis of the future, and commented that “Gordon uses something called Total Factor Productivity (TFP), ...while economic measurements like TFP can be useful for understanding the impact of a tractor or a refrigerator, they are much less useful for understanding the impact of Wikipedia or Airbnb”.

Source: 1) Quartz, 2016, Bill Gates’s advice on how to read one of the most provocative economics books of the year, <https://qz.com/742686/bill-gates-recommends-this-economics-book-so-long-as-you-skip-the-last-two-chapters/>  
2) <https://www.nytimes.com/2016/01/31/books/review/the-powers-that-were.html>.

## 3.2 Social impact

### Transforming public service delivery

The advent of the internet in the mid-1990s triggered the rapid diffusion of e-government systems to automate core administrative tasks, improve the delivery of

public services, and promote transparency and accountability. By 2014, all 193 Member States of the United Nations had national websites: 101 enabled citizens to create personal online accounts, 73 to file income taxes online, and 60 to register a business.

In all, 190 countries had automated government financial management, 179 had automated customs, and 159 had automated tax systems. And 148 countries had digital identification schemes, although only 20 had multipurpose digital identification for such services as voting, finance, health care, transportation, and social security.<sup>17</sup>

Digital technologies can strengthen government capability and empower citizens through three mechanisms: 1) they overcome information barriers and promote participation by citizens in services and in elections; 2) they enable governments to replace some factors used for producing services through the automation of routine activities, particularly discretionary tasks vulnerable to rent-seeking, and to augment other factors through better monitoring, both by citizens through regular feedback on service quality and within government through better management of government workers; and 3) by dramatically lowering communication costs through digital platforms, they enable citizens to connect with one another at unprecedented scale, fostering citizen voice and collective action.<sup>18</sup>

Some governments in the region have been taking innovative policy action to utilize frontier technologies in the delivery of public services. As an example, in Singapore, the Government recently set up a new agency, GovTech, to create an enabling environment for frontier technologies. GovTech's objective is to drive digital transformation across government. It will work with public sector organizations, the ICT industry and citizens to apply technologies such as AI and machine learning to government services.<sup>19</sup> Setting up such agencies should support the evolution of next-generation public

services. Moreover, by hiring staff with technology skills, the Government is supporting the development of a new wave of civil servants fit for the twenty-first century.

### Reducing inequality and supporting inclusion

The relationship between technology and inequality is multifaceted.<sup>20</sup> Technology has brought equality dividends by enabling productive transformation and rapid economic growth in the region. Technologies, notably ICT, have brought improved access to basic services such as finance and education, and are preventing and mitigating the environmental hazards that often disproportionately affect the poor. However, technology could widen inequality as countries differ in terms of investments, policy support or technological capabilities; or because technology is skill- and capital-biased and enables rent seeking; or because certain conditions need to be in place for vulnerable populations to benefit from technology, including ICT infrastructure, skills and access to appropriate technology solutions.

Nevertheless, governments are using technologies to reduce inequalities and support inclusion. As an example, Aadhaar technology has enabled the financial inclusion of 1.2 billion people in India. The Aadhaar programme in India is a Government-led, technology-based financial inclusion system. The system 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 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.<sup>21</sup>

### 3.3 Environmental protection

Frontier technologies have the potential to be applied for environmental protection. Governments in Asia and the Pacific have promoted the adoption of state-of-the-art technologies to address environmental impacts. For instance, in Republic of Korea, the entire smart city of Songdo is built around the Internet of Things. Among other benefits, smart cities reduce traffic pollution; save energy and water and create a cleaner environment.

Although the access and use of frontier technologies has not reached its full potential in developing countries, advanced technologies, such as space technology applications, are helping anticipate and respond to climate risks. For example, in Mongolia large geospatial datasets, disaggregated to district levels are helping forecast droughts. Combining this information with detailed maps of poverty by province and district and of livestock at a given time, is enabling the identification of those herders at highest risk of being affected by localized drought. Costs of mitigation actions through additional livestock feed can also be calculated thus facilitating timely implementation of localized interventions and prioritization of relief measures to the poorest.

Since 2017, ESCAP has provided around 220 satellite imagery and tailored tools and products to its Member States for early warning, response and damage assessment of earthquakes, floods, drought, typhoons, cyclones and landslides. These space-based data, products and services are equivalent to

approximately US\$1 million (in data, products and services), all of which are provided free of charge by ESCAP Member States, through the Regional Space Applications Programme for Sustainable Development network and the partnership with other United Nations agencies and international and regional initiatives.

## ENDNOTES

- <sup>1</sup> Metcalfe and Ramlogan, 2008.
- <sup>2</sup> Porter, 1990.
- <sup>3</sup> This box draws useful information from United Nations, Economic and Social Commission for Asia and the Pacific, 2017a.
- <sup>4</sup> Bennington-Castro, 2017.
- <sup>5</sup> See <https://channels.theinnovationenterprise.com/articles/ai-in-developing-countries>
- <sup>6</sup> Hoyler and others, 2014.
- <sup>7</sup> See <https://channels.theinnovationenterprise.com/articles/ai-in-developing-countries>
- <sup>8</sup> See <http://www.itu.int/en/ITU-T/academia/kaleidoscope/2016/Pages/jules-verne-corner.aspx>
- <sup>9</sup> Education for All Global Monitoring and the UNESCO Education Sector (2015).
- <sup>10</sup> Ibid.
- <sup>11</sup> Vajjala, 2016.
- <sup>12</sup> Flinders, 2016.
- <sup>13</sup> Mendoza, 2015.
- <sup>14</sup> Zahraee, Assadi and Rahman, 2016.
- <sup>15</sup> See <https://www.richardvanhooijdonk.com/en/6-smartest-smart-cities-world/>)
- <sup>16</sup> Marr, 2018.
- <sup>17</sup> World Bank, 2016.
- <sup>18</sup> Ibid.
- <sup>19</sup> Flinders, 2016.
- <sup>20</sup> Relationship between technology and inequality is comprehensively studied in the forthcoming publication titled "Inequality in Asia and the Pacific in the Era of the 2030 Agenda for Sustainable Development").
- <sup>21</sup> Government of India, 2017.

## 4. CHALLENGES OF HARNESSING FRONTIER TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT

To effectively develop and implement frontier technologies for sustainable development, challenges vary depending on the context in a country or industry. However, this section covers three common areas where impacts of frontier technologies may not necessarily produce sustainable development results, namely, 1) the impacts of frontier technologies on jobs, 2) a new frontier technology divide, and 3) ethical issues and trust.

### 4.1 Impact of frontier technologies on jobs

The significance of this challenge has long been recognized. In 1933, John Maynard Keynes voiced concerns regarding technological unemployment<sup>1</sup> and today, debates on the impact of frontier technologies on jobs are ubiquitous (see the list of studies in appendix 1). In considering only 15 major developed and emerging economies, the World Economic Forum predicts that frontier technological trends will lead to a net loss of over 5 million jobs by 2020.<sup>2</sup> The World Bank estimates that up to two thirds of all jobs are susceptible to automation in the developing world in the coming decades from a pure technological standpoint.<sup>3</sup> Analysis by McKinsey Global Institute predicts that, technically, about half of jobs globally can be automated. In Asia-Pacific economies, jobs of 785 million workers or 51.5 per cent of total employment in the region could be automated.<sup>4</sup> Similarly, results from a firm-level survey suggest that automation may have significant impacts on 60 per cent to 89 per cent, depending on the countries and sectors, of the job security of salaried

workers in the following 5 major sectors of Association of Southeast Asian Nations (ASEAN) economies: automotive and auto parts; electrical and electronics; textiles, clothing and footwear; business process outsourcing; and retail.<sup>5</sup>

It is important to note that the estimation results vary according to the sampling and analytical methodologies. For instance, different studies show that 7 per cent to 55 per cent of the jobs in Japan could be lost to automation. Therefore, the results of the existing studies need to be interpreted with caution (figure 12).

#### **Jobs in less developed countries are more susceptible to automation than in more advanced countries**

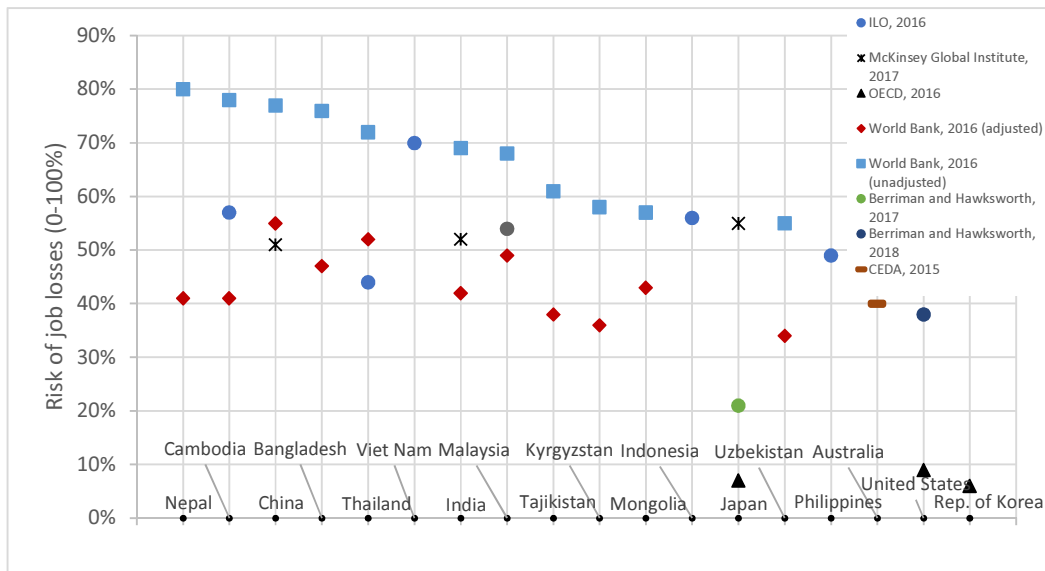
Figure 12 shows that jobs in developing countries, especially the least developed countries, are more susceptible to automation from a technical perspective. For example, in Nepal, 41 per cent or 80 per cent of the jobs, according to different studies, can be automated. Similarly, 41 per cent, 57 per cent and 78 per cent of the jobs in Cambodia can be automated according to different study reports.<sup>6</sup> In contrast, in advanced economies such as Japan and Republic of Korea, some studies estimate that less than 10 per cent of the jobs will be lost to automation.

From a technical perspective, a job can be more easily automated if the relevant activities and tasks are routine (UNCTAD 2017). Based on an OECD survey that asked workers about the intensity of tasks in their daily work that can be clearly regarded as routine and follow predefined patterns, the

manufacturing sectors with the greatest intensity in routine tasks were identified as food, beverages and tobacco; textiles, apparel and leather; and transport equipment (top-left of figure 13).

apparel and leather; and transport equipment (top-left of figure 13).

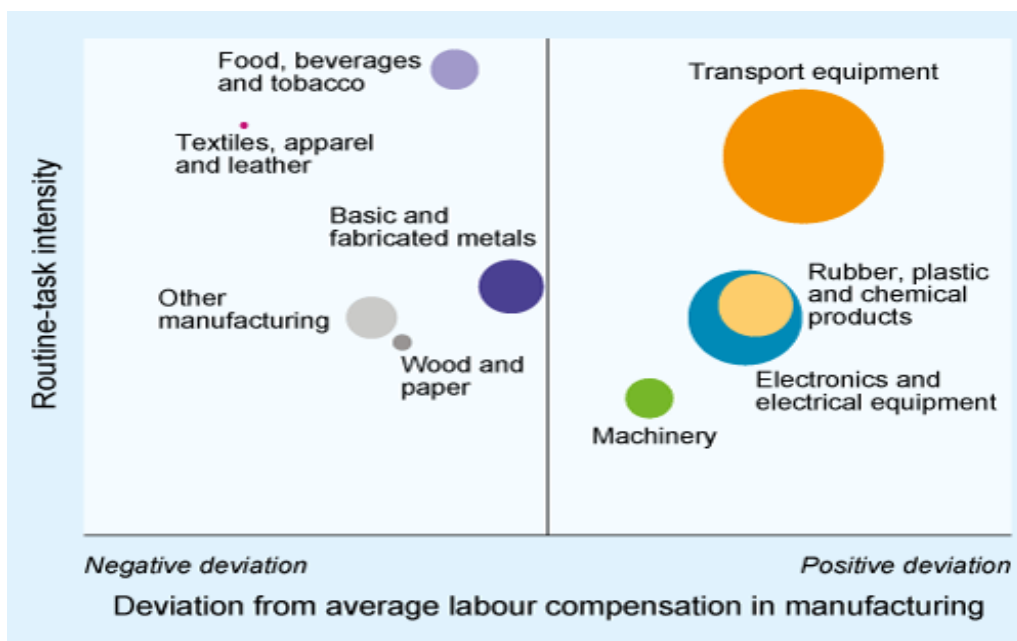
**Figure 12. Range of estimates of the share of jobs at risk of being lost to automation**



Source: Compiled by the ESCAP study team according to the existing studies, as shown in the figure.

**Note:** The sample in the figure include countries in ESCAP region. United States is included for benchmarking. Detailed data are shown in Appendix 1 at the end of this report.

**Figure 13. Proximate relationship between technical and economic feasibility of routine task automation and estimated stock of industrial robots, by manufacturing sector**



Source: UNCTAD, 2017.

**Note:** The axes have no scaling to underline the proximate nature of the relationship shown in the figure. Bubble sizes reflect the stock of industrial robots.



### What is technically feasible is not always economically viable

Despite the numerous forecasts on how automation or robots will replace human labour, many existing studies mainly focus on the technical feasibility of job displacement while neglecting the factor that what is technically feasible is not always economically viable.<sup>7</sup>

To illustrate, this report examines scenarios of robots replacing labour in different countries with different wages. As shown in figure 14, lower wages result in a longer payback time for automation investment, defined by the time to recover the investment for robots through savings from labour and avoidance of breakdowns. In the scenario that investing \$250,000 for two robots while each robot replaces two operators per shift, payback time in Russian Federation, Malaysia and China can be over 11, 7 and 6 years; while the payback time in Republic of Korea, Japan, New Zealand, Singapore and Australia can be only around 1.5 years or less. In the case of other countries in the sample including Tajikistan, Bangladesh, Pakistan, Indonesia, Philippines, Viet Nam, Turkmenistan and Thailand, where the annual salary is below \$5,500, the initial investment on robots cannot be recovered within the 15 years life span of the machines.

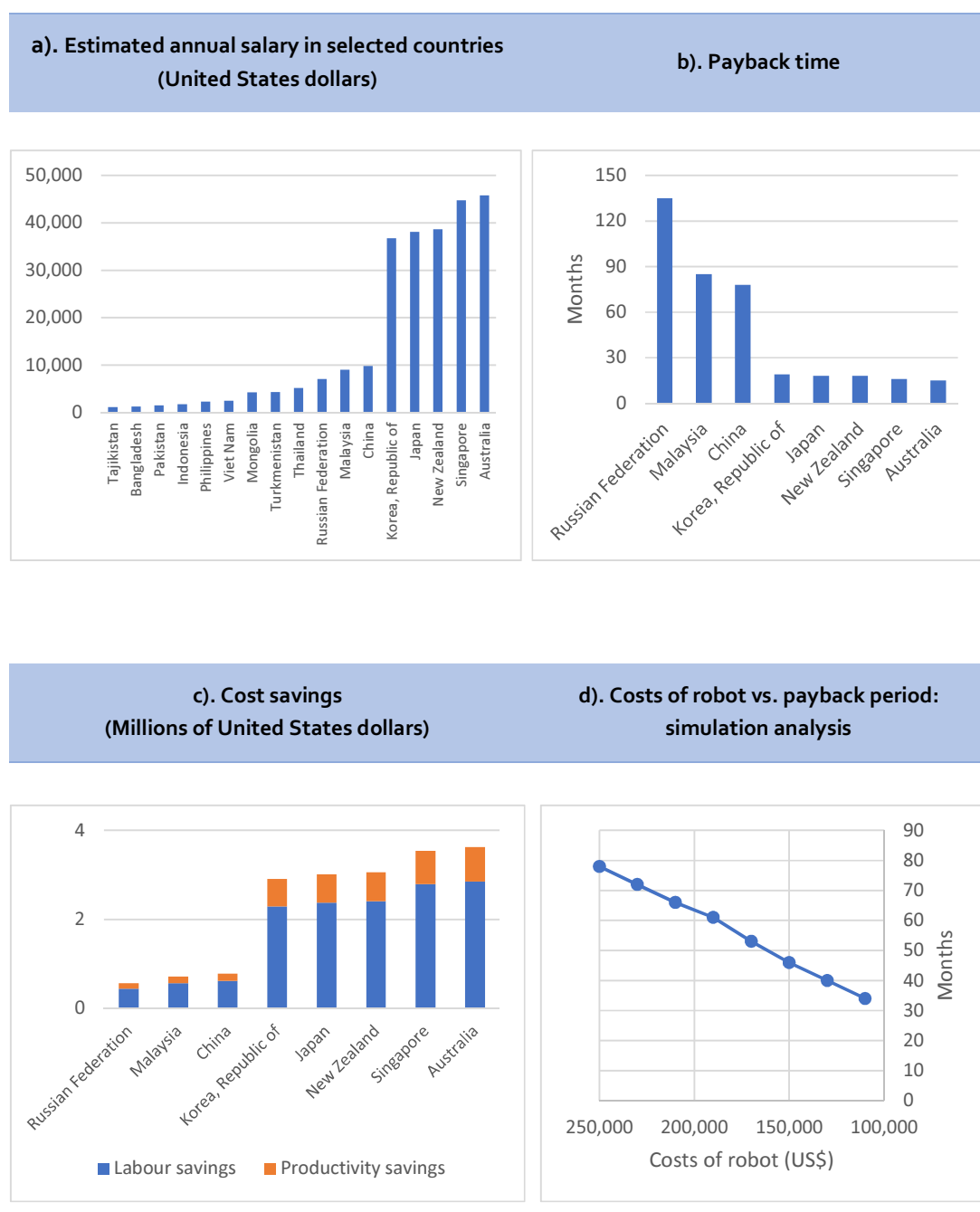
Figure 14 d) shows that, when the cost of a robot is reduced from \$250,000 to \$110,00, payback time is reduced from 6.5 years to less than 3 years. This simulation analysis is largely consistent with observations by Bain and Company which noted that in 2010, the estimated payback period in China for replacing workers by automation was about

5.3 years. By 2016, the combination of falling prices of robots and the rising cost of human labour had dropped the payback period to 1.5 years. By the end of the decade, it may fall to less than one year.<sup>8</sup>

As discussed earlier, robot deployment is largely decided by economic feasibility. Robot deployment has remained very limited in those manufacturing sectors where labour compensation is low, even if these sectors have high values on the routine-task intensity. Robot deployment in the textiles, apparel and leather sector has been lowest among all manufacturing sectors even though this sector ranks second in terms of the technical feasibility of automating workers' routine tasks.

Indeed, the same UNCTAD report points out that robot deployment has remained very limited. AI provides another example. It has been mainly developed and applied in a few sectors in several advanced economies. Therefore, AI has had limited impacts on job markets in many developing countries. Even in AI-advanced countries, according to a survey conducted by McKinsey of 3,000 AI-aware C-level executives across 10 countries and 14 sectors, "the majority of firms did not expect artificial intelligence to significantly reduce the size of their workforce".<sup>9</sup> MIT Technology Review have also highlighted that "artificial intelligence has so far been mainly the plaything of big tech companies like Amazon, Baidu, Google, and Microsoft, as well as some startups. For many other companies and parts of the economy, artificial intelligence systems are too expensive and too difficult to implement fully".<sup>10</sup>

**Figure 14. Simulation analysis of job losses to robots**



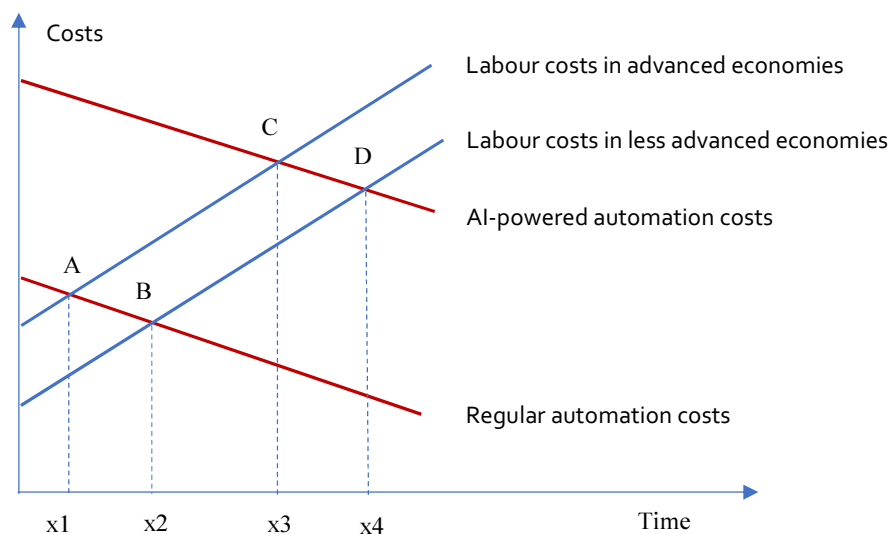
Source: ESCAP calculation based on 1) equation provided by Robotic Industries Association (<https://www.robotics.org/roi-calculator.cfm>) and 2) data on wages from the Global Wage Report 2016/17 prepared by International Labour Organization (<http://www.ilo.org/global/research/global-reports/global-wage-report/2016/lang--en/index.htm>).

**Note:** The scenario is in line with the sample provided by Robotic Industries Association (<https://www.robotics.org/roi-calculator.cfm>) based on the following assumptions: 1) Total System Cost: \$250,000 for installing two robots; 2) Robot System Usage: 2 Shifts/Day, 5 Days/Week and 50 Weeks/Year. Further assume that average Robot Electrical costs are roughly \$0.50 per hour; 3). 2 operators are removed per shift; 4) 10 per cent of labor are retained to operate system per shift; 5) expected productivity gain: 27 per cent; and 6) the annual labour costs per operator including fringe benefits, consistent with figure 14 a) are inputted for calculation.

However, it is important to note that current low adoption of AI is reflective of the fact that the industry is still at the nascent or pilot stage of development. For instance, four driverless buses started trial operation in Shenzhen, China in December 2017.<sup>11</sup> In the same year, Alibaba opened its AI powered cafe where facial recognition technology expedites the process for payment.<sup>12</sup> This should not be confused with the possible wider application of AI technology in the future. Indeed, diffusion patterns for successful technologies generally follow a distinctive “S” shape, with the rate of adoption initially slow and confined to so-called first adopters, increasing rapidly as the technology becomes established, but then slowing as markets approach saturation, with only harder to reach or resistant adopters left.<sup>13</sup>

Ultimately, decisions on the adoption of automation technologies often hinge on cost-benefits analysis. Figure 15 provides a schematic analysis of costs for the adoption of automation technologies or labour. Assuming labour costs keep rising while automation costs keep decreasing, the equilibrium is first achieved in more advanced economies between regular automation and labour (point A). This means, from a cost-benefit perspective, advanced economies are more likely to adopt regular automation after this point. The equilibrium is achieved later in a less developed country (point B). Given the high costs, AI-automation tends to be adopted later than regular automation (point A versus point C, or point B versus point D). Again, advanced economies tend to adopt AI-powered automation earlier than less advanced economies.

**Figure 15. A schematic analysis of costs for the adoption of AI-powered automation or labour**

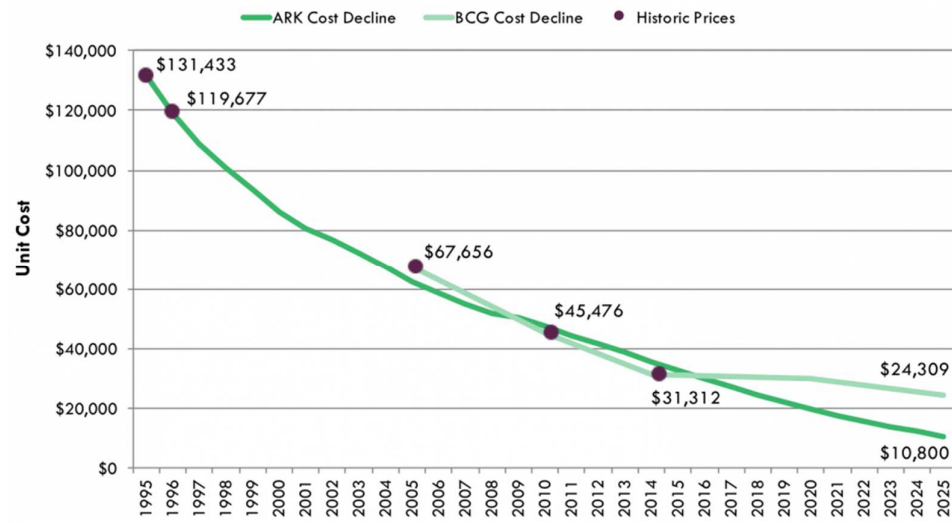


Source: ESCAP, 2017b.

Evidence on rising labour costs vis-à-vis declining cost of robot dexterity is also emerging. As shown in figure 16, average

industrial robot cost declined by 76 per cent from 1995 to 2015 (figure 16).

**Figure 16. Industrial robot cost decline**



Source: ARK Investment Management LLC (ark-invest.com)

### The frontier technological transition is not a question of “if” but “when”

In short, the nature of technological displacement of labour is about how fast rather than whether it will happen. Market mechanisms will dictate that start-ups, SMEs, corporations and industries, choose the most cost-effective method of production. Government needs to be proactive in analyzing the pace and scale of automation, and put responsive and adaptive policies in place (to be elaborated in section titled “Policy Priorities”).

Although the prevailing narrative is that more and more jobs will be lost to machines, it is also a distinct possibility that, in the future, humans and machines work together. In addition, history has told that we may have yet to imagine the industries of the future and the new jobs that economies will demand. At the dawn of the Digital Revolution who would have imagined how the likes of Facebook, Uber, Alibaba and

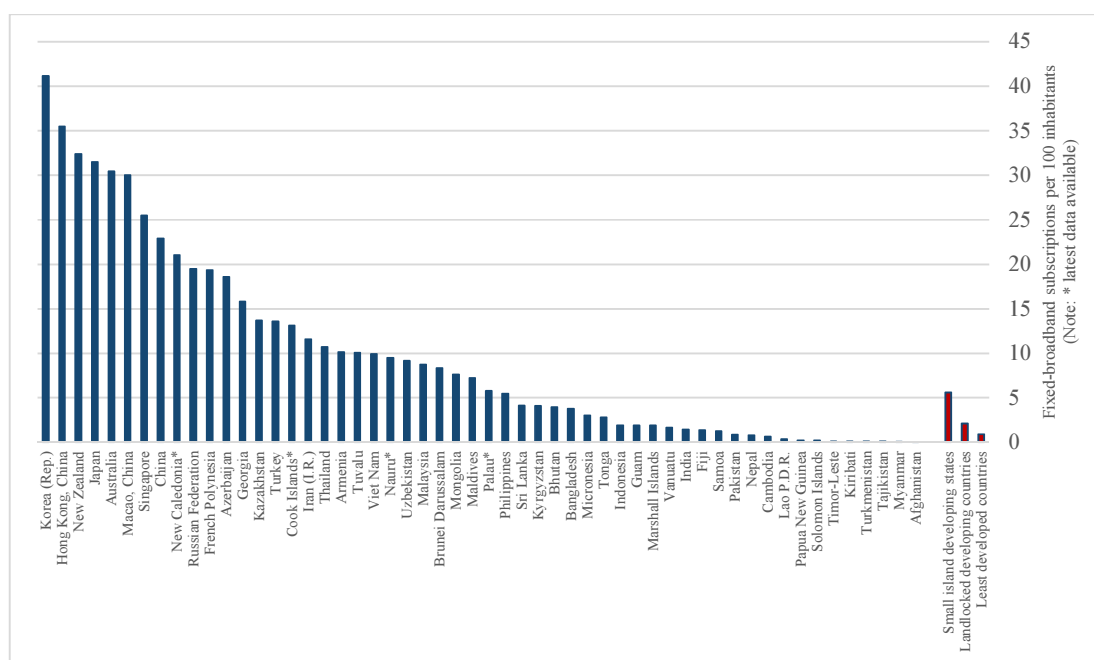
AirBnB would have created new industries and fundamentally reshaped existing ones?

## 4.2 A new frontier technology divide

### The digital divide

Despite the rapid penetration of the internet globally, several billion have been left behind.<sup>14</sup> As ICT infrastructure is the backbone of many frontier technologies, there is a risk of a new frontier technology divide on the back of already existing digital divide. For example, the fixed broadband subscriptions per 100 inhabitants in the Asia-Pacific region is still far lower than in Europe and North America, and remains below the world’s average of 11.2 in 2016. Eighteen ESCAP member countries continue to have less than 2 broadband subscriptions for the same indicator (as shown in figure 17).<sup>15</sup>

**Figure 17. Fixed-broadband subscriptions per 100 inhabitants in ESCAP member countries**



Source: ESCAP based on ITU World Telecommunication/ICT Indicators Database ([https://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2018/Fixed\\_broadband\\_2000-2016.xls](https://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2018/Fixed_broadband_2000-2016.xls)) (accessed July 2017)

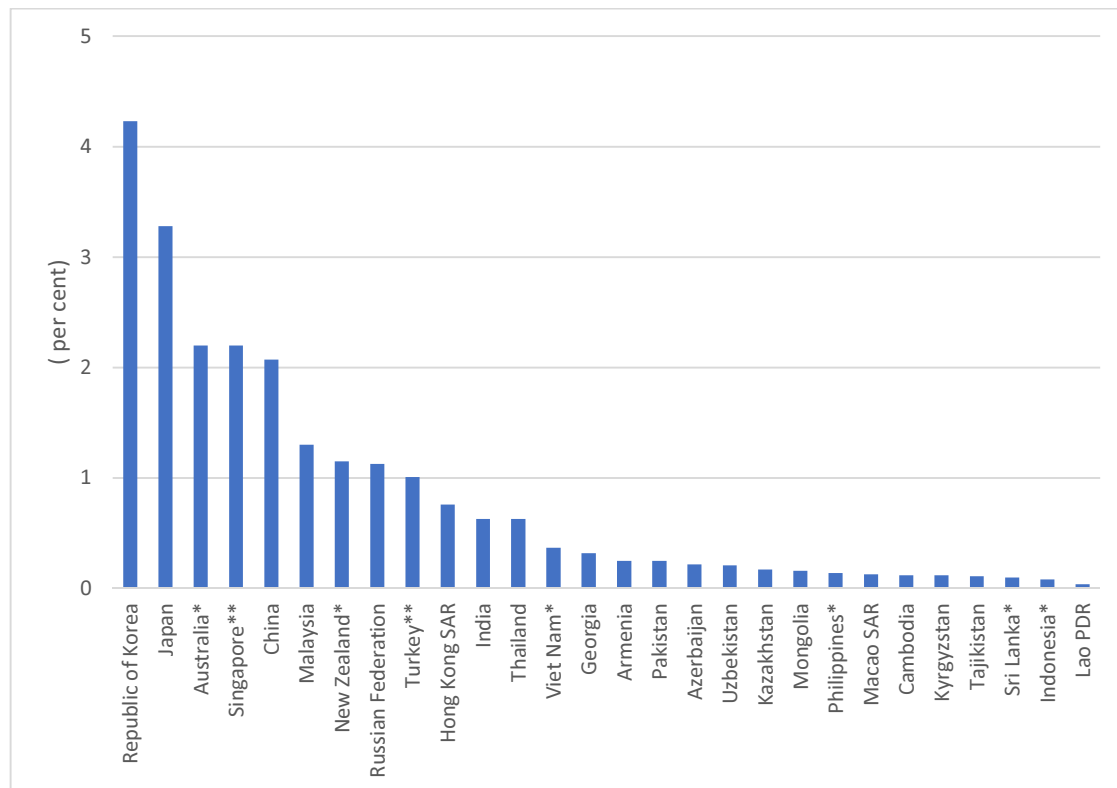
## The spectrum of R&D expenditure in the region

Another perspective to assess the frontier technology divide is gross domestic expenditures in research and development (R&D) as per cent of the GDP (as shown in figure 18). Of the 28 countries for which data are available, only five countries in the region – Australia, China, Japan, Republic of Korea and Singapore – spend 2 per cent or more of GDP on R&D. On the other end of the spectrum, half of the countries spend 0.25 per cent or less. This group includes least developed countries such as Cambodia and Lao Peoples' Democratic Republic, landlocked developing countries such as Armenia, Azerbaijan, Mongolia, Kazakhstan, Kyrgyzstan, Uzbekistan and Tajikistan, and developing countries such as Indonesia, Pakistan, Philippines and Sri Lanka.

## Technology diffusion to the very poorest

Technology diffusion is rarely automatic. Among other reasons, some technologies, despite their technical superiority, may not be commercially viable or affordable for some groups of people or communities. In extreme cases, some technologies may not go beyond the laboratory. Also, the technology life cycle - often depicted as a S-Curve and divided into several stages: development, market introduction, growth, maturity and sometimes decline – means new technologies are often only accessible to a small group of people or sectors before mainstream adoption. One of the most prominent examples of this theory is that it took 30 years for electricity and 25 years for telephones to reach 10 per cent adoption in the USA (figure 19).

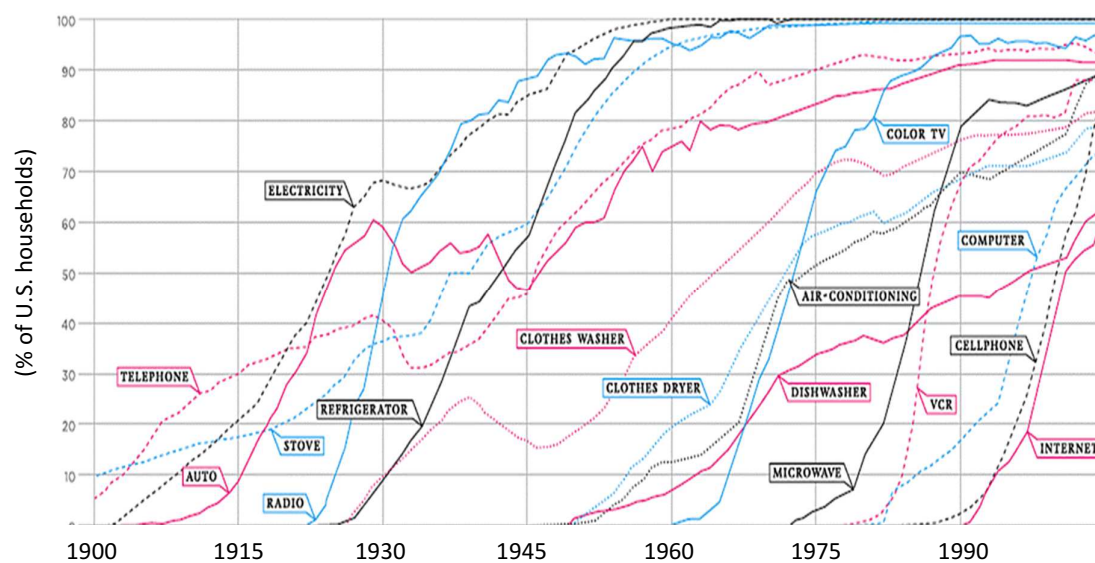
**Figure 18. Gross domestic expenditure on R&D as a share of GDP**



Source: ESCAP, based on data from UNESCO, Institute for Statistics Data Center. Available from: <http://data.uis.unesco.org/Index.aspx?queryid=74> (accessed January 2018).

Note: \*: the latest data available is year 2013; \*\*: the latest data available is year 2014.

**Figure 19. Technology adoption in the USA**

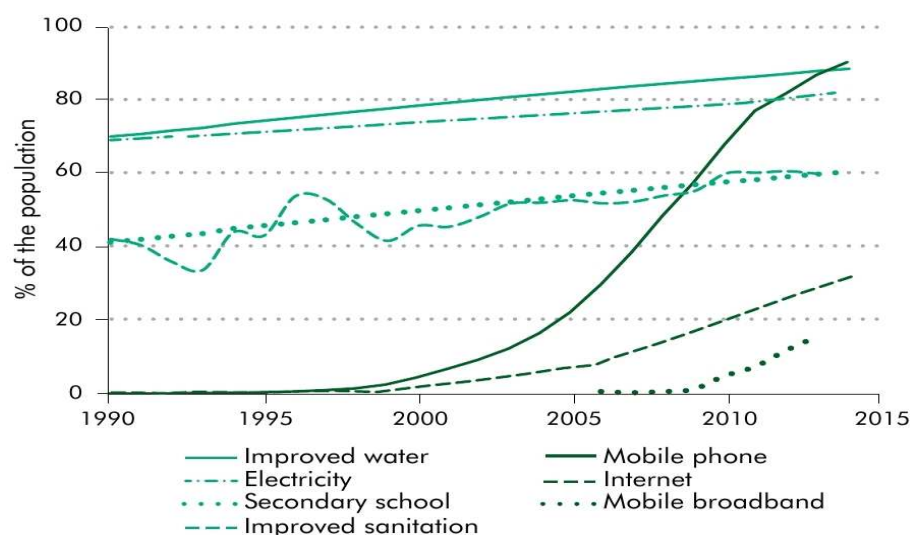


Source: New York times, <https://archive.nytimes.com/www.nytimes.com/imagepages/2008/02/10/opinion/10op.graphic.ready.html>  
<https://www.technologyreview.com/s/427787/are-smart-phones-spreading-faster-than-any-technology-in-human-history/>

On the other hand, evidence has shown that technology adoption has been accelerating. It took decades for the telephone to reach 50 per cent of households, beginning before 1900. However, it took five years or less for cellphones to accomplish the same penetration in 1990 (figure 20). Similarly, technologies, especially digital

technologies, have been spreading more rapidly than before in developing countries (figure 20). Nearly 70 per cent of the bottom fifth of the population in developing countries own a mobile phone. In addition, the number of internet users has more than tripled in a decade from 1 billion in 2005 to an estimated 3.2 billion at the end of 2015.<sup>16</sup>

**Figure 20. Technologies are spreading rapidly in developing countries**

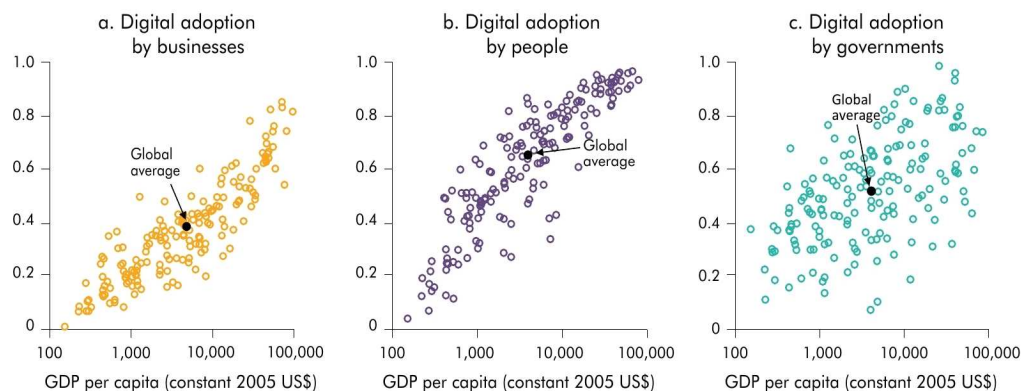


Source: World Bank, 2016.

Despite such achievements, there are wide gaps among developed and less developed countries in adopting technologies. As shown in figure 21, high-income or wealthy

countries (measured by GDP per capita) demonstrated better adoption of technologies.

**Figure 21. Adoption of technologies by countries worldwide**



Source: World Bank, 2016.

**Note:** The figures show the diffusion of digital technologies across countries as measured by the Digital Adoption Index. The sample cover 172 countries worldwide.



The SDGs are aiming to “leave no one behind”. If market forces dominate, the poor may be the last group who benefit from frontier technologies. Policy interventions (as elaborated in chapter 5) should guide frontier technologies to serve and benefit those who generally cannot afford them if the ambitions of the 2030 Agenda for Sustainable Development are to be met.

### 4.3 Ethical issues

The frontier technologies discussed in this report are associated with various ethical issues. For robotics, there are concerns about the impact of automation on jobs (as discussed in section 4.1). For Internet of Things, as the information is shared among devices connected to the internet, there are concerns relating to data security and privacy. Also, ownership and management of data can be problematic. For instance, the owner of an internet-connected device may not be clear what data is collected by service providers and how the data are used.<sup>27</sup>

3D printing may bring ethical issues on responsibility and accountability. If a 3D printed product causes damage, laws and regulations may not be clear on who should be responsible, the owner of the printer, the manufacturer of the printer, or the person who printed the device.

When 3D printing is related to bioprinting, moral, ethical, and legal issues surrounding bioprinting can be a challenge for many countries, especially in terms of readiness of the legal system.

Ethical issues on AI have also attracted much debate. Topics have included:

- The existential risk for mankind: The late physicist Stephen Hawking warned of the importance of regulating AI stating, “The development of full

artificial intelligence could spell the end of the human race”.<sup>22</sup>

- Bias: Experts have highlighted that bias could be the real AI danger. John Giannandrea, the former Google AI Chief, commented, “the real safety question, if you want to call it that, is that if we give these systems biased data, they will be biased”.<sup>23</sup>
- Unpredictable and inscrutable nature of AI: Sophisticated AI algorithms mean, in some situations, that the designers or engineers of the algorithm cannot explain how the AI system makes decisions (box 4). This certainly carries risks. For instance, what decisions will a driverless car make when there is an emergency?

Balancing privacy and openness of data is a common ethical dilemma for all the frontier technologies discussed in this report. The data made available through the open and big data movements has combined with advancements in computing, machine learning and behavioural economics to fuel the growth of several frontier technologies. How governments manage data, now and in the future, will be important. Striking the right balance between privacy, ownership and transparency is a difficult task. A survey<sup>24</sup> conducted by the Omidyar Network in 60 countries found that within the sample:

- The scale of global distrust is enormous with 2 out of 3 respondents having no trust in the private sector and governments with content of their phone or online conversations.
- Trust drops sharply by 18 per cent between those with primary education and those with secondary education or higher. An average of 58 per cent of



respondents with a primary school education reported data-trust, while only 40 per cent of individuals with advanced degrees indicated data-trust.

- Finally, the data shows a trend that trust diminishes as national income increases.<sup>25</sup>

These findings raise questions in our pursuit of the SDGs. As we strive towards education for all and raising incomes, will this come at the cost of trust between citizens, governments and the private sector?

At the global level, there are challenges for collecting, disseminating and storing data, especially for vulnerable communities in times of crises. The issues surrounding the security and privacy of data collected in hostile conflict environment are even more critical to address, as there is often a need to protect informants; safeguard information from manipulation; and employ mechanisms to ensure the veracity of the data collected and utilized.

#### Box 4. Creativity and unpredictability of artificial intelligence

Underlying AI technology, deep learning has proved very powerful at solving problems in recent years, and it has been widely deployed for tasks like image captioning, voice recognition, and language translation. Siemens has been using AI and Internet of Things to find ways to reduce emissions from gas turbines. AI shows the capacity to find new ways to run the turbines. "Our engineers do it from their experience, their domain know-how. AI does it in a different way," says Roland Busch, Siemens' Chief Technology Officer. "Sometimes the system itself comes to a solution which you had never thought about. It's a little bit scary".

On the other hand, deep learning can be a double-edged sword. Its algorithm can be difficult to understand even by its creators, and therefore, its decision may be very unpredictable. MIT Technology review comprehensively reviews the risks related to deep learning and proposed the question, "How well can we get along with machines that are unpredictable and inscrutable?"

Source: 1). <https://www.ft.com/content/99399b86-59c3-11e7-9bc8-8055f264aa8b>; 2). <https://www.technologyreview.com/s/604087/the-dark-secret-at-the-heart-of-ai/>. 3). <https://www.cnet.com/news/was-ubers-driverless-car-crash-avoidable-some-experts-say-the-self-driving-car-should-have-braked/>

## ENDNOTES

- <sup>1</sup> Keynes, 1933.
- <sup>2</sup> World Economic Forum, 2016b.
- <sup>3</sup> World Bank, 2016.
- <sup>4</sup> McKinsey Global Institute, 2017d.
- <sup>5</sup> International Labour organization, 2016.
- <sup>6</sup> World Bank, 2016; International Labour organization, 2016.
- <sup>7</sup> United Nations Conference on Trade and Development, 2017.
- <sup>8</sup> Bain and Company, 2018.
- <sup>9</sup> McKinsey Global Institute, 2017b.
- <sup>10</sup> MIT Technology Review, 2018.
- <sup>11</sup> Shenzhen Daily, 2017.
- <sup>12</sup> See <http://technode.com/2017/07/17/alibabas-taobao-maker-festival-show-face-recognition-payment/>
- <sup>13</sup> Institute of Development Studies, 2016.
- <sup>14</sup> For instance, a survey conducted by Facebook in 2015 estimated that 4 billion people have no access to internet  
<https://www.weforum.org/agenda/2016/02/4-reasons-4-billion-people-are-still-offline/>. World Bank (2016) estimated that nearly 6 billion people do not have high-speed internet.
- <sup>15</sup> ITU World Telecommunication/ICT Indicators Database 2017, 21th Edition/December 2017. Available from <https://www.itu.int/en/ITU-D/Statistics/Pages/publications/wtid.aspx>.
- <sup>16</sup> World Bank, 2016.
- <sup>17</sup> More systematic discussion of ethical issues on Internet of Things is available from Fairfield, 2017.
- <sup>18</sup> Gilpin, 2014.
- <sup>19</sup> See <http://web.mit.edu/ebm/www/index.html>
- <sup>20</sup> Stephens and others, 2013.
- <sup>21</sup> United Nations, 2017.
- <sup>22</sup> See <http://www.bbc.com/news/technology-30290540>
- <sup>23</sup> MIT Technology Review, 2017.
- <sup>24</sup> Omidyar Network, 2017.
- <sup>25</sup> This does not reflect the income level of individual respondents, rather the income level of the countries in which they reside).

## 5. POLICY PRIORITIES

While there are question marks over the scale and pace of the frontier technological transition, it would be prudent for governments to be prepared, and to put effective policies in place. As stated by Nobel laureate Robert Shiller, “[w]e cannot wait until there are massive dislocations in our society to prepare for the Fourth Industrial Revolution”.<sup>1</sup>

Technology and innovation underpin the Fourth Industrial Revolution and national science, technology and innovation (STI) policies should provide a guide to all stakeholders in preparing for frontier technological impacts and transitions.

National STI policies serve several functions. First, they articulate the government's vision regarding the contribution of STI to their country's social and economic development. Second, they set priorities for public investment in STI and identify the focus of government reforms. Third, the development of these strategies can engage stakeholders ranging from the research community, funding agencies, business, and civil society to regional and local governments in policy making and implementation. In some cases, national strategies outline the specific policy instruments to be used to meet a set of goals or objectives. In others, they serve as visionary guideposts for various stakeholders.<sup>2</sup>

While, national innovation systems theory has traditionally been the guideline for developing STI policy, a next generation technology policy framework is required for the Fourth Industrial Revolution future that we face. To date, several countries in the region have shown strong political will to

develop policies for specific frontier technologies. A few examples are highlighted below:

In China, President Xi Jinping called to turn China into nation of innovators.<sup>3</sup> In 2017, China published a comprehensive AI development policy with the overarching goal to make the country “the front-runner and global innovation centre in AI” by 2030.<sup>4</sup>

Japan's Artificial Intelligence Technology Strategy Council was launched by Prime Minister Abe in April 2016.<sup>5</sup> The Council subsequently developed the Artificial Intelligence Technology Strategy, which was published in 2017.<sup>6</sup> The strategy outlines some of the priority areas for Japan in the areas of AI research and development, and promotes collaboration between relevant government agencies, industry and academia in order to further AI research. Japan has also proposed setting up an international set of basic rules for developing AI (to be further elaborated in Section 5.5).<sup>7</sup> The Government has also devised Japan's Robot Strategy<sup>8</sup> recognizing the need for robot regulatory reform.

Republic of Korea has developed what has been coined the world's first robot tax.<sup>9</sup> The Ministry of Science and ICT of the Republic of Korea has also laid out the “Artificial Intelligence Information Industry Development Strategy”, which aims to strengthen the foundation for AI growth.<sup>10</sup> In 2016, the Government also published their “Intelligence Information Society Fourth Industrial Revolution Medium- to Long-term Comprehensive Response Plan”.<sup>11</sup>

Several government initiatives have also facilitated the development of 3D printing. For example, China has moved to bolster its 3D printing sector with enabling policies and fiscal support as part of the country's broader strategy to develop high-technologies to drive the economy. The government expects the industry to maintain an annual growth rate of more than 30 per cent in the coming years and its revenue to top 20 billion yuan (around \$3 billion) in 2020, according to guidelines released by the Ministry of Industry and Information Technology and other agencies in the country.<sup>13</sup>

Countries in the Asia-Pacific region are also developing roadmaps, plans and standards for Internet of things. These include:<sup>12</sup>

The ASEAN ICT Masterplan 2020 and ASEAN Smart Network Initiative: One of five outcomes of the Masterplan focuses on "Sustainable Development through Smart City Technologies" which includes the deployment of Internet of Things technologies.

- Australian authorities freed up additional spectrum bands dedicated to the use of Internet of Things in December 2015.
- India's Internet of Things Draft Policy, 2015: The Government is driving adoption of Internet of Things by investing in smart cities and promoting start-ups. In collaboration with the private sector, it established a Centre of Excellence for Internet of Things.
- Japan's General Framework for Secured Internet of Things Systems, 2016.
- Republic of Korea's Master Plan for Building the Internet of Things, 2014.

- Malaysia's National Internet of Things Strategic Roadmap, 2014.
- New Zealand's Business Growth Agenda 2017 includes initiatives to accelerate the adoption of Internet of Things technologies through market research and the establishment of an Internet of Things Alliance, a collaboration between industry and government.
- Singapore's Internet of Things Standards Outline in Support of the Smart Nation Initiative, 2015.

While these policies and strategies are very much technology specific, as an initial step towards understanding the policy response to the opportunities and challenges that frontier technologies present more broadly, this section discusses six key policy areas that could form the backbone of a next generation technology policy which focusses on creating an enabling environment for frontier technologies, and is aligned to sustainable development objectives.<sup>14</sup>

The six policy priorities are:

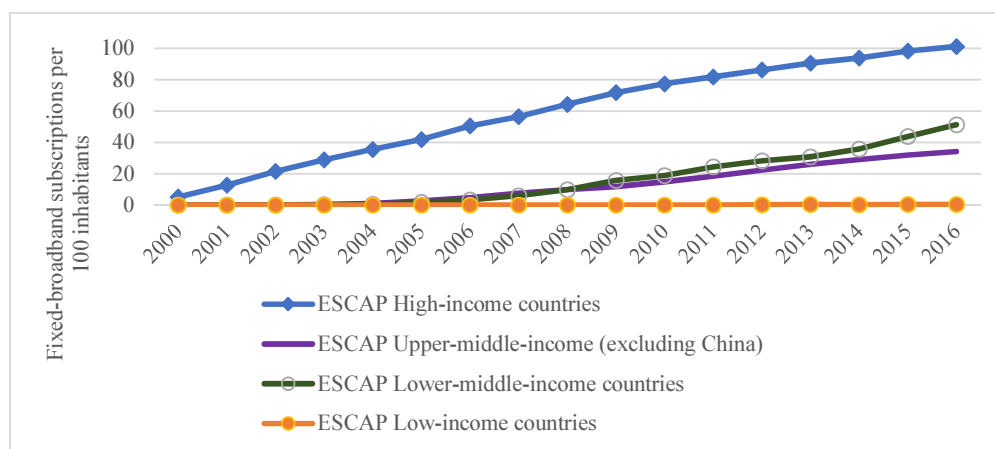
1. Inclusive ICT infrastructure;
2. Developing a workforce fit for a Fourth Industrial Revolution future;
3. Developing innovative regulatory frameworks;
4. Incentivizing responsible frontier technology development in the private sector;
5. Catalysing the role of government in frontier technologies' evolution; and
6. Creating a platform for multi-stakeholder and regional cooperation.

## 5.1 Inclusive ICT infrastructure

A prerequisite for the development and application of frontier technologies is developed ICT infrastructure. As shown in figure 22, ICT usage is unequally distributed among countries. High-income countries, those that are at the forefront of frontier technology development, have seen very rapid increases, while middle-income countries, after a slow start, are experiencing steeper increases. The situation in low-income countries on average, remains unchanged.

Even if middle-income and to some extent low-income countries are not at the forefront of developing frontier technologies, equalizing opportunities embedded in the possibility of buying such technology or adapting parts of it to local circumstances could be lost if digital infrastructure deficits persist. In this regard, a continued focus on bridging the digital divide - particularly “last mile” connectivity - should be a policy priority so as not to fuel a new frontier technology divide.

**Figure 22. Total fixed-broadband subscriptions by income group, excluding China**



Source: Produced by ESCAP, based on data from ITU World Telecommunication/ICT Indicators Database (accessed July 2017).

## 5.2 Developing a workforce fit for a Fourth Industrial Revolution future

While the scale and pace of frontier technological adoption and diffusion are still unknown, it would be prudent for governments to develop a workforce fit for a Fourth Industrial Revolution future. Some directions to consider include: a greater emphasis on entrepreneurship training to develop job creators as well as job seekers, adult education, life-long learning, and reskilling to deal with current and future technological transitions. Education must

also instil new expectations about work and the marketplace for jobs. This will require innovative education policies such as those promoted by the Government of Singapore. One such policy offers adults personal accounts which they can use to buy training, and another uses tax incentives to encourage firms to invest more in their lower paid workers.<sup>15</sup> In addition, governments could strengthen social protection systems to protect the workers that are vulnerable to losing their jobs. Such forward-thinking policies could support a strategy to facilitate redeployment, not unemployment.

## 5.3 Developing innovative regulatory frameworks

### Responsive and adaptive regulation

To avoid hindering the development of frontier technologies' application for sustainable development, regulatory processes need to become responsive and adaptive. However, enabling regulation for innovation is difficult to formulate and as such, innovations in regulation processes are urgently required. The Fintech Supervisory Sandbox, launched by the Hong Kong Monetary Authority in 2016, is an example of this, allowing banks and their partnering tech firms to conduct pilot trials of their FinTech initiatives without the need to achieve full compliance with supervisory requirements in early-stage development. This arrangement enables banks and tech firms to gather data and user feedback so that they can make refinements to their new initiatives, thereby expediting the launch of new technology products, and reducing development costs.

Effective regulation should allow innovation to flourish while still safeguarding society and the environment. Balancing these demands will be an important government agenda as frontier technologies evolve, and one that will require sharing effective practices and innovative approaches between governments. Responsive and adaptive regulation may provide a solution. It emphasizes that policy needs to support the development of frontier technologies while also allowing for faster responses to ensure that the public aren't exploited and that new dangers are averted.<sup>16</sup>

### Frontier technology ethics

Governments have already begun to tackle the ethical issues highlighted in this report. For example, in Germany, the Federal

Government has proposed rules for decision-making to promote ethical behaviour by systems guiding crash scenarios for driverless cars. These rules prioritize human life above property damage and do not discriminate between human lives. Although industry is driving advances in AI technology, governments must play a key role in ethical and governance considerations. Member States consensus on standards and ethical principles for technological advancements will be critical to ensure that technological transitions are well-managed.

## 5.4 Incentivizing responsible frontier technology development in the private sector

### Shared value

As the predominant investor in frontier technologies, the private sector will shape how they impact the economy, society and the environment. However, to create positive impact on these three dimensions of sustainable development, corporations need to move beyond the concept of corporate social responsibility and redefine their objective, and associated measures of success, as creating "shared value".<sup>17</sup> Shared value is not corporate social responsibility. It measures value across the three dimensions of sustainable development at the core of business strategy. To further promote shared value, policymakers need to create the right incentives, so these values move from corporate social responsibility departments to the boardrooms.

Governments can play a critical facilitating role by creating an environment to ensure the development, adaptation and diffusion of frontier technologies by the private sector is appropriate to their own country context.

Typical measures can be subsidies or tax incentives for the development of products by the private sector which bring substantial societal or environmental benefits, especially these related to the SDGs.

### Public-private partnerships

Past experiences show that public-private partnerships may provide alternatives to financing the development of frontier technologies. For example, a public-private partnership that combined government funding and policy direction with private infrastructure investment and management underpinned the success of the Republic of Korea's fixed broadband penetration. The Government invested less than \$1.8 billion, compared with over \$33 billion from the private sector, in establishing the backbone network serving larger cities from 2005 to 2014.<sup>18</sup>

Public-private partnership can take many forms. For instance, a government can promote and drive joint research with the private sector and academia in the areas of strategic national interest or direct effects on public good. Governments may also provide support to the private sector for implementation of pilot projects. For instance, a private company will need government support to test a driverless bus in a city.

### Engaging the technology giants

Leading technology companies could be important partners for addressing the SDGs. For instance, Microsoft's A Cloud for Global Good has brought tangible benefits to developing countries.<sup>19</sup> Efforts by leading global technology companies to make frontier technologies publicly available and transparent would enable developing countries to learn about the latest developments and identify solutions to

social and environmental issues.<sup>20</sup> An important example in this respect is the Partnership on AI to Benefit People and Society<sup>21</sup> founded by Amazon, Apple, DeepMind, Facebook, Google, IBM and Microsoft in 2016. The partnership states that its goals are to study and formulate best practices on the development, testing, and fielding of AI technologies, advancing the public's understanding of AI, to serve as an open platform for discussion and engagement about AI, and its influences on people and society, and identify and foster aspirational efforts in AI for socially beneficial purposes.<sup>22</sup> In Asia, Huawei published its first report dedicated to technology for sustainable development in 2017 and stated that "It is our responsibility to support the UN in its pursuit of the Sustainable Development Goals, and it's one that we take seriously."<sup>23</sup>

On the other hand, technology companies such as Amazon, Google, Facebook, Alibaba and eBay dominate their respective sectors. This may restrain effective market competition and lead to winner-take-all market outcomes. Indeed, some companies have been subjected to antitrust investigation.<sup>24</sup> While the important role of the private sector in sustainable development has been well noted, government's need to put effective policies in place to manage any potential conflicts between maximizing corporate objectives of maximizing shareholder wealth, and potentially negative social and environmental impacts.

## 5.5 Catalysing the role of government in frontier technologies' evolution

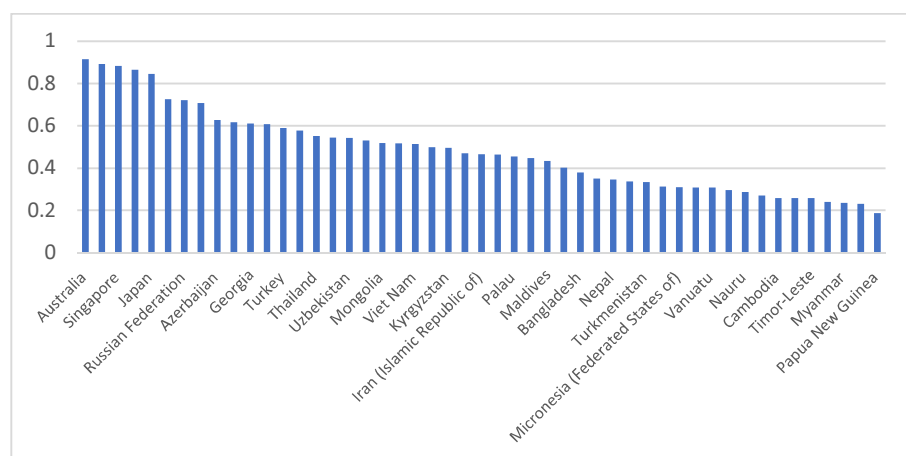
### Public sector innovation skills

It will be critical for government and public sector workers to develop innovation skills if countries are to meet the diverse range of goals set out in the SDGs.<sup>25</sup> Governments will need to support an agile, forward-thinking and technologically skilled civil service to respond to a rapidly changing world and the opportunities frontier technologies present. While caricatures of public servants that depict them as hostile to innovation are out of date, public organizations continue to need skills and better processes if they are to resist the tendency of inertia.<sup>26</sup> The Government of

Singapore's Digital Services Team provides an example of an initiative by a government that has focused on bringing in non-traditional civil service skills. The team of software developers, user experience designers and architects build digital services using an agile project management method that emphasizes small changes to services based on feedback from user testing and research.

Digital literacy is a key skill that will enable governments to digitize many of their services, increasing effectiveness and efficiency. According to an e-government survey of the United Nations Department of Economic and Social Affairs (DESA),<sup>27</sup> several countries in Asia and the Pacific top the survey's list (figure 23).

Figure 23. E-Government Development Index 2016



Source: DESA, 2016.

**Note:** The E-Government Development Index measures ICT infrastructure, services and capacity, and is an indicator of the digital-readiness of governments across the globe

### The government as a market maker and shaper

As highlighted previously in this report, the private sector has been the prime investor in frontier technologies. However, increasingly, governments in the Asia-Pacific region are establishing dedicated

agencies to help realize the transformative potential of frontier technologies. One such agency is Singapore's SGInnovate, which was launched in November 2016<sup>28</sup> as the venture capital arm of Singapore's Infocomm Development Authority.<sup>29</sup> This government-owned company specializes



in supporting frontier technology and “deep technology” initiatives and start-ups in Singapore, with a focus on AI, robotics and blockchain.<sup>30</sup> The creation of SGInnovate complements the Singaporean Government’s strategy to boost the country’s frontier technology capabilities, through its government-wide partnership and national programme on Artificial Intelligence Singapore.<sup>31</sup> Singapore’s National Research Foundation will invest up to S\$150 million over the next five years in the programme, in order to create a supportive ecosystem for AI start-ups and companies developing AI products.<sup>32</sup> The initiative builds on Singapore’s vision of becoming a Smart Nation as well the recommendations of the Committee on Future Economy to realize the growth opportunities of the digital economy and build stronger digital capabilities.<sup>33</sup>

SGInnovate is also a key player in the Artificial Intelligence Singapore initiative and focuses on supporting AI start-ups in access to talent and building their customer base. The focus of this agency is to support the human capital development requirements for frontier technology businesses, noting the longer timelines required to build such companies and making them viable. Some of the objectives of SGInnovate include building the competencies in the areas of machine learning, deep learning and data analytics, through their participation in tailor-made training programmes. SGInnovate also intends to expand and deepen networks and communities working on frontier technologies.<sup>34</sup> SGInnovate also provides investment capital to frontier technology start-ups. They will also be providing a range business building support for growth and scaling of frontier technology businesses as

well as collaborative spaces for networking.<sup>35</sup>

## 5.6 Creating a platform for multi-stakeholder and regional cooperation

Cross-government cooperation; inter-governmental knowledge-sharing and consensus-building; and honest, open and regular discussion with civil society and the private sector, specifically technology developers will be critical to ensure that frontier technologies have a positive impact on sustainable development.

As a first step, developing a set of overarching principles governing the development of frontier technologies should be a first order priority. Globally, leadership on such an endeavour has been sub-optimal, however, given Asia and the Pacific’s prominent position in several frontier technologies, the region is well placed to lead on governance globally, to build trust and ensure effective deployments aligned to the SDGs.

As an example, during Japan’s 2016 Group of Seven presidency, then Minister of Internal Affairs and Communications proposed some basic principles that could guide AI research and development. The principles, which were presented during the Group of Seven ICT Ministers meeting in April 2016 in Takamatsu, Kagawa Prefecture, Japan; were an outcome of ongoing studies on the benefits and impacts of AI networking on the Japanese society and economy.<sup>36</sup> Similarly, in the United Kingdom (UK), several recommendations on the ethical principles of AI are being proposed (box 5).

### Box 5. The artificial intelligence research and development principles / guidelines proposed by Japan to the Group of Seven countries and the United Kingdom

The intention of the guidelines was to enhance the benefits and minimize the potential risk of artificial intelligence, in order to ensure the artificial intelligence research and development is human-centred and protects the interests of users. Given the rapidly developing nature of artificial intelligence technology, the guidelines should not be perceived as regulations, but rather proposed guidelines to be shared internationally as non-regulatory, non-binding soft law. The draft artificial intelligence research and development Guidelines include:

1. Principle of collaboration – Developers should pay attention to the interconnectivity and interoperability of artificial intelligence systems.
2. Principle of transparency – Developers should pay attention to the verifiability of inputs/outputs of artificial intelligence systems and the explainability of their judgements.
3. Principle of controllability – Developers should pay attention to the controllability of artificial intelligence systems.
4. Principle of safety – Developers should take it into consideration that artificial intelligence systems will not harm the life, body, or property of users or third parties through actuators or other devices.
5. Principle of security – Developers should pay attention to the security of artificial intelligence systems.
6. Principle of privacy – Developers should take it into consideration that artificial intelligence systems will not infringe the privacy of users or third parties.
7. Principle of ethics – Developers should respect human dignity and individual autonomy in research and development of artificial intelligence systems.
8. Principle of user assistance – Developers should take it into consideration that artificial intelligence systems will support users and make it possible to give them opportunities for choice in appropriate manners.
9. Principle of accountability – Developers should make efforts to fulfil their accountability to stakeholders including artificial intelligence systems' users.

The guidelines also call for governments and international organizations to promote dialogues amongst relevant stakeholders to promote common perceptions of artificial intelligence benefits and challenges and to review the guidelines and their operation. Furthermore, standardization bodies and other related entities are asked to prepare and release recommended models that align with the proposed artificial intelligence guidelines. The guidelines also call for governments to support artificial intelligence developer communities in addressing challenges and mitigate the risks, and for policymakers to actively promote policies to support the research and development of artificial intelligence.

In the UK, a report "AI in the UK: Ready, Willing and Able?" prepared by the House of Lords Select Committee on Artificial Intelligence makes several recommendations on the ethical principles of AI namely:

1. Artificial intelligence should be developed for the common good and benefit of humanity.
2. Artificial intelligence should operate on principles of intelligibility and fairness.
3. Artificial intelligence should not be used to diminish the data rights or privacy of individuals, families, or communities.
4. All citizens should have the right to be educated to enable them to flourish mentally, emotionally, and economically alongside artificial intelligence.
5. The autonomous power to hurt, destroy or deceive human beings should never be vested in artificial intelligence.

Source: 1). Draft AI R&D GUIDELINES for International Discussions, [http://www.soumu.go.jp/main\\_content/000507517.pdf](http://www.soumu.go.jp/main_content/000507517.pdf);  
2) <https://www.parliament.uk/business/committees/committees-a-z/lords-select/ai-committee/news-parliament-2017/ai-report-published/> ; and 3) Financial Times, April 16, 2018 Britain urged to take ethical advantage in artificial intelligence.

## ENDNOTES

- <sup>1</sup> Hutt, 2016.
- <sup>2</sup> OECD, 2016.
- <sup>3</sup> China Daily, 2017b.
- <sup>4</sup> State Council, 2017b.
- <sup>5</sup> The Council manages five National Research and Development Agencies that fall under the jurisdiction of the Ministry of Internal Affairs and Communications, Ministry of Education, Culture, Sports, Science and Technology, and Ministry of Economy, Trade and Industry.
- <sup>6</sup> Strategic Council for AI Technology, 2017.
- <sup>7</sup> The Japan Times, 2016.
- <sup>8</sup> The Headquarters for Japan's Economic Revitalization, 2015.
- <sup>9</sup> Daily Telegraph, 2017.
- <sup>10</sup> Lee and Choi, 2016.
- <sup>11</sup> Ministry of Science and ICT, 2017.
- <sup>12</sup> Porter and Kramer, 2011.
- <sup>13</sup> Asia Foundation, 2017.
- <sup>14</sup> As such, these policy areas do not address specific frontier technologies or sectors.
- <sup>15</sup> See <http://www.nesta.org.uk/2017-predictions/lifelong-learners>
- <sup>16</sup> Nesta, 2017.
- <sup>17</sup> Porter and Kramer, 2011.
- <sup>18</sup> World Bank, 2016.
- <sup>19</sup> For instance, to respond to a 7.8 magnitude earthquake in Nepal in 2015, Microsoft and the United Nations Development Programme built a cloud-based application which allowed reconstruction crews to record precise coordinates and measurements for each building prior to demolition. The application also was used to manage daily cash payments to thousands of local workers, many of whom were clearing debris.
- <sup>20</sup> In 2017, the United Nations Children's Fund joined the partnership, [https://www.unicef.org/media/media\\_95995.html](https://www.unicef.org/media/media_95995.html)
- <sup>21</sup> See <https://www.partnershiponai.org/>
- <sup>22</sup> See [https://www.unicef.org/media/media\\_95995.html](https://www.unicef.org/media/media_95995.html)
- <sup>23</sup> Huawei, 2016.

- <sup>24</sup> See, for example, the case that Google was subjected to antitrust investigation by the European Commission, <https://www.ft.com/content/b3779ef6-b974-11e7-8c12-5661783e5589>.
- <sup>25</sup> United Nations, Economic and Social Commission for Asia and the Pacific, 2016.
- <sup>26</sup> Mulgan, 2014.
- <sup>27</sup> United Nations, Department of Economic and Social Affairs, 2016.
- <sup>28</sup> See <https://www.opengovasia.com/articles/sginnovate-to-focus-on-artificial-intelligence-blockchain-and-medtech-during-2018>
- <sup>29</sup> See <https://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=21766070>
- <sup>30</sup> See <https://www.crunchbase.com/organization/sginnovate>
- <sup>31</sup> Organizations part of the Artificial Intelligence Singapore partnership include: National Research Foundation (NRF), the Smart Nation and Digital Government Office, the Economic Development Board, the Infocomm Media Development Authority, SGInnovate, and the Integrated Health Information Systems.
- <sup>32</sup> See <https://www.imda.gov.sg/infocomm-and-media-news/buzz-central/2017/5/ai-analytics-and-fintech-boost-for-singapore-digital-economy> / <https://www.nrf.gov.sg/programmes/artificial-intelligence-r-d-programme>
- <sup>33</sup> See [https://www.nrf.gov.sg/Data/PressRelease/Files/201705031442082191-Press%20Release%20\(AI.SG\)%20\(FINAL\)%20-web.pdf](https://www.nrf.gov.sg/Data/PressRelease/Files/201705031442082191-Press%20Release%20(AI.SG)%20(FINAL)%20-web.pdf)
- <sup>34</sup> See <https://www.opengovasia.com/articles/sginnovate-to-focus-on-artificial-intelligence-blockchain-and-medtech-during-2018>
- <sup>35</sup> See <https://www.opengovasia.com/articles/sginnovate-to-focus-on-artificial-intelligence-blockchain-and-medtech-during-2018>
- <sup>36</sup> Principles proposed during the Group of Seven meeting: (1) Principle of Transparency: Ensuring the abilities to explain and verify the behaviours of the artificial intelligence network system; (2) Principle of User Assistance: Giving consideration so that the artificial intelligence network system can assist users and appropriately provide users with opportunities to make choices; (3) Principle of Controllability: Ensuring controllability of the artificial intelligence network system by humans; (4) Principle of Security: Ensuring the robustness and dependability of the artificial intelligence network system; (5) Principle of Safety: Giving consideration so that the artificial intelligence network system will not cause danger to the lives/bodies of users and third parties; (6) Principle of Privacy: Giving consideration so that the artificial intelligence network system will not infringe the privacy of users and third parties; (7) Principle of Ethics: Respecting human dignity and individuals' autonomy in conducting research and development of artificial intelligence to be networked; and (8) Principle of Accountability: Accomplishing accountability to related stakeholders such as users by researchers/developers of artificial intelligence to be networked.

## 6. CONCLUSION

This report shows that frontier technologies hold great promise for contributing to sustainable development. However, there are challenges particularly regarding the future of work and jobs.

This report highlights that for many developing countries, especially the least developed countries, many jobs are still safe in the short term due to lower labour costs relative to current frontier technological upgrading and transitioning costs.

In the long term, frontier technologies will have far reaching consequences throughout the region and across the globe. While there are questions over the scale and pace of the frontier technological transition, it would be prudent for governments to prepare and put effective policies in place.

This report highlights policy areas that could form the basis of a next generation technology policy fit for the Fourth Industrial Revolution future that we face. Creating an enabling environment for frontier technologies to positively impact economy, society and environment, and to reduce current and potential inequalities should also be a fundamental principle of future technology policy if it is to effectively support the SDGs. The broad contours of this framework could include a focus on:

1. Inclusive ICT infrastructure.
2. Developing a workforce fit for a Fourth Industrial Revolution future.
3. Developing innovative regulatory frameworks that do not stifle innovation and deal with ethical issues.
4. Incentivizing the private sector to pursue responsible frontier technology development.
5. Catalysing the role of government in frontier technologies' evolution.

6. Creating a platform for multi-stakeholder and regional cooperation.

The impacts of frontier technologies are far from pre-ordained. However, frontier technological breakthroughs require us to think differently about how we have traditionally formulated technology policy.

When developing policy on this agenda, it is important to note that concerns regarding the economic implications of emerging technologies are nothing new. Textile workers destroying looms in nineteenth century England for fear of losing their jobs, to robots displacing workers on assembly lines, are just two examples from past industrial revolutions. In this regard we need to listen to historians, not just futurists. It will be critical to learn from the past as we shape the future of frontier technologies.

Many countries are developing specific frontier technology policies and Fourth Industrial Revolution strategies however, they are in their infancy. To support countries to prepare, the evaluation of the impact of these experimental strategies should be a policy priority to establish what works and equally importantly, what does not. Through these activities, best practice next generation technology frameworks can be developed.

Finally, cross-government cooperation; inter-governmental knowledge sharing and consensus building; and honest, open and regular discussion with the civil society and private sector, specifically technology developers, will be critical to ensure that frontier technologies have a positive impact on sustainable development. It is here where the United Nations system could play a critical role.

## APPENDIX 1

### Existing studies on possible job losses to automation

Country	Jobs lost to automation (%)	Country	Jobs lost to automation (%)		
OECD, 2016c					
Austria	12	Japan	7		
Belgium	7	Korea	6		
Canada	9	Netherlands	10		
Czech	10	Norway	10		
Denmark	9	Poland	7		
Estonia	6	Slovak	11		
Finland	7	Spain	12		
France	9	Sweden	7		
Germany	12	UK	10		
Ireland	8	USA	9		
Italy	10				
World Bank, 2016					
	Unadjusted*	Adjusted**	Unadjusted*	Adjusted**	
Albania	73	52	Macedonia	68	49
Angola	74	53	Malaysia	68	49
Argentina	65	65	Malta	56	56
Bangladesh	77	47	Mauritius	67	48
Bolivia	67	41	Mongolia	60	43
Bulgaria	62	44	Nepal	80	41
Cambodia	78	41	Nicaragua	65	40
China	77	55	Nigeria	65	40
Costa Rica	68	49	OECD	57	57
Croatia	63	63	Panama	65	47
Cyprus	61	61	Paraguay	64	46
Dominican Republic	62	45	Romania	69	49
Ecuador	69	49	Serbia	66	47
El Salvador	75	46	Seychelles	61	61
Ethiopia	85	44	South Africa	67	48
Georgia	63	39	Tajikistan	62	38
Guatemala	75	47	Thailand	72	52
India	69	43	Ukraine	64	40
Kyrgyzstan	58	36	Uruguay	63	63
Latvia	57	57	Uzbekistan	55	34
Lithuania	56	56	West Bank and Gaza	64	39
International Labour organization, 2016					
Cambodia	57	Thailand	44		
Indonesia	56	Vietnam	70		
Philippines	49				

Country	Jobs lost to automation (%)	Country	Jobs lost to automation (%)
<b>McKinsey Global Institute, 2017b</b>			
China	51	Japan	55
India	52		
<b>Berriman and Hawksworth, 2017</b>			
Japan	21	USA	38
UK	30	Germany	35
<b>PricewaterhouseCoopers, 2018</b>			
Austria	34	Netherlands	31
Belgium	30	New Zealand	24
Chile	27	Norway	25
Cyprus	30	Poland	33
Czech	40	Republic of	22
Denmark	30	Russia	23
Finland	22	Singapore	26
France	37	Slovakia	44
Germany	37	Slovenia	42
Greece	23	Spain	34
Ireland	31	Sweden	25
Israel	29	Turkey	33
Italy	39	UK	30
Japan	24	USA	38
Lithuania	42		
<b>David, 2017</b>			
Japan	55		
<b>Committee for Economic Development of Australia, 2015</b>			
Australia	40		
<b>Ng, 2017</b>			
Malaysia	54		

Source: Compiled by ESCAP study team. The studies mentioned in this table are listed in the references.

**Note:** \* Probabilities of automation from technical perspective; \*\* Probabilities of automation in the light of technical feasibility and pace of technology adoption.

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