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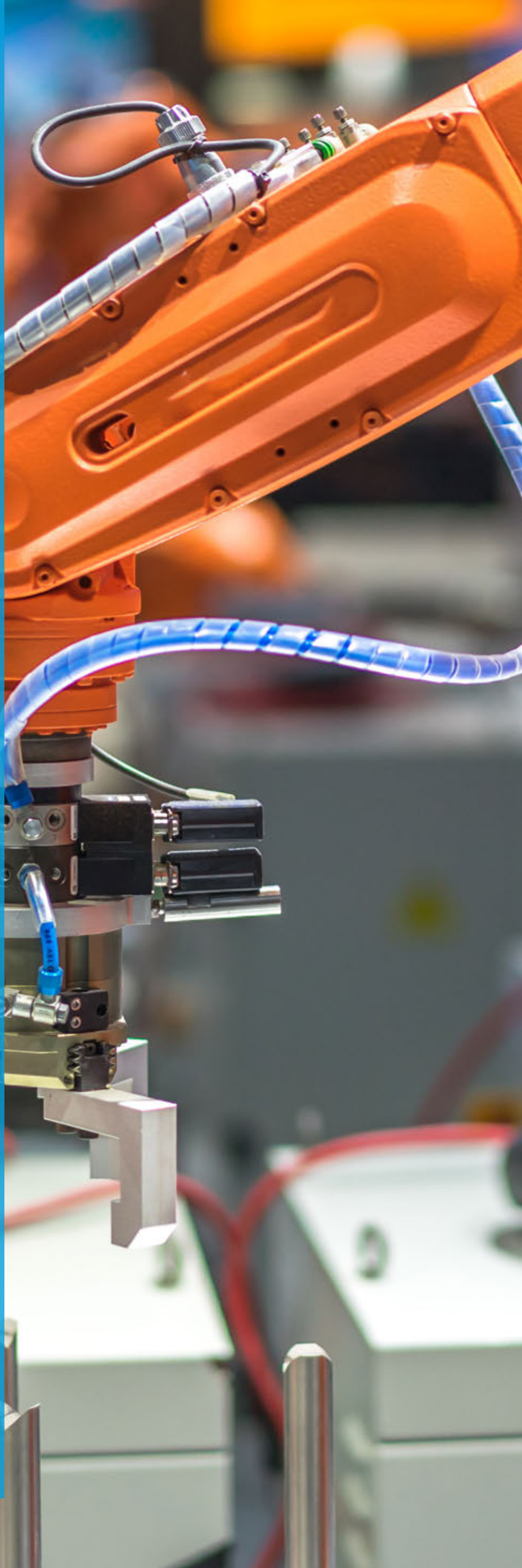

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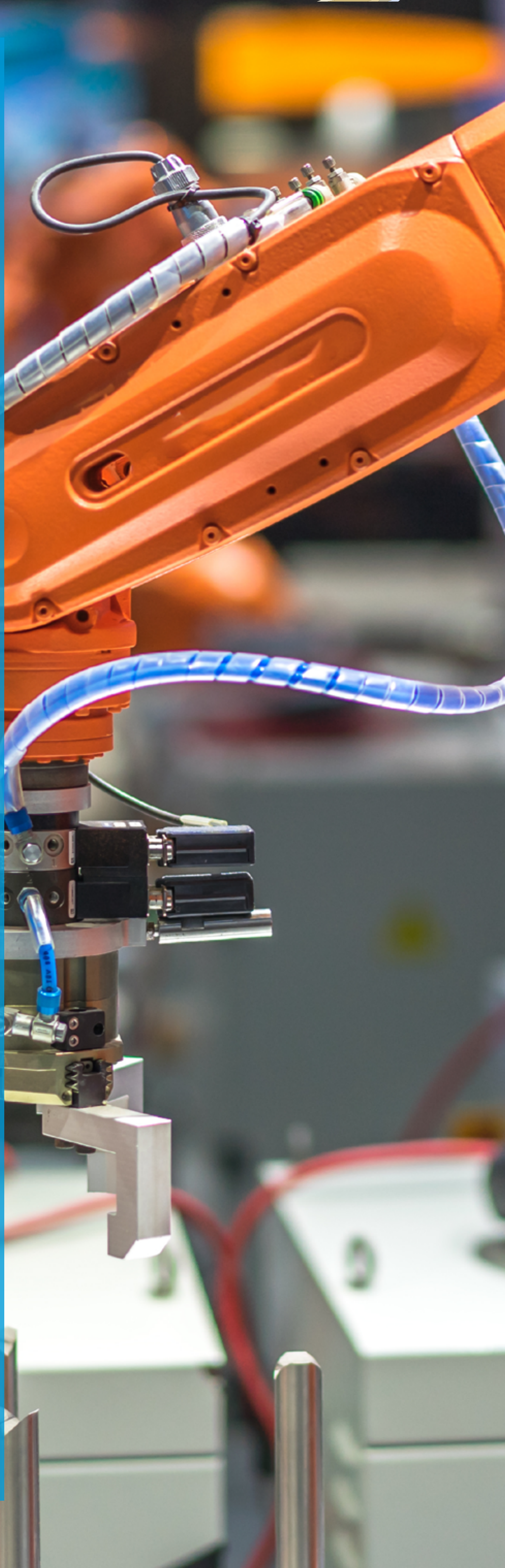

Industry 4.0 for Inclusive Development

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Note

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This series of publications seeks to contribute to exploring current issues in science, technology and innovation, with particular emphasis on their impact on developing countries.

The terms “country” and “economy”, as appropriate, also refer to territories or areas. The designations of country groups are intended solely for statistical or analytical convenience and do not necessarily express a judgment about the stage of development reached by a particular country or area.

The term “dollars” ($) refers to United States dollars unless otherwise specified.

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Abbreviations

CSTD	Commission on Science and Technology for Development
COVID-19	coronavirus disease
DOST	Department of Science and Technology, Philippines
ESCWA	Economic and Social Commission for Western Asia
GDP	gross domestic product
FDI	foreign direct investment
GVC	global value chain
ICT	information and communications technology
ITU	International Telecommunication Union
SME	small and medium-sized enterprises
STI	science, technology and innovation
UNIDO	United Nations Industrial Development Organization

I. Introduction

The world is at the beginning of a new technological revolution based on industry 4.0 technologies such as artificial intelligence, robotics and the Internet of things. In addition, the impact of and response to the coronavirus disease (COVID-19) pandemic have accelerated the dissemination of such digital technologies.

At its twenty-fourth session, in May 2021, the Commission on Science and Technology for Development (CSTD) selected "Industry 4.0 for inclusive development" as one of its two priority themes for the 2021–2022 intersessional period. This priority theme is relevant with regard to Sustainable Development Goal 9 on industry, innovation and infrastructure. To contribute to a better understanding of this theme and to assist CSTD in its deliberations at its twenty-fifth session, the CSTD secretariat has prepared this study based on relevant literature and country case studies contributed by CSTD members. The study builds in particular on the analysis and empirical evidence in two recent United Nations publications, namely Technology and Innovation Report 2021: Catching Technological Waves – Innovation with Equity of UNCTAD, which examines how the development and diffusion of frontier technologies affect and are affected by socioeconomic inequalities (UNCTAD, 2021a); and Industrial Development Report 2020: Industrializing in the Digital Age of the United Nations Industrial Development Organization (UNIDO), focused on the emergence and diffusion of the advanced digital production technologies of industry 4.0 and their impact on the industrialization process in developing countries (UNIDO, 2020).

This study focuses on industry 4.0 with regard to automation and data-driven changes in manufacturing technologies and processes and the trend towards the use of smart factories, predictive maintenance, three-dimensional printing and smart sensors in production processes and software to monitor, control and surveil workers. These processes affect differences in the relative productivity of firms in different sectors and economies and thereby have an impact on the prospects in developing countries for industrialization and structural transformation, which are critical in achieving inclusive development and reducing disparities within and between countries. Such changes in manufacturing also affect wages and employment opportunities due to differences in skill levels and prevailing disparities in education choices and options resulting from social contexts and personal characteristics such as age, gender and ethnicity. Developing countries need to design and implement policies to take advantage of industry 4.0 while minimizing potential adverse effects. The study focuses on industry 4.0 in manufacturing sectors and its impact on inequalities within and between countries and does not cover the application of technologies associated with industry 4.0 (e.g. artificial intelligence and the Internet of things) in other economic sectors (agriculture, services and other industry outside manufacturing) or with regard to final consumption goods and services. The latter perspective is examined in depth in Technology and Innovation Report 2021 and was covered under the priority theme selected by CSTD for the 2019–2020 intersessional period: "Harnessing rapid technological change for inclusive and sustainable development" (UNCTAD, 2020a).

Questions addressed in this study include the following: How can developing countries take advantage of the window of opportunity presented by industry 4.0 for technological upgrading and economic catch-up? What can Governments do to ensure that industry 4.0 does not increase inequality? What is the role of international cooperation in facilitating this process?

The findings are that the use of industry 4.0 technologies in manufacturing can increase productivity and reduce the environmental impact of industrialization and may create rather than replace jobs yet may not shift the manufacturing wage advantage from emerging to industrialized economies. At the same time, most firms in developing countries are not ready to use such technologies; most continue to use analog technologies in production processes and need to further industrialize to benefit from industry 4.0. There is a risk of slow industrialization and dissemination of industry 4.0 in the manufacturing sector in developing countries, further increasing inequalities between countries, and replicating the patterns seen in previous technological revolutions. Developing countries cannot afford to miss this new wave of technological change. Much will depend on national policy responses. Each country requires science, technology and innovation (STI) policies appropriate to the level of development to prepare people and firms for a period of rapid change. This will require a balanced approach, building a robust and diversified industrial base while disseminating industry 4.0 technologies in manufacturing. It will also require forging and strengthening partnerships and international collaboration to facilitate economic diversification and technology dissemination and adoption by manufacturing firms in developing countries.

The study is structured as follows. Chapter II presents a big-picture view of significant trends in global inequalities, industrialization in developing countries and the effects of the pandemic on these trends. Chapter III examines the elements that constitute industry 4.0, including its long-term impact as a technological paradigm and recent market trends. Chapter IV discusses how industry 4.0 could impact inequalities through profits, wages and jobs, and the long-term effects of a technological revolution. Chapter V focuses on some of the key issues related to industry 4.0 from the perspective of developing countries. Chapter VI covers the actions Governments, the private sector and other stakeholders can take to harness industry 4.0 for inclusive development. Chapter VII discusses areas for international collaboration. Chapter VIII presents conclusions and recommendations. Annex A highlights the experiences of some States with industry 4.0 based on contributions from CSTD members. Annex B presents questions for discussion to further the dialogue on harnessing industry 4.0 for inclusive and sustainable development.

II. Trends in industrialization, inequalities and the effects of the pandemic

As highlighted in Technology and Innovation Report 2021, over the past 40 years, within-country inequality has increased in many regions, in some cases reaching significant levels. This concerns not only developed countries such as the United States of America and several countries in Europe but also developing countries such as China and India.

In terms of inequality between countries, each wave of technological progress since the industrial revolution has been associated with sharper inequalities. Before the 1800s, there was little income disparity between countries; rather, inequality was a matter of domestic class divides. Currently, global inequality is defined by location, as the average gap in per capita income between developed and developing countries is over $40,000 (UNCTAD, 2021a). Inequality is driven by birthplace, whereby a person born in a poor country pays a citizenship penalty (Milanovic, 2016). In upper middle-income and high-income countries, the average share of the population living in extreme poverty is only 2 per cent; in lower middle-income countries, the share is 14 per cent and in low-income countries, 45 per cent (UNCTAD, 2021a). Similar disparities exist in child mortality rates and the prevalence of children who are underweight. Significant gaps also persist in education, particularly at higher levels: in 2018, in low-income countries, only 41 per cent of the population in the relevant age group was enrolled in secondary education, compared with 90 per cent in upper middle-income and high-income countries (UNCTAD, 2021a). This gap is particularly important because inequality in education perpetuates income and other forms of inequality.

Progress has been faster for access to essential services such as clean water and electricity but slower for access to basic sanitation. In low-income and lower middle-income countries, only 63 per cent of the population have access to basic sanitation, compared with 86 per cent in upper middle-income countries and near-universal access in high-income countries (UNCTAD, 2021a). Low-income countries also tend to have greater internal inequalities. In 2018, in low-income countries, only 33 per cent of the rural population had access to electricity, compared with 70 per cent of the urban population. This gap was much narrower in lower middle-income countries (81 and 96 per cent, respectively, and nearly non-existent in upper middle-income and high-income countries (UNCTAD, 2021a). Gender disparities are also more pronounced in low-income countries in relation to rates of mortality, vulnerable employment and literacy.

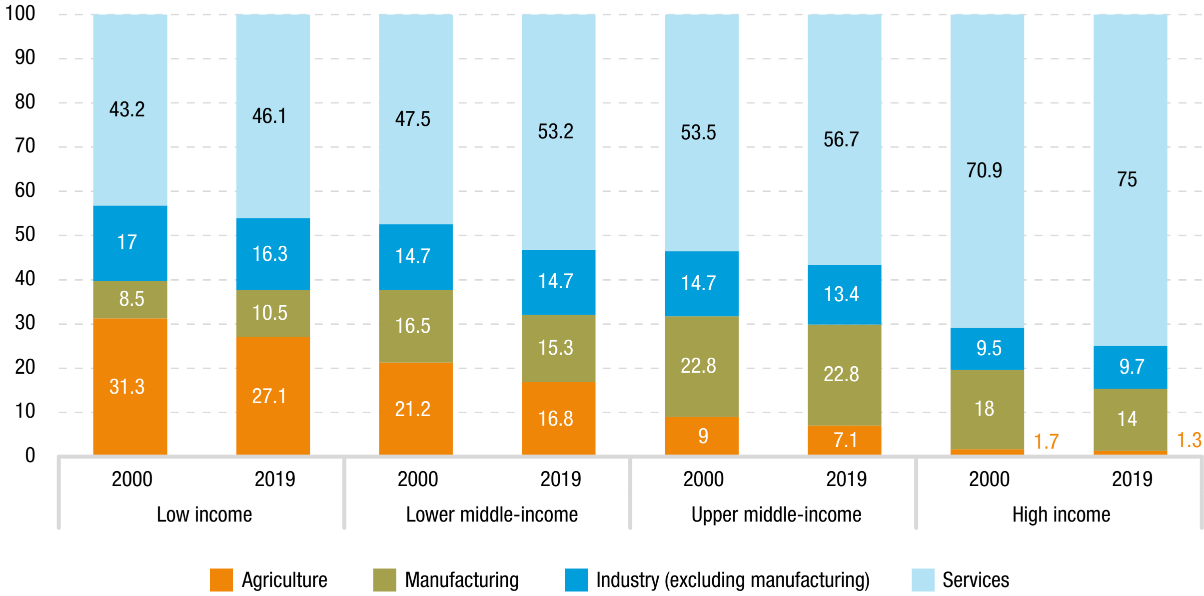
Technology is not the only factor affecting inequalities between and within countries. The impact of technological change is an essential factor but choices in trade, investment, monetary and fiscal policies and education are also critical.

Historically, successful development has been associated with industrialization, technological upgrading and structural transformation, with shifts of output and employment from low value added activities, particularly subsistence agriculture, towards higher value added sectors of industry and services. Within industry, manufacturing offers better prospects for technological adoption and productivity growth, with spillover effects and the potential for higher wages in the whole economy. However, in the past two decades, on average, developing countries have followed a pattern of structural change characterized by a shift of value added and employment mainly from agriculture to services, with a minor increase or even a reduction in the share of manufacturing value added in total gross domestic product (GDP; figures 1 and 2). This pattern shows slow industrialization in low-income countries and early deindustrialization in lower middle-income countries.

There are also several disparities between developed and developing countries in the global production of more sophisticated products. In 2016, in developing countries, the average proportion of medium and high-technology value added was 40.8 per cent, compared with 48.9 per cent in developed countries. In the least developed countries, it was much lower, at 8.8 per cent and, of greatest concern, the proportion had declined from 16.5 per cent in 2000 (UNCTAD, 2021a).

Figure 1

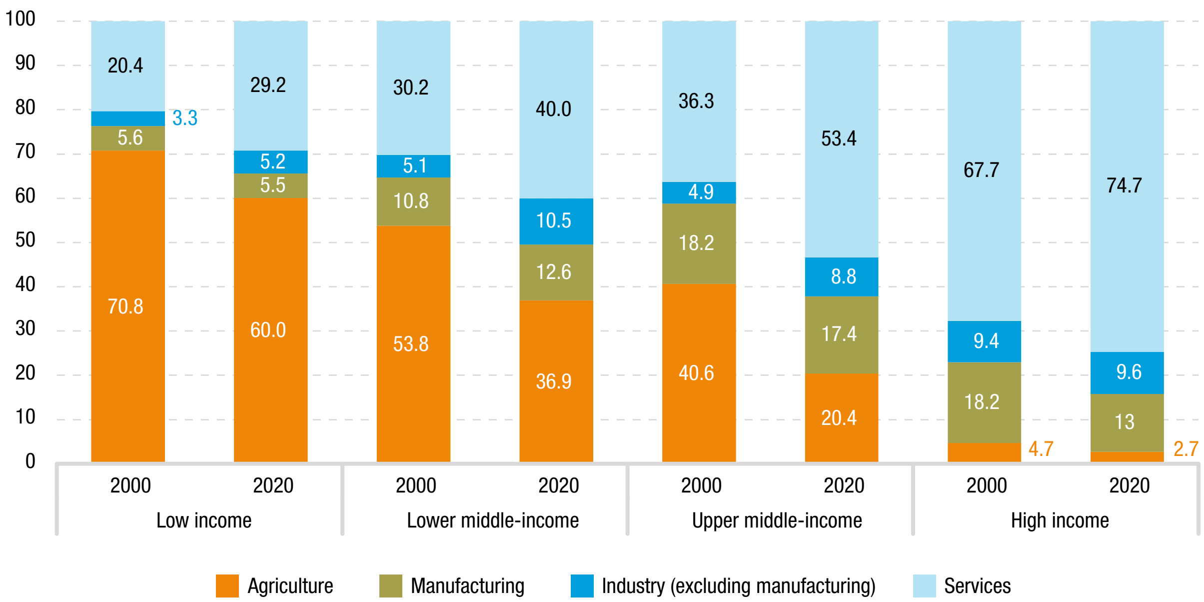
Share of gross domestic product by broad economic sector and income grouping
(Percentage)



Source: UNCTAD secretariat calculations, based on data from the UNCTADstat database.

Figure 2

Employment level, by broad economic sector and income grouping
(Percentage)



Source: UNCTAD, 2021a.

Uneven and slow industrialization in developing countries has occurred despite the rapid expansion of foreign direct investment (FDI) and associated global value chains (GVCs) since the 1990s. GVCs account for some 80 per cent of international trade, and most developing countries are increasingly participating in GVCs; their share in global value added trade increased from 20 per cent in 1990 to over 40 per cent in 2013 (UNCTAD, 2013). This increase was made possible due to policies (liberalization and export-led growth policies) and technological changes (e.g. declining costs of communications and trade) (UNCTAD, 2021b). In particular, rapid technological development has allowed for the segmentation of production processes, leading to the geographical diversification of production and the development of associated complex cross-border supply chains (UNCTAD, 2021b). This expansion of production bases has often taken the form of multinational enterprises from developed countries taking advantage of lower labour costs and market access in developing countries through FDI, thereby shifting more labour-intensive work to developing countries. This expansion of FDI and GVCs has become an important source of capital flow for developing countries, which have turned to higher productivity and more diversified productive capacities. From a development perspective, the inflow of FDI has provided opportunities for skill development, human capital growth and technology transfer in developing countries (Economic and Social Commission for Asia and the Pacific, 2021). However, there is a mixed experience among developing countries in terms of technological learning through participation in GVCs, as learning opportunities depend on the governance of GVCs, the level of supplier competency and the maturity of national innovation systems (Pietrobelli and Rabellotti, 2011). Empirical evidence suggests that firms in developing countries tend to engage more in fabrication, a lower-skill part of GVCs, and firms from developed countries perform more higher-skill research and development functions (Shin et al, 2012; Timmer et al, 2019).

Human capital is an important factor in technological learning and innovation but cannot account on its own for the uneven and slow industrialization as, in most developing countries, worker skills have increased in the past two decades. In 2000–2020, in developing countries, the share of medium-skill jobs increased by 6 percentage points in low-income and lower middle-income countries and by 10 percentage points in upper middle-income countries, in contrast with the job polarization in developed countries, that is, the process of reduction in medium-skill jobs compared with high- and low-skill jobs (UNCTAD, 2021a). In the same period, the shares of high-skill workers increased in all countries, notably in middle-income countries, increasing by about 6 percentage points. However, structural factors affect where skills are employed; the bulk of the increase in medium-skill jobs has been in services and sales (figure 3). Increases in medium-skill jobs associated with manufacturing (e.g. plant and machine operation, assembly and craft work) have been less pronounced.

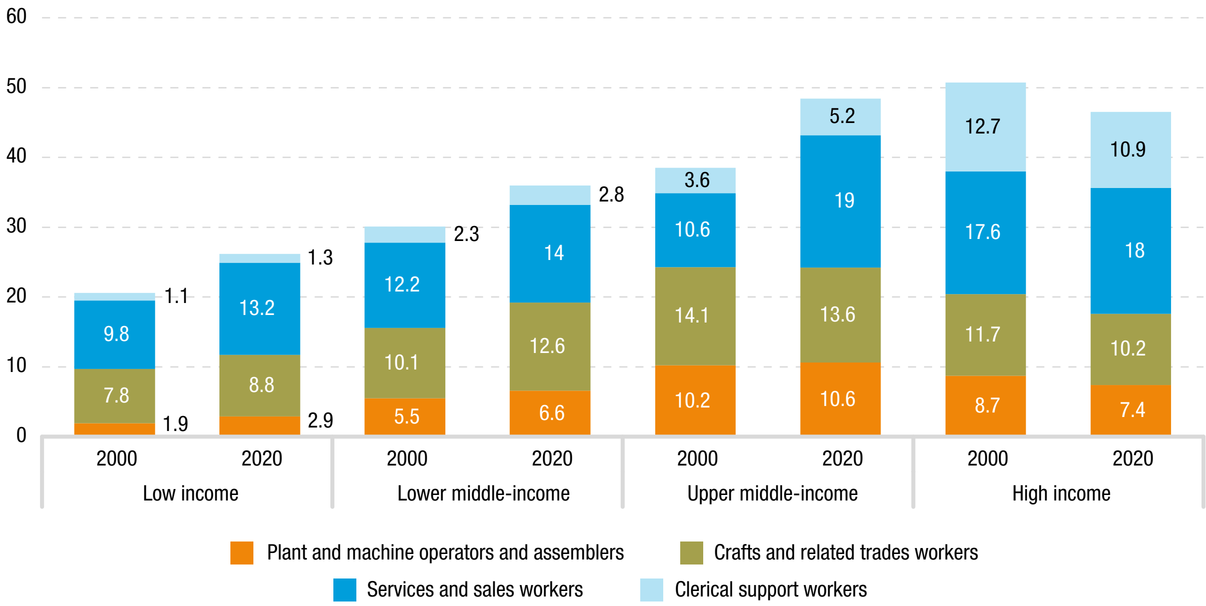
Given the persistent differences in the economic structures of developing and developed countries, despite the worldwide increase in labour productivity in the past 30 years, the productivity gap between these country groupings has increased. The difference between low- and high-income countries in output per worker (in constant international 2011 prices) grew from about $60,000 in 1991 to almost $90,000 (UNCTAD, 2021a). Many developing economies are still predominantly agricultural and resources-based and there are significant gaps in productivity between the traditional and modern sectors in these economies (McMillan et al, 2014). There is also a large informal economy in most developing countries, which is both a symptom and a factor of lower productivity (La Porta and Shleifer, 2014). Globally, around 2 billion workers (60 per cent of the total labour force) were in informal employment in 2019, and 93 per cent of the world's informal employment is in developing countries (International Labour Organization, 2018; International Labour Organization, 2021).

The COVID-19 pandemic is expected to increase job informality and insecurity. According to some estimates, it has led to fewer jobs being available, longer gaps between jobs and reduced work hours, equivalent to a loss of 100 million full-time jobs in 2021 and 26 million full-time jobs in

2022 (International Labour Organization, 2021). The impact on manufacturing sectors depends on the production and trade structure in a country. For example, in Bangladesh, workers in microenterprises and small and medium-sized enterprises (SME) in the textile, apparel and leather sectors were more significantly affected by layoffs (UNIDO, 2021a). In Thailand, the pandemic could lead to the unemployment of 8.4 million people, 1.5 million of whom are in manufacturing, particularly in the malt beverages and automotive industries (UNIDO, 2021b). Firms in countries with high levels of unemployment and underemployment may have fewer incentives to adopt some industry 4.0 technologies to reduce labour costs, delaying their deployment.

Figure 3

Employment in medium-skill jobs by type of activity (Percentage of total civil employment)



Source: UNCTAD secretariat calculations, based on data from the International Labour Organization database.

The pandemic has also significantly affected international investment flows. In 2020, global FDI fell by 35 per cent (UNCTAD, 2021b). Developing economies were relatively resilient, with a decline of 8 per cent, mainly due to robust flows in Asia. The fall in FDI flows across developing regions was uneven, with a drop of 45 per cent in Latin America and the Caribbean and 16 per cent in Africa. Capital expenditure in FDI manufacturing projects was reduced globally by almost 90 per cent in June and July 2020, on a year-on-year basis (East and Kaspar, 2020). In the first half of 2021, FDI rebounded strongly, reaching an estimated $852 billion, but the recovery was uneven, with high-income economies more than doubling quarterly inflows and low-income economies experiencing a reduction of 9 per cent (UNCTAD, 2021c). This slow recovery may reduce opportunities for these regions to benefit from FDI related to industry 4.0.

Private sector decisions regarding participation in GVCs may also be affected by experiences of the COVID-19 crisis. UNCTAD (2020b) has identified four possible trajectories for GVCs as a result of the pandemic, depending on the starting points of the industry, as follows:

- Reshoring, leading to shorter, less fragmented GVCs and greater geographical concentration of value added, primarily in higher technology-intensive sectors (e.g. automotive, machinery and equipment and electronics); this trajectory could make access to and upgrading in GVCs more difficult for developing countries

- Diversification of economic activities primarily affecting services and GVC-intensive manufacturing (e.g. textiles and apparel), increasing opportunities for new entrants with high-quality hard and soft digital infrastructure
- Regionalization, reducing the physical length of supply chains, benefiting developing regions with industries seeking investments in regional markets in sectors such as food and beverages and chemicals
- Replication and creation of shorter value chains and bundling of production stages with more geographically distributed activities and concentrated value added; relevant in particular for hub-and-spoke sectors such as pharmaceuticals and regional processing industries

Of these four potential trajectories, reshoring could hinder the deployment of industry 4.0 technologies in developing countries, given that it is more likely to affect high technology-intensive sectors, which are the leading users of such technologies.

Against this backdrop of persistent inequalities, the slow industrialization trend in most developing countries and the impact of COVID-19 on employment, FDI and GVCs, what might be the effect of the emergence and dissemination of industry 4.0 technologies in manufacturing? Would it facilitate or hinder industrialization in developing countries? Would it reduce or increase inequalities?

To help answer these questions, chapter III examines the concept of industry 4.0, how industry 4.0 technologies are used in manufacturing and the changes such technologies bring about in production processes.

III. Industry 4.0: Concept and main characteristics

Industry 4.0, often interchangeably called the fourth industrial revolution, refers to the smart and connected production systems made possible by new technologies, particularly involving the increased use of automation and data exchanges (UNIDO, 2017). The technologies identified as part of industry 4.0 vary by source, yet it is commonly understood that artificial intelligence, the Internet of things, big data, robotics and three-dimensional printing are integral parts of this new wave (UNCTAD, 2019a; UNCTAD, 2021a).

The use of such industry 4.0 technologies in manufacturing results in smart manufacturing production systems, also known as smart factories or smart production. Smart production integrates and controls production using sensors and equipment connected to digital networks supported by artificial intelligence (UNIDO, 2020). Industry 4.0 in manufacturing entails new forms of interaction between humans and machines through a combination of traditional and new technologies under three main components, namely, hardware, software and connectivity (table 1). Hardware components comprise both modern industrial robots (robots operating separately from workers in the execution of tasks), cobots (robots operating with workers), intelligent automated systems and three-dimensional printers, as well as traditional and less technologically advanced machinery, equipment and tools.

Table 1

Selected industry 4.0 technologies in manufacturing

Technology component	Description
Hardware	
Industrial robots	Programmable machines that carry out actions and interact with the environment via sensors and actuators either autonomously or semi-autonomously; they usually work in the place of and separated from workers, almost entirely automating processes on factory floors (e.g. spot welding robots used in the automotive industry)
Cobots	Robots that work in collaboration with workers, are easily reprogrammable (e.g. by a worker guiding the arm of a cobot through a new path) and used for various tasks (e.g. packaging, palletizing and the automated operation of industrial machine tools in a manufacturing plant)
Three-dimensional printers	Printers that produce three-dimensional objects based on digital information, used for prototyping and for final production in manufacturing; three-dimensional printing (also known as additive manufacturing) can create complex objects with fewer required materials
Software	
Big data	Data sets of a size or type beyond the ability of traditional databases to capture, manage and process; enabling decision-making by tapping into traditionally inaccessible or unusable data
Artificial intelligence	The capability of a machine to engage in cognitive activities typically performed by the human brain; artificial intelligence applications that focus on narrow tasks are already widely available (e.g. making online purchasing recommendations and detecting spam or credit card fraud)
Connectivity	
Internet of things	Internet-enabled physical devices that collect, share and act based on data, with a vast field of application (e.g. wearable devices, smart health, smart homes, smart cities and industrial automation); in manufacturing, the Internet of things connects traditional machinery and tools with actuators and sensors
Actuators	The component of a machine responsible for moving and controlling a mechanism or system, which may be pneumatic, hydraulic, electric, thermal or magnetic (e.g. may be used to measure heat or motion energy to determine the resulting action in a machine)
Sensors	Devices that detect the external and internal conditions of equipment and products and send the information through a digital network, comprising accelerometers, gyroscopes and sensors for information on temperature, humidity, pressure, proximity, level, gas, infrared light and optics

Source: UNCTAD, based on UNCTAD, 2021a, and UNIDO, 2020.

Such technologies are not new to manufacturing; it is the other components, namely, software and connectivity, that make smart production different. The software component comprises more traditional information and communications technology (ICT) such as enterprise systems, computer-aided manufacturing, computer integrated manufacturing and computer-aided design, as well as data analytics based on big data and artificial intelligence. Connectivity is accomplished through digital networks and, more importantly, the industrial Internet of things, by connecting traditional machinery and tools with actuators and sensors, allowing them to collect, transmit and act on data related to the production process. Together, these components create a networked system designed to sense, make predictions about and interact with the physical world and to take decisions, supporting production in real time (UNIDO, 2020).

For example, sensors (Internet of things equipment) can detect particular actions such as temperature change and send the data (big data) for analysis by artificial intelligence. The analysed data and follow-up instructions can then be communicated to optimize the downstream stages of the manufacturing process, such as those using robotics or three-dimensional printers, thereby minimizing downtime or streamlining the production process (UNIDO, 2021c).

Two key principles of industry 4.0 are as follows:

- Automation and decentralization of tasks, predictions and decisions, including automation by robotics and of analyses, predictions, decision-making processes and self-correction, using big data and artificial intelligence without the need for human interference
- Interconnection and the ability of machines, sensors, devices and people to connect and exchange data and information; the Internet of things allows people, devices, algorithms, artificial intelligence and other components to communicate and interact, improving efficiency, productivity and problem-solving capabilities

A A new technological paradigm?

Industry 4.0 is considered a new technological revolution based on digital technologies and connectivity, the integration of technologies and the interconnections between the physical, digital and biological spheres (Schwab, 2017). A technological revolution, or new technological–economic paradigm, has a more profound and broader impact than the introduction of an incremental or radical technology. It changes economies and societies, how people relate with each other and the environment and requires profound institutional changes. The literature on technological change and innovation has identified five technological revolutions since the industrial revolution, each taking around 50 years to unfold (Perez, 2002; Perez, 2010; Perez, 2015). Under the framework followed by the World Economic Forum, the first three revolutions coincide with the industrial revolution, the fourth and fifth coincide with the second and third industrial revolutions and industry 4.0 is therefore the fourth industrial revolution (table 2).

How does the fourth industrial revolution differ from previous revolutions? In the first industrial revolution, water and steam power were used to mechanize production; in the second, electric power, to create mass production; and in the third, electronics and information technology, to automate production (World Economic Forum, 2016). Building on the latter, the fourth industrial revolution is expected to use and combine hardware, software and connectivity, as noted above, to collect and analyse vast amounts of data with active interactions among technologies (UNIDO, 2021c). Not all scholars view industry 4.0 as a new technological paradigm. For example, some are of the view that artificial intelligence, big data, robots and other technologies associated with industry 4.0, and the changes they bring, are part of the fifth technological revolution that started in the 1970s and are not a new paradigm (Perez, 2013; Perez, 2015).

Unlike the third industrial revolution, which has reached many parts of the world, the fourth industrial revolution does not yet have a global reach. As with other technological revolutions, only a few countries are leading this process, underpinned by dynamics such as economies of scale

Table 2
Technological–economic paradigms

Industrial revolution	Technological revolution	New technology or new and redefined industry	Technological–economic paradigm
First	Industrial revolution (from 1771)	Mechanized cotton industry, wrought iron, machinery	Factory production, mechanization, productivity, timekeeping and timesaving, local networks
	Age of steam and railways (from 1829)	Steam engine and machinery, iron and coal mining, railway construction, rolling stock production	Economies of agglomeration, industrial cities and national markets, scale as progress, standardization of parts, energy when needed (steam)
	Age of steel, electricity and heavy engineering (from 1875)	Cheap steel, steam engine for steel ships, heavy chemistry and civil engineering, electrical equipment industry, copper and cables, canned and bottled food, paper and packaging	Large steel structures, economies of scale of plants and vertical integration, distribution of power for industry (electricity), science as a productive force, worldwide networks, universal standardization, cost accounting
Second	Age of oil, automobiles and mass production (from 1908)	Mass-produced automobiles, cheaper oil and oil fuels, petrochemicals (synthetics), internal combustion engine, home electrical appliances, refrigerated and frozen foods	Mass production and markets, economies of scale and horizontal integration, standardization of products, energy intensity, synthetic materials, functional specialization, suburbanization, global agreements
Third	Digital revolution (age of ICT; from 1971)	Cheaper microelectronics, ICTs, the Internet and the digital revolution, control instruments, biotechnology and new materials	Information intensity and instant communications, knowledge as capital, digital platforms and social media, connectivity and mobility, electronic commerce and electronic government, segmentation of markets, economies of scope, flat organizations and network structures, GVCs
Fourth	Industry 4.0 (from the 2010s)	Artificial intelligence, the Internet of things, robots, drones, three-dimensional printing, blockchain, smart production, smart cities, renewable energy	Automation, digital integration, niche markets, local production on demand, sustainability, smart production, decentralization of processes, increased vertical and horizontal integration, reconfiguration of production, self-correction

Source: UNCTAD, based on Perez, 2002, and Schwab, 2017.

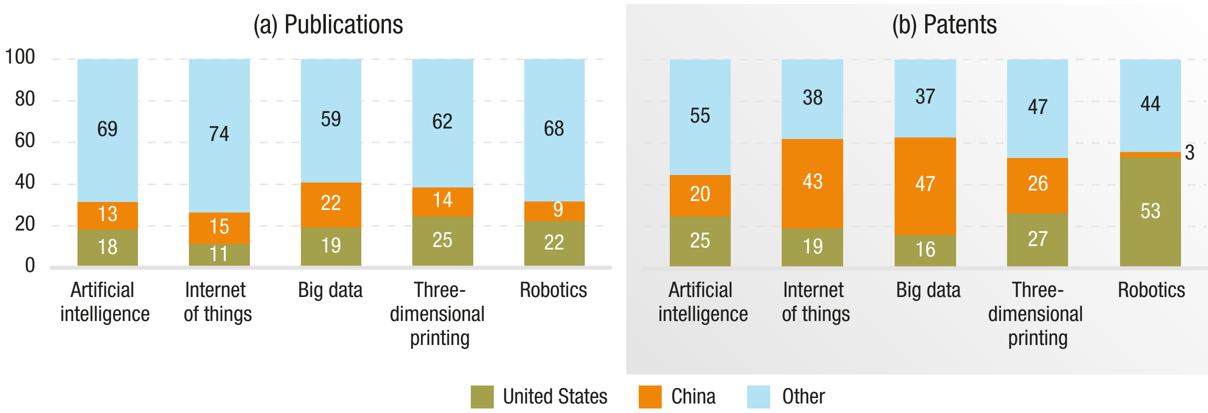
and network effects. Evidence regarding the dissemination in developing countries of industry 4.0 technologies in production is limited, yet recent studies carried out in Senegal and Viet Nam suggest that a large share of firms in developing countries are not yet using industry 4.0 technologies (Cirera, Comin, Cruz and Lee, 2021; Cirera, Comin, Marcio et al, 2021). This pattern seems to occur even in high middle-income developing countries. For example, in Brazil, microenterprises and SME account for over 90 per cent of all enterprises, and most still use second industrial revolution technologies.

Although the technologies and solutions under industry 4.0 may seem to be in the distant future for many, all will be affected by this wave sooner or later, as the fourth industrial revolution is said to have no historical precedent in terms of the speed of spread, the breadth of industries affected and the magnitude and depth of changes it brings (World Economic Forum, 2016). Therefore, it is critical that all countries understand the implications of the fourth industrial revolution in various dimensions.

B Development and use of industry 4.0 in manufacturing

14. A few countries and a relatively small number of firms lead the development of industry 4.0 technologies. China and the United States are dominant in the number of publications and patents, accounting for approximately 26–41 per cent of relevant publications and 45–63 per cent of patents worldwide (figure 4). Similarly, with regard to major provider firms for each technology, United States firms are dominant players in the market, particularly those based on digital technologies (table 3).

Figure 4
Share of publications and patents by technology (Percentage)



Source: UNCTAD, 2021a.

Table 3
Major provider firms by technology

Artificial intelligence	Internet of things	Big data	Three-dimensional printing	Robotics
Alphabet	Alphabet	Alphabet	Three-dimensional Systems	ABB
Amazon	Amazon	Amazon Web Services	Ex One	FANUC
Apple	Cisco	Dell Technologies	Hewlett Packard Enterprise	KUKA
IBM	IBM	Hewlett Packard Enterprise	Stratasys	Mitsubishi Electric
Microsoft	Microsoft	IBM		Yaskawa
	Oracle	Microsoft		Hanson Robotics
	PTC	Oracle		Pal Robotics
	Salesforce	SAP		Robotis
	SAP	Splunk		Softbank Robotics
		Teradata		Alphabet/Waymo
				Aptiv
				General Motors
				Tesla

Source: UNCTAD, 2021a.
Note: Companies from the United States are shown in blue; from China, in orange; from elsewhere, in grey.

One possible explanation for the high penetration rate of United States firms in artificial intelligence, the Internet of things, big data and blockchain technology is the prevalence of cloud computing platforms owned by United States companies. The services covered by such platforms may vary, yet the platforms generally offer a wide range of one-stop services related to artificial intelligence, the Internet of things, big data and others on a pay-as-you-go basis. Concentration of large platforms is likely to continue, as more users prefer to use the services of such platforms rather than to build their own systems and competitors find it difficult to catch up due to network effects, increasing switching costs for users and economies of scale (UNCTAD, 2019b).

As highlighted by UNCTAD in Digital Economy Report 2021: Cross-Border Data Flows and Development – For Whom the Data Flow, China and the United States are leaders in investment and capacity in industry 4.0 technologies and are home to the largest digital platforms, accounting for 90 per cent of the market capitalization, as well as half the world's hyperscale data centres, the highest rates of adoption of fifth-generation networks (over 45 per cent), 94 per cent of all funding of artificial intelligence start-ups in the past five years and 70 per cent of the world's leading researchers in artificial intelligence (UNCTAD, 2021d). However, it is not clear whether China and the United States will extend their advantages in digital platforms into industry 4.0 technologies in manufacturing. As discussed above, an essential technology for industry 4.0 in manufacturing is the Internet of things. Firms from Western Europe have made significant investments in this technology and, together with China and the United States, account for about three quarters of all spending related to the Internet of things (UNCTAD, 2021d).

High-technology manufacturing and research and development capacity is another critical element in the diffusion of industry 4.0. In this regard, UNIDO, in Industrial Development Report 2020, based on the work of Foster-McGregor et al (2019), presents an assessment of the trade and patenting of technologies associated with industry 4.0 for manufacturing and divides economies into four major categories, namely, frontrunners, followers, latecomers and laggards. The frontrunners are the 10 economies with 100 or more global patent family applications in industry 4.0 technologies, together accounting for 91 per cent of all global patent families and almost 70 per cent of exports and 46 per cent of imports, and these are the economies that create, sell and buy products using such technologies.[1] The followers are economies engaged with such technologies but with a smaller share of patents and trade. Some, follower innovators, have a higher percentage of global patents;[2] others, follower exporters, have high values of exports of industry 4.0 technologies;[3] and others, follower importers, have a high percentage of imports of such technologies.[4] Together, frontrunners and followers comprise 50 economies actively engaging with industry 4.0 technologies. Other countries have shown low (latecomers) or no (laggards) levels of activity in patenting or trading such technologies. Moreover, even among the 50 frontrunner and follower economies, industry 4.0 technologies have been adopted in only a few sectors and only a few firms have implemented smart production. Among latecomers and laggards, manufacturing firms mainly use analog technologies and are still in the process of adopting digital technologies, and lack full command of such technologies (UNIDO, 2020).

C Benefits of industry 4.0 in manufacturing

The application of industry 4.0 technologies in manufacturing may result in productivity, energy efficiency and sustainability gains.

In terms of productivity, firm-level surveys in Ghana, Thailand and Viet Nam show that firms that adopt advanced digital production technologies become more productive, even after controlling

[1] China; France; Germany; Japan; Netherlands; Republic of Korea; Switzerland; United Kingdom of Great Britain and Northern Ireland; United States; Taiwan Province of China.

[2] For example, Israel, Italy and Sweden.

[3] For example, Austria and Canada.

[4] For example, Mexico, Thailand and Turkey.

for firm age, investments in research and development and machinery, human capital and GVC participation (UNIDO, 2020). At the firm level, industry 4.0 can be a source of productivity increase through greater visibility of every step of production and the possibility of identifying areas for optimization. For example, one case study in Mexico of a power tool manufacturing plant showed that the use of Wi-Fi radiofrequency identification tags attached to nearly every material in a real-time location system allowed floor managers to slow down or speed up processes and determine how quickly employees completed tasks, resulting in greater labour efficiency by 10 per cent and increases in critical labour resource utilization rates by 80–90 per cent (Enterprise Insights, 2018). Smart production can also increase productivity by reducing downtime and maintenance costs. Firms that have adopted predictive maintenance have saved 20–30 per cent in maintenance costs (McKinsey Global Institute, 2020). Estimates suggest that asset availability may potentially be increased by 5–15 per cent (McKinsey Global Institute, 2018). For example, in Portugal, a vehicle plant that installed vibration and temperature sensors on a machine with a long history of malfunctions was able, through use of the Internet of things, to identify non-conformities early on, allowing for planned replacements and a return of approximately 200 per cent on the initial investment (Fernandes et al, 2021). UNIDO (2020) also notes that industry 4.0 technologies positively affect the productivity of an economy as a whole. Economies actively engaging with such technologies show a faster growth in manufacturing value added than other economies. Importantly, such increases in productivity are associated with increases in employment.

The digitalization of manufacturing processes can offer opportunities for energy savings through the optimization or replacement of technologies that demand greater energy and the introduction of energy optimization functionalities and adaptations in business processes (UNIDO, 2017). Integrating real-time data capabilities in existing tools and systems can result in operational improvements and cost savings for manufacturers. For example, in a case study of a multinational company providing equipment and services to the plastics industry, the use of industry 4.0 technologies reduced power consumption in one plant by around 40 per cent; the company used submeters, that is, sensors measuring the flow of energy, for specific measurements of energy usage and pressure across several pieces of equipment and found that some equipment used power even when not in use, with machinery operating at higher levels of power than needed for optimal performance, and the ensuing changes in production parameters saved the equivalent of over $200,000 per year in energy costs (Efficiency Vermont, 2020). In smart factories employing the Internet of things and robots, improvements in algorithms could result in the continuous optimization of and increases in energy efficiency. For example, at a smartphone manufacturer based in China, changes in algorithms to optimize the operation of robots resulted in an increase in productivity by 50 per cent, without requiring new robots or machines to be purchased (Automate, 2020).

Reducing waste can also improve the sustainability of production. The savings gained from using three-dimensional printing instead of traditional production methods can be substantial in production processes and with regard to the weight and energy consumption of products using parts produced through such printing. For example, additive manufacturing in the production of less flight-critical lightweight parts for aircraft, such as brackets, hinges, seat buckles and furnishings, could result in a reduction of over 50 per cent in the weight of such parts, reducing aircraft mass by 4–7 per cent and fuel consumption by as much as 6.4 per cent (Huang et al, 2016).

IV. Industry 4.0 and inequalities

Given the benefits of industry 4.0 noted in chapter III and considering the disparities in development and diffusion, how might it impact socioeconomic inequalities?

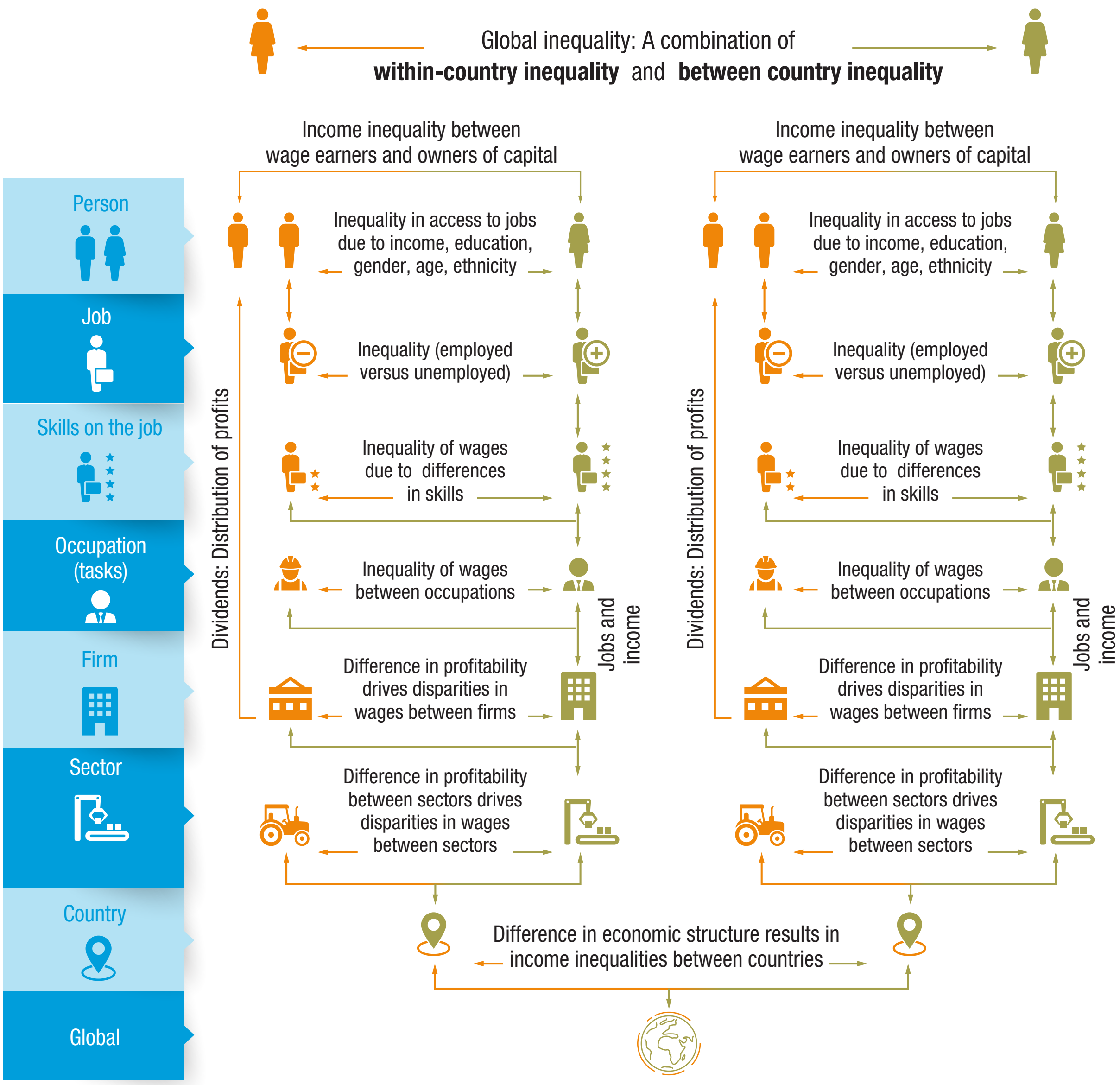
As noted in chapter II, several factors affect inequalities, and technologies are only one such factor. The impact of industry 4.0 on inequalities can be considered from two perspectives, namely, with regard to the economic channels through which technology affects inequalities (profits, wages and jobs); and the framework of long waves of technological revolutions. Each of these perspectives provides some information that can help build a picture of how the development and diffusion of industry 4.0 technologies in manufacturing could impact inequalities within and between countries.

A Effects on inequalities in profits, wages and jobs

At a higher level of analysis, new technologies can affect inequalities through the perspective of people as consumers and users of technologies as final products, such as in using a smartphone to communicate with friends, or users of technologies in production processes, such as in using a smartphone as a business tool (UNCTAD, 2021a). With regard to the use of industry 4.0 technologies in manufacturing and how this can impact inequalities, the relevant perspective of analysis is with regard to production (see UNCTAD, 2021a, chapter 4). From this perspective, technological change and innovation affect inequality through jobs, wages and profits, in a long chain reaction throughout the structure of an economy (Acemoglu and Autor, 2011; Auerswald, 2010; Brynjolfsson and McAfee, 2016; Van Reenen, 2011; Vivarelli, 2014). Technological change creates, destroys and changes jobs, resulting in winners and losers in the process, and international trade transmits these effects across countries. It also impacts profits and wages, which affect inequalities between wage earners; between wage earners and the owners of capital; and between the owners of capital. Inequalities related to profits, wages and jobs are common and could arise at different points in the economic structure, for example, among occupations, firms and sectors (figure 5).

The resulting income inequality between any two people is a composition of the various disparities. In a stylized manner, this may be described as follows: inequalities first emerge between those who have a job (and thus have a labour income) and those who are unemployed. Among the former, inequalities can further arise due to differences in wages. Such disparities result from differences in skills in the same occupation, in occupations within a firm, between firms within a sector and between sectors within a country (Barth et al, 2016; Hartmann et al, 2017; Juhn et al, 1993; Mueller et al, 2017). At each of these levels, there is a hierarchy of competence and competition for the distribution of the rewards of production. For example, within an occupation, some skills are considered more productive, are in greater demand or are less available, and can command a higher wage (Juhn et al, 1993; Keep et al, 2006; Leuven et al, 2004). Within a firm, some occupations are considered more productive than others and are rewarded with higher wages. Some professions can also have control over a productive or social bottleneck (e.g. some regulated professions) and thereby earn some form of rent (Bol and Weeden, 2015). Within a country, the more innovative and productive sectors and firms can claim higher profits and pay higher average wages (Guadalupe, 2007). Income inequalities also emerge between wage earners and owners of capital. Profits of firms are distributed to investors through dividends. Professional workers in some firms may also be remunerated with equity (company shares) as part of compensation and thereby also become capital owners. The increasing financialization of the economy and potential conflicts of interest in the determination of executive pay in large corporations are significant factors in labour income inequality (Lin and Tomaskovic-Devey, 2013). However, how profits are divided between labour and capital depends on social and economic frameworks, how different groups in societies negotiate the division of power and the levels of income and wealth inequality that

Figure 5
Inequalities from the perspective of production



Source: UNCTAD, 2021a.

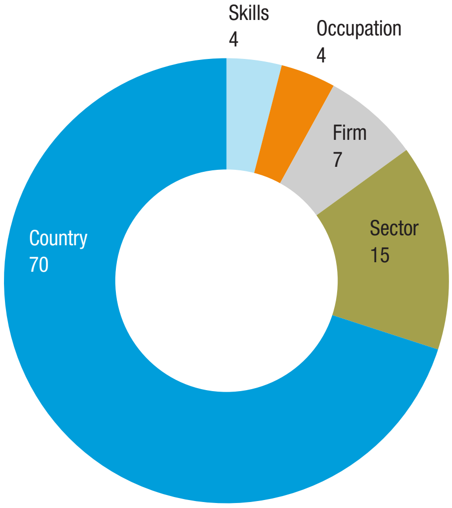
are considered tolerable. At the same time, vertical inequalities (rich versus poor) and horizontal inequalities (between groups defined by cultural or personal characteristics) can affect access to education and choices of occupations, firms and sectors in which to work, which then affect opportunities to work and levels of income. For example, in some places and family situations, only boys are sent to school and girls remain at home to deal with household tasks and therefore do not have the same access to education and opportunities to develop skills required to get a job. In addition, some industries such as construction and mining may, in some countries, be considered sectors for men, and women may not work in these sectors, reducing their job options. Inequality is also seen in differences in the economic structures in countries. In a country, existing sectors and their contribution to output and employment characterize the economic structure and level of productive capacities and, therefore, average productivity and income. Differences in economic structures therefore drive inequalities between countries.

The contribution of each of these elements to income inequality in a particular country is conditional on many factors, such as labour, social and economic policies, the level of development and the size of sectors and firms. For example, a study of the significant decrease in earning inequality in Brazil in 1996–2012 found that firm effects were not only significant but also positive; they accounted for 40 per cent of the total decrease in inequality, particularly through a decline in firm productivity-pay premiums (Alvarez et al, 2018). A study of inequality in the United States in 1978–2013 found that two thirds of the rise in the disparity of earnings was due to an increase in the dispersion of average earnings between firms, compared with the other one third, which occurred within firms (Song et al, 2019). In contrast, a study of inequality in Sweden found that there was a smaller contribution from between-firm differences in wages, attributed to national labour market institutions that reduced the scope for variation in wages between firms, through collective wage agreements (Akerman et al, 2013).

The literature can provide a rough idea of the average magnitude of the contribution of each level to inequality. Estimates suggest that, in general terms, country of birth explains around 70 per cent of the variation in global income, relevant not only in terms of magnitude but also because 97 per cent of the global population remain in their country of birth (Milanovic, 2015). Sector-level inequalities contribute about 20 per cent of income differences of workers within a country; and firm-level differences, about 10 per cent. Differences in occupation and skills, as measured by levels of literacy and numeracy, account for about 10 per cent of cross-country differences in income (Devroye and Freeman, 2001; figure 6). Therefore, in low-income developing countries and the least developed countries, a focus by Governments on reducing sectoral inequalities and cross-country inequalities would be more effective. For countries at the technological frontier, a focus on reducing firm-level and occupational inequality would result in higher gains.

Figure 6

Contribution of different sources of inequality to global income inequality (Percentage)



Source: UNCTAD secretariat calculations, based on Milanovic, 2015, and Devroye and Freeman, 2001.

With regard to industry 4.0 in manufacturing, new technologies are used mainly in process innovation to increase productivity. Therefore, the initial direct impact of industry 4.0 is on inequality related to firm productivity within sectors and disparity in wages due to changes in occupations and tasks.

Manufacturing firms deploying industry 4.0 technologies and introducing new products can earn greater profits than other firms in the same sector due to temporary monopolistic situations of being the only providers of a new good or service. Process innovation using new technologies is expected to save labour and reduce costs and potentially prices, increasing market shares and profits. These higher profits, either through product or process innovation, could spill over to higher average wages in firms, contributing to income inequalities within the production system. At the same time, Schumpeterian rents (higher profits earned by innovators) are a critical incentive for innovation. In most sectors, however, although innovation creates winners and losers among firms, inequalities are not permanent. Competition creates incentives for other firms in the same industry to adopt industry 4.0 technologies for smart production, and differences in firm profitability tend to be reduced.

The introduction of smart production can create, change or replace occupations within a firm. One hypothesis of how technology is incorporated into occupations is skill-biased technological change, in which technology complements skilled workers, with higher skill levels associated with greater gains from adopting industry 4.0 technologies in manufacturing (Acemoglu and Autor, 2011). However, despite its success in explaining many decades of data, this hypothesis cannot explain the recent phenomenon of job polarization, which is seen in a range of developed countries (Autor et al, 2015; Dauth, 2014; Goos et al, 2014; Graetz and Michaels, 2018; Michaels et al, 2013). A different hypothesis is routine-replacing technological change, which predicts increased demand for labour in non-routine tasks relative to routine tasks (Acemoglu and Autor, 2011; Autor, 2013; Autor and Handel, 2013). Smart production is also expected to benefit workers performing non-routine tasks, in both manual and cognitive jobs, which can affect both high- and low-paid jobs. Workers performing routine tasks are expected to face further pressures from ever more capable machines and artificial intelligence software.

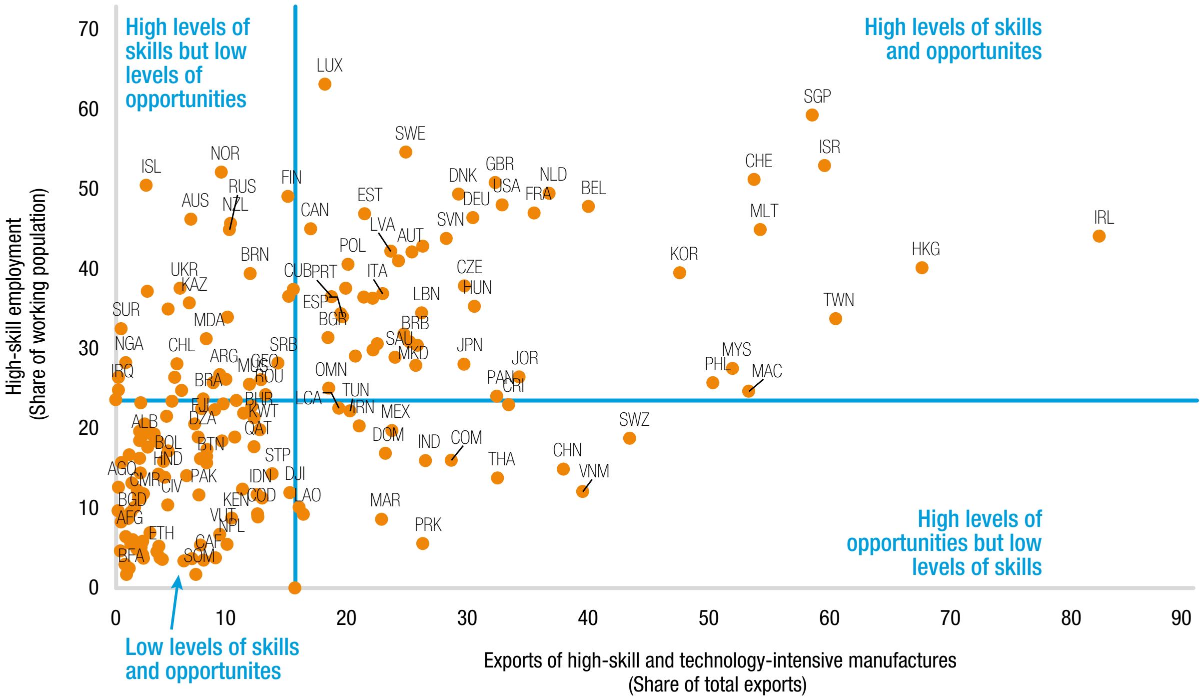
At the global level, countries with more manufacturing sectors in which more firms adopt industry 4.0 technologies could expect to experience greater increases in productivity than other countries. At the same time, skilled workers may be better prepared to transition to smart production and less negatively affected by changes in occupations and tasks. The performances of economies in exports of high-skill and technology-intensive manufactures and in high-skill employment can therefore indicate the economies that may initially be better positioned to benefit from the diffusion of industry 4.0 technologies, and it is possible to assess whether this pattern tends to increase or reduce inequalities between countries (figure 7).

As shown in the figure, a simplified version of this analysis considers how countries perform in high-skill and technology-intensive manufacturing exports (as a share of total exports) and high-skill employment (as a share of the working population), thereby dividing countries into four groups. One group of economies, including the United States and many economies in East Asia, Europe and South-East Asia, comprises economies with high levels of opportunity for the diffusion of industry 4.0 technologies, due to their specialization in high-skill and technology-intensive manufacturing, and with large shares of high-skill employment. Eight economies in this group[5] show above-average performance levels and may benefit the most from industry 4.0 in manufacturing relative to their populations and exports. A second group of economies, including, for example, China, India, Mexico, Thailand and Viet Nam, comprises economies with high levels of opportunity given their share of high-technology exports, but shares of high-skill employment that are below the global average, indicating that the lack of skills may be an obstacle in broadly diffusing industry 4.0 technologies in manufacturing. A third group of economies, including, for example, developing countries with a greater reliance on commodities in the economic structure, such as Argentina, Brazil, Chile, Kazakhstan and Nigeria, comprises economies with shares of high-skill employment that are above the global average, indicating the potential for workers to adapt to industry 4.0 in manufacturing, but low levels of opportunity in terms of firms in high-technology sectors, and these economies may find it difficult to broaden the use of industry 4.0 technologies in manufacturing beyond the pockets of high-skill and technology-intensive manufacturing sectors. A fourth group

[5] Ireland; Israel; Malta; Republic of Korea; Singapore; Switzerland; Hong Kong, China; Taiwan Province of China.

Figure 7

Determining which economies may initially be better positioned to benefit from industry 4.0: Indicators of readiness
(Percentage)



Source: UNCTAD secretariat calculations, based on data from the UNCTADstat and the International Labour Organization databases.
Note: The solid lines represent the global averages under these two indicators. Data labels use International Organization for Standardization economy codes.

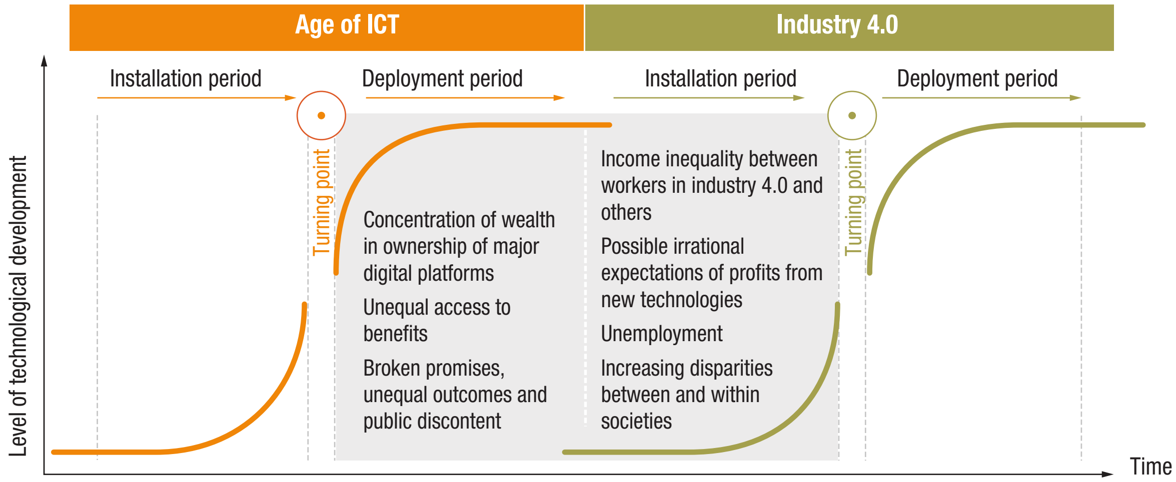
of economies, including most developing countries, comprises economies with shares under both indicators that are below global averages; they do not have many high-technology sectors in the economic structure nor many high-skill jobs, and the diffusion of industry 4.0 technologies could therefore be slower. The analysis thus suggests that the initial diffusion of industry 4.0 technologies is more likely to increase inequalities between countries.

B Effects on inequalities through technological revolutions

Many crises and long-term factors can affect inequality, including wars, epidemics and the effects of trade and globalization. One such factor is the impact of technological revolutions. The framework of the interrelationship between technological revolutions and financial capital highlights how different phases in the surge of a new technological–economic paradigm can affect inequalities in countries at the centre of the technological revolution (Perez, 2002; Perez, 2010). The two main phases are the installation period of a new paradigm, which is driven by the supply of innovations in the core industries exploring potential solutions with the new technologies, and the deployment phase, in which the new technologies are applied to other sectors (figure 8).

The first phase entails the installation of the new technological paradigm, starting in a few sectors and places at the centre of the technological wave, such as the technology sector in the United States during the installation phase of the age of ICT. In this phase, there is the potential for increasing income inequality between workers in the core industries of the new paradigm, including finance, and others. In particular, the financial sector may fuel possible irrational expectations of profits from the new technology sectors and could decouple from the real economy in search

Figure 8
Technological revolutions and inequalities



Source: UNCTAD, 2021a.

of increasingly greater gains. The final part of the installation phase may therefore be marked by sharp inequalities. The decoupling of finance and productive capital can lead to financial crises that pave the way for changes in society and institutions, to adapt to the new technological–economic paradigm.

The second phase entails the deployment of the technological paradigm and tends to be a time of more equitable participation in the growth of an economy and the distribution of gains. However, once new technologies have become a part of society and economy at the end of the deployment phase, this may be a time of social discontent, following the realization that the social progress promised through the use of new technologies has left many people behind. It may also be a period of merging and concentrating power in a few firms at the core of the paradigm, giving rise to significant fortunes in the hands of a few.

If this framework is applied to the present, the impact of industry 4.0 on inequalities depends on whether the world is at the beginning of a new technological–economic paradigm or whether industry 4.0 is a continuation of the age of ICT.

In the first scenario, countries at the technological frontier are at the end of the deployment phase of the age of ICT and the start of the installation phase of the age of industry 4.0. This could be a period of discontent with the unequal outcomes and unrealized promises of widespread progress through the use of ICTs, as well as with the significant concentration of wealth among the owners of the major digital platforms. At the same time, there are concerns about the possible impact on inequality caused by new technologies. Such effects have not yet materialized given that the new paradigm is in an early phase, yet some have foreseen the ways in which it could increase disparities through impacts on production and consumption. Among developing countries, historically, the installation phase of a new technological paradigm has provided opportunities for some countries to catch up and others to forge ahead. For example, in the installation phase of the age of ICT, some countries in Asia were able to catch up technologically and economically by developing capabilities to enter the ICT sector in both hardware and software, resulting in structural change towards technology-intensive export sectors (Fagerberg and Verspagen, 2021). Similarly, the installation phase of industry 4.0 could take place when countries entering sectors associated with the new paradigm experience greater growth and catch up to the technological frontier. An increase in within-country inequality in countries at the technological frontier may be seen in the next couple of decades. At the same time, some developing countries may catch up and others may forge ahead, reducing inequality between countries. However, most developing countries would still need to catch up with the previous technological paradigms before progressing to industry 4.0.

In the second scenario, a period of increasing prosperity in developed countries could take place, with the increase in productivity currently experienced in the technology sectors taking place in other, traditional sectors of the economy through the diffusion of industry 4.0 technologies. However, this could also be a period of consolidation of the technological gap between countries at the technological frontier and others. Historically, catch-up trajectories tend to occur in the installation, not deployment, phase of a paradigm. In this scenario, therefore, there may be lower levels of inequality within countries at the technological frontier, but a persistent gap between countries.

Both scenarios offer a dismal prospect for most developing countries unless effective action, supported by the international community, is taken to promote and support further economic diversification towards more technologically intensive industries and processes and, at the same time, attempts to enter the sectors associated with the new paradigm.

V. Particular challenges

In addition to the potential increase in income inequality between countries due to temporal and geographic disparities in the diffusion of smart production, industry 4.0 can lead to some other potential challenges. At the centre of these challenges are the following two features of industry 4.0 technologies (Department of Economic and Social Affairs, 2020):

- Labour-saving: Allows employers to produce the same amount of output with less labour (substituting labour with capital) through automation, therefore reducing the need for labour
- Skill-biased: Relatively high levels of skill are required to utilize the technology and productivity of and demand for high-skilled workers increases more compared with low-skilled workers

A Displacements of workers and wage inequality

With regard to the labour-saving feature, there has been a proliferation of predictions about how many jobs will be lost due to industry 4.0 technologies. Most estimates conclude that there is a risk that many jobs will be lost and that the risk is more acute in developing countries, which tend to have more routine-type jobs (Department of Economic and Social Affairs, 2020). For example, research suggests that in developing countries, two thirds of all jobs are susceptible to automation (World Bank, 2016). In developed countries, most estimates suggest that medium-skilled jobs that are more routine have a higher risk of disappearing (Department of Economic and Social Affairs, 2020). However, most alarmist scenarios do not consider that not all tasks of a job are automated and, importantly, new products, tasks, professions and economic activities are created throughout an economy (UNCTAD, 2021a). Job displacement could occur initially (partial equilibrium), but in considering the longer term (general equilibrium), it may be seen that new technologies could bring new demands and therefore create more jobs, as in previous industrial revolutions.

There are several compensatory effects that may not have been considered. For example, employment could increase through the following: additional employment in the capital goods sector; decrease in prices; new investments; decrease in wages; increase in incomes; and introduction of new products. The compensatory mechanism through the introduction of new products is the most significant way in which to counterbalance the labour-saving tendencies of process innovation and, in relation to the impact of technological change in developing countries, the main channels of effect are trade and FDI and technology transfer, which depend on the absorptive capacities of countries (Vivarelli, 2014).

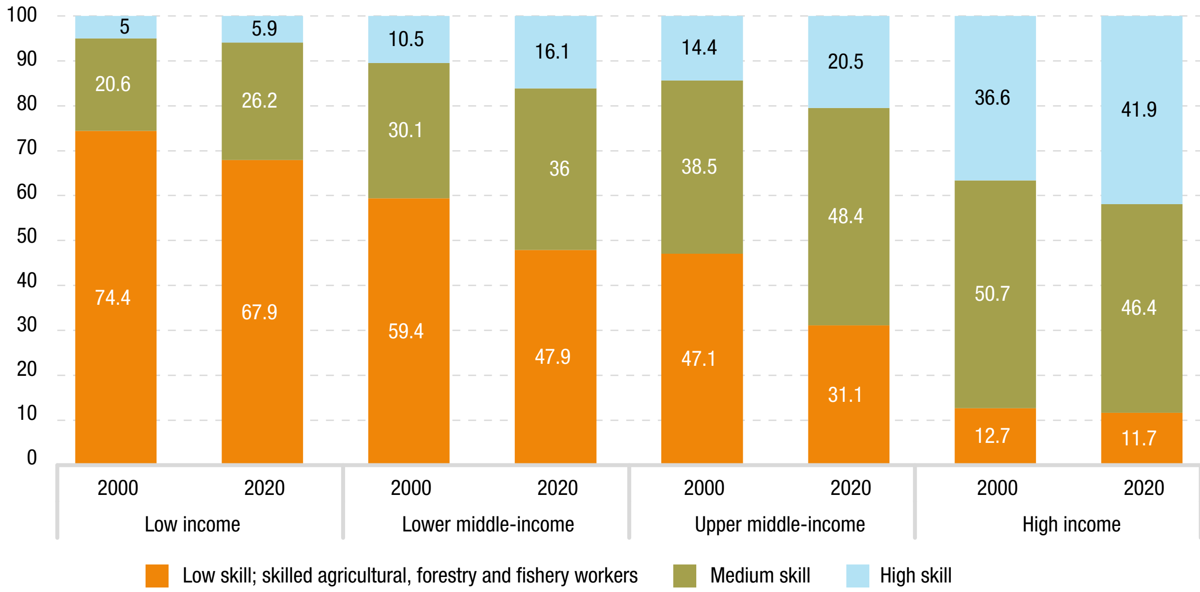
Displacement could also occur at the level of tasks belonging to workers rather than among workers, which could lead to, for example, the automation of manual and routine tasks while retaining workers in the workforce (UNIDO, 2019). Developing countries, in general, might be more significantly affected by automation, yet countries have different factor endowments, comparative advantages and sector compositions and, combined with uncertainty as to which sectors may be more prone to job displacement (manufacturing could be prone to automation through the use of robotics but services could be prone to automation through the use of artificial intelligence and other technologies), overall effects might not be as straightforward as the estimates suggest (UNIDO, 2019).

Empirically, there has not been strong evidence that suggests large-scale job displacements due to industry 4.0 technologies, as indicated by estimates. In fact, at least in the United States, in which the adoption of industry 4.0 technologies is advanced and which is also home to world-leading technology companies, labour productivity growth has slowed in recent years, which is the opposite of what estimates might suggest, as the replacement of labour with capital should increase labour productivity per worker (Krugman, 2021). In the United States, during the first months of the pandemic, there was a trend of increasing automation due to the shortage of labour, but the mid- to long-term effect and persistence of this trend remains to be seen (Ding and Molina, 2020).

Aside from the displacement of workers, industry 4.0 technologies could also potentially affect wage inequality. The skill-biased nature of technologies could create more demand for high-skilled workers and less demand for low-skilled workers, pushing up wages for the former and lowering wages for the latter. This difference in wages, or the skill premium (or return to education), has been widening in recent decades despite the growth in educational attainments among the workforce (Department of Economic and Social Affairs, 2020). This may lead to the belief that the speed of technological development has been faster than growth in educational attainment (the race between technology and education) as higher educational attainment should reduce the skill premium. On average, higher-income countries have a larger percentage of high-skilled workers and lower-income countries have a larger percentage of low-skilled workers (figure 9); the widening skill premium due to industry 4.0 could therefore work to the disadvantage of lower-income countries at the global level.

Figure 9

Employment by skill level as share of total civil employment (Percentage)



Source: UNCTAD, 2021a.

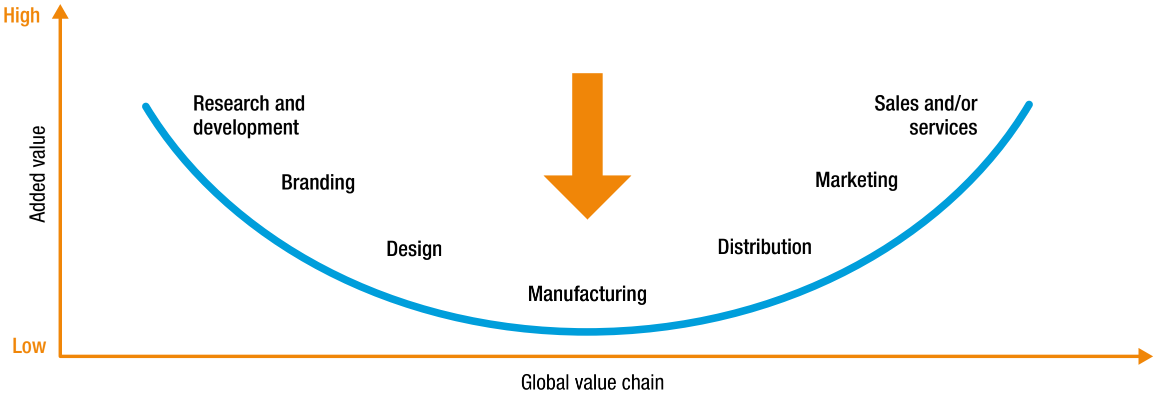
It is important to note that this analysis assumes that wages are always equal to worker productivity or skill levels, yet there are other determinants of wages. For example, declining membership among labour unions and weaker bargaining power could lower wages at given productivity levels (UNIDO, 2019). In addition, dominant employers could pay lower wages to employees, exercising monopsonist power in the labour market. At the higher end, there has been an emergence of leading managers who are considered highly skilled yet have significantly high wages, which their productivity level might not justify (Department of Economic and Social Affairs, 2020). All of these elements could factor into an increased skill premium and, therefore, the net effect of technological development on this premium is difficult to measure.

B Reshoring of production and restructuring of foreign direct investment and global value chains

With the emergence of industry 4.0 technologies, the landscape of FDI and GVCs may change. Through the use of labour-saving technologies, labour-intensive work in developing countries could be replaced by the use of technologies such as artificial intelligence and robotics in developed countries, reducing the comparative advantage of the former in manufacturing within GVCs, which could lead to the reshoring of production from developing countries to developed countries. Industry 4.0 technologies could increase the comparative advantage of developed countries in skill-intensive and capital-intensive industries, including intangible components that have become prevalent due to digital technologies. Combined, these effects could deepen the "smile curve" of GVCs (figure 10), with developed countries adding more value and developing countries losing shares of value addition within GVCs (UNCTAD, 2018a).

Figure 10

Deepening the global value chain smile curve



Source: UNCTAD secretariat calculations, based on UNCTAD, 2018a.

On the other hand, firm-level decisions on FDI are based on not only labour costs but also other factors such as market access, favourable policy environments and incentives. Whether reshoring would occur also depends on implementation factors, such as switching costs, inertia and the coordination complexity associated with reshoring (UNCTAD, 2018a). Digital technologies could also encourage the participation of more firms in GVCs by bridging distances and reducing costs related to trade and assembly (World Trade Organization, 2019). A recent study states that reshoring remains a rare phenomenon but also finds an association between the adoption of industry 4.0 technologies in developed countries and reshoring (International Labour Organization, 2020). Evidence from 2,500 firms from eight countries in Europe[6] shows that reshoring is not common; only 5.9 per cent of the firms surveyed had reshored and 16.9 per cent had offshored, and the main reason for reshoring from emerging economies was flexibility in logistics rather than labour costs (UNIDO, 2020).

C Protecting workers in the industry 4.0 era

As in previous industrial revolutions, an expected main characteristic of the fourth industrial revolution is a boost in productivity. In the latter, this can be achieved due to the development of artificial intelligence, the Internet of things and big data, which allows for the workforce to be managed more effectively. At the core is the large amount of data collected using sensors, wearable devices, global positioning systems, logs of worker performance and behaviour and the ratings and evaluations provided by users, combined with analyses conducted through the use of algorithms and artificial intelligence (De Stefano, 2018). The use of such data has the potential to improve productivity and enhance benefits to employees, yet there are several concerns, as follows: surveillance and monitoring practices can lead to intrusions into worker privacy; algorithms may be developed based on a narrow vision of productivity and efficiency (often to implement just-in-time work practices) without consideration of the hidden costs associated with tasks, resulting in a failure to capture the actual performance of the workforce; and algorithms and artificial intelligence

[6] Austria; Croatia; Germany; Netherlands; Serbia; Slovenia; Spain; Switzerland.

(particularly self-learning intelligence) are prone to discrimination and unneutral outcomes and may be biased, easy to manipulate, reflect cultural or gender-related biases and other prejudices and preferences and contain errors, with little transparency (UNCTAD, 2021a). Given such concerns, collective agreements have been implemented in various countries to regulate the use of technology in monitoring workers and directing work, aimed at preserving human dignity and the health and safety of workers; such efforts are still at an early stage (De Stefano, 2018; De Stefano and Aloisi, 2018).

D Gender-related implications

Industry 4.0 could bring about important changes related to power, knowledge and wealth and may impact the pursuit of gender equality. For example, there are nearly four times as many women (26 per cent) as men (7 per cent) employed as clerks or service workers, which are occupations considered more likely to be replaced by computers and automation.

Will the fourth industrial revolution be "gender-blind"? It is critical to examine the impact that industry 4.0 might have through a gender perspective. How will society, and women in particular, be affected by this accelerated pace of technological change? Given the current state of technology, 10 per cent of the workforce, or 54 million workers in 30 countries,[7] is at a high risk of being displaced by technology within the next two decades and a greater proportion of women (11 per cent) face a high risk of automation compared with men (9 per cent), with 26 million women's jobs potentially at stake in these countries (International Monetary Fund, 2018). As discussed in chapter V, however, these estimates do not account for new jobs and other compensatory effects; nevertheless, they illustrate the fact that women are usually more at risk of being displaced than men.

Artificial intelligence is at the forefront of industry 4.0 and it is therefore useful to consider gender-related trends in the sector. Machine learning data, algorithms and other design choices that shape artificial intelligence systems tend to reflect and amplify existing biases and prejudices, especially with regard to gender, because women are underrepresented in this sector. Women account for only 26 per cent of data and artificial intelligence-related positions in the workforce (World Economic Forum, 2020). Higher concentrations have been observed in some countries,[8] yet they are still below 30 per cent, with many countries reporting 18 per cent or less of women in the sector (World Economic Forum, 2018).

The effects of new technologies need to be better understood, particularly artificial intelligence, as such technologies have the potential to reverse momentum in gender equality through effects on women's employment and labour force participation and access to financial resources, thereby affecting women's economic and livelihood opportunities. Such an understanding can help in being able to address how industry 4.0 could be used to narrow the gender gap.

[7] 28 member countries of the Organisation for Economic Co-operation and Development; Cyprus; Singapore.

[8] Italy; Singapore; South Africa.

VI. Harnessing industry 4.0 for inclusive and sustainable development

This chapter discusses the actions that Governments, the private sector and other stakeholders can take in order for developing countries to be able to benefit from industry 4.0, contributing to national development priorities and accelerating progress towards achieving the Sustainable Development Goals. The main policy recommendations are accompanied by concrete examples provided by CSTD members and United Nations entities of strategies, policies, programmes and policy instruments focused on industry 4.0.

Several developing countries have undertaken the digitalization of industry and begun the partial adoption of industry 4.0 technologies. However, Governments face various challenges related to infrastructure, support institutions, appropriately skilled labour and the general preparedness of key industries. One challenge faced by Governments with regard to the preparedness of industries is the need to cultivate an understanding of future scenarios and remain informed about potential implications, opportunities and risks. There is also the challenge of ensuring that adequate infrastructure, including energy and ICT, is in place to support the adoption and implementation of industry 4.0, enabling countries to reap the benefits of technological change. Other challenges that Governments may face in promoting industry 4.0 to accelerate progress towards the Goals relate to a widening technology and knowledge gap, its implications for skills, gender equality and increasing inequalities, which will need to be managed to increase societal acceptance for change.

Strategic responses to the deployment of industry 4.0 technologies are highly contextual, reflecting national priorities and capacities for resource mobilization and levels of industrialization, digital infrastructure and technological and productive capabilities, as follows (UNIDO, 2020):

- Developed countries with advanced manufacturing bases are already at the frontier of technological adoption and have focused policy responses on sustaining and regaining manufacturing leadership
- Emerging developing countries have sought to narrow the technological gap, increase competitiveness and expand participation in higher value added parts of GVCs; policy responses have focused on fostering innovation and technological adoption in manufacturing and some of these countries have firms at the technological frontier deploying, or ready to deploy, industry 4.0 technologies; and a challenge is to facilitate deployment in traditional manufacturing sectors of the economy
- Less technologically advanced and less diversified developing countries have fewer sectors exposed to the deployment of industry 4.0 technologies and lower levels of technological and innovation capacities in general; they should focus on diversifying economies, increasing the share of manufacturing in total output and establishing the required conditions for building digital infrastructure and skills to prepare for the deployment of industry 4.0 technologies

Critical policy areas that stakeholders in developing countries, regardless of technological level, should consider in facilitating the deployment of industry 4.0 technologies in manufacturing, to reduce technological and income inequalities between countries and ensure that industry 4.0 contributes to reducing inequalities within countries, are addressed in the following sections.

A Creating preconditions for harnessing industry 4.0

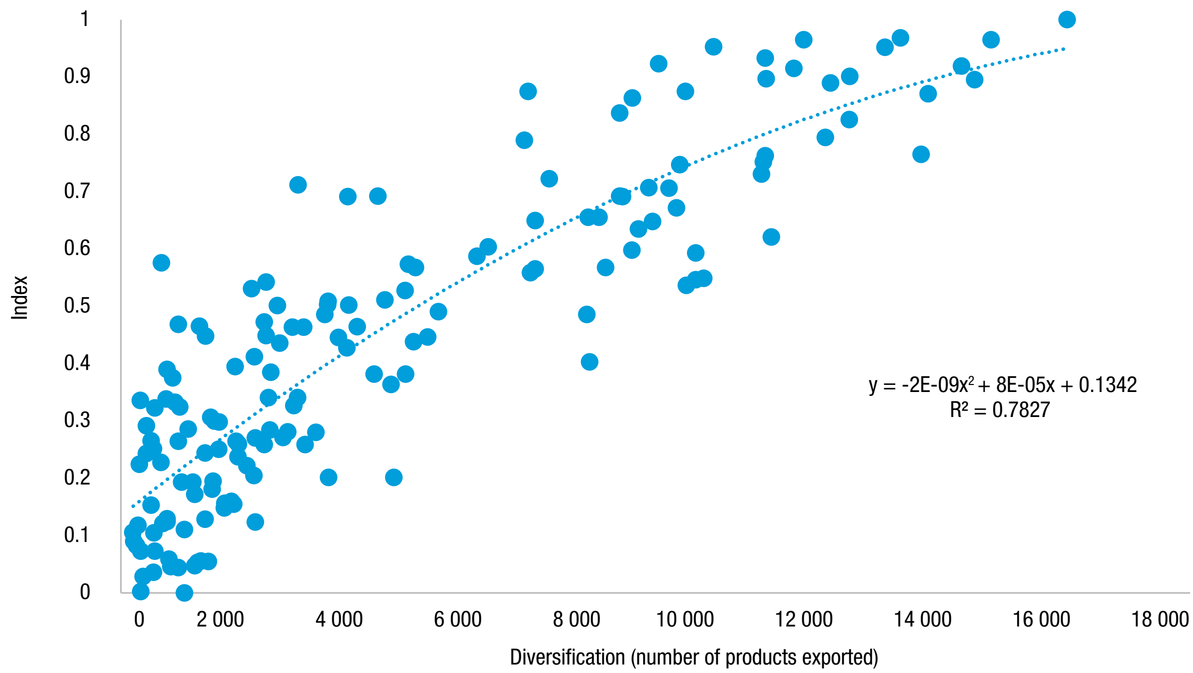
Developing countries will not be able to broadly harness industry 4.0 for development if they have weak industry (manufacturing) and digital infrastructure and low levels of skills. In the absence of these elements, few firms in developing countries will be able to use industry 4.0 technologies and even fewer will be able to adopt the use of smart production. While working to put in place the preconditions for industry 4.0, developing countries should also develop the framework conditions required to deploy industry 4.0 technologies in manufacturing, including developing national strategies that direct, in a coherent and coordinated manner, the development and deployment of industry 4.0; creating a multi-stakeholder mechanism institutionalizing a participatory approach to fostering industry 4.0; building international cooperation to accelerate the transfer of technology and know-how; and setting an enabling intellectual property regime (UNIDO, 2020).

Diversifying the economy and building a manufacturing sector

As discussed in chapters III and IV, the diffusion of industry 4.0 is only beginning in developed and emerging countries. There is a way to go before it becomes a reality in the production structure in developing countries, particularly low-income countries and the least developed countries. This is due to the fact that waves of technological change start in one or two of the most technologically advanced countries, then begin to spread around the world, first to other advanced economies, then to more complex sectors in emerging economies and, only after some time, to more peripheral economies. One reason for this is that less diversified developing countries have production structures far from the core sectors of the new technological paradigm (e.g. computers and digital products), and it may take longer to deploy new technologies in production bases if their economies are not diversified. A high level of diversification is associated with greater readiness to use, adopt and adapt frontier technologies, based on the UNCTAD frontier technology readiness index (figure 11). Therefore, promoting diversification can facilitate the deployment of this new technological wave.

Figure 11

Association between UNCTAD frontier technology readiness index and diversification of economies, 2019



Source: Freire, 2021.

Note: The number of products exported is based on United Nations standard international trade classification (5-digit level), revision 3, disaggregated by unit value using the methodology in Freire, 2017.

To successfully facilitate the broad diffusion of industry 4.0 technologies and harness the benefits, developing countries should diversify production bases by mastering existing technologies (automation machinery and equipment); otherwise, they risk being left behind. The approach depends on the level of economic development and economic structure in each country.

In practice, the focus of a national policy framework should be on the policy objectives more related to the already-installed production base and the maturity of the technology in use. For example, less diversified countries may focus on diversifying economies, on technological learning and on mastering the technologies in use in the sectors that the country is attempting to promote, for increased jobs and value addition. In this regard, developing countries, in particular, low-income countries and the least developed countries, should go back to the basics of economic development, focusing on development strategies and programmes in diversifying economies, shifting output of and employment in economic activities from low value added sectors to high value added sectors. The State plays a crucial role in pushing for and facilitating the emergence of productive capacities in the industrial sector, particularly, but not necessarily exclusively, in the private sector. Governments should facilitate the identification of potential sectors for diversification and the entry of businesses into these sectors, promote key potential new sectors of national interest (e.g. by targeting job creation, food security, energy security, industrialization and digital transformation), strengthen the effectiveness of innovation systems to support diversification, build coherence between STI policy and other economic policies (e.g. industrial, fiscal, trade-related and educational) and involve a wide range of actors. Concerns about the impact of production on the environment and related to the risks of climate change should be at the centre of such strategies and programmes, promoting diversification and technological upgrading towards greener manufacturing and a circular economy.

Developing a digital infrastructure

Digital infrastructure is a precondition for promoting the use, adoption, adaptation and development of industry 4.0 technologies by enterprises and businesses, including SME. Physical infrastructure, coupled with digital technologies, allows an economy to digitalize economic activities (Brennen and Kreiss, 2014). The deployment of industry 4.0 technologies requires digital infrastructure, platforms and data. Digital infrastructure is complex and generally includes ICT networks (core digital infrastructure for connectivity); data infrastructure (data centres, submarine cables and cloud infrastructure); digital platforms; and digital devices and applications (UNCTAD, 2019b). The quality of Internet access directly affects the ability of firms in developing countries to use digital technologies. Examining the relationship between broadband availability and skills upgrading in Africa shows evidence that, for example, fast Internet has led to productivity improvements in Ethiopia and increases in exports from several countries (Hjort and Poulsen, 2019). Decreased telecommunications costs and faster Internet connections can enable SME to overcome information-related barriers to entry and market failures.

However, there is a substantial digital divide at the global level between developed countries and developing countries and between developing countries and the least developed countries (Banga and Te Velde, 2018). This affects disparities between countries, as manufacturing activities are becoming gradually digitalized, further increasing the trade competitiveness of developed countries (UNCTAD, 2017). In the least developed countries, small firms attain 22 per cent of the connectivity score of large firms, compared with the rate for small firms in developed countries, at 64 per cent (International Trade Centre, 2015). A persistent lack of Internet access presents an obstacle to the development of SME in developing countries, creating unequal competitive conditions compared with developed country counterparts (International Trade Centre, 2021). In addition, firms in many low-income developing countries also face significant electricity-related constraints that impact the ability to use the Internet, with operations restricted due to frequent power outages, for example in many countries in sub-Saharan Africa (see Cirera, Comin, Cruz and Lee, 2021, for a discussion in the context of Senegal). The extent of digitalization also varies significantly across developing countries and the least developed countries. For example, in Senegal, 75 per cent of large firms have Internet access but only 34 per cent of firms with more than five employees have access (Cirera, Comin, Cruz and Lee, 2021). Many companies in sub-Saharan Africa are not connected to the Internet (Guerriero, 2015). Compared with countries in Asia, countries in Africa have, on average, significantly lower download and upload speeds and face greater delays in processing network data (Banga and Te Velde, 2018). Furthermore, the least developed countries are largely not making productive use of broadband technologies (International Telecommunication Union (ITU), 2021).

Having easy Internet access does not necessarily mean companies will embrace industry 4.0 technologies, as illustrated by experiences in the diffusion of electronic commerce. In 2004, the results of sector-specific surveys in Bangladesh, Egypt, Kenya, Morocco, Nigeria, Senegal, South Africa and Uganda suggested that, while Internet access was relatively high among businesses, the adoption of electronic business processes was low (UNCTAD, 2004). In 2021, a survey in Viet Nam led to similar results, whereby despite almost universal access to the Internet, the percentage of firms with websites, social media and cloud computing usage remained small (Cirera, Comin, Marcio et al, 2021). This highlights the challenge of low technological and innovation capacity in developing countries. Many developing countries with low levels of technological development have only limited mechanisms through which to induce the adoption of new technologies.

Governments in developing countries should work towards providing business sectors with affordable, high-quality access to the Internet. Key policy aspects include the mobilization of investment in ICT infrastructure, both public and private, and the creation of a regulatory environment that provides for sound competition in the telecommunications sector. Infrastructure investment should be placed in the context of structural transformation to provide developing countries building industrial capacities with an alternative perspective of how to plan, execute and coordinate such investments. Governments should also try to bridge the connectivity gap between small and large firms in low-income developing countries and the least developed countries.

Building skills for industry 4.0

Developing country Governments need to ensure that businesses, including SME, have the digital skills and knowledge to use ICT efficiently in different business functions such as market research, product development, sourcing, production, sales and after-sales services (World Trade Organization, 2018). With technology increasing faster than skills, the risk of a skills mismatch is also increasing (Banga and Te Velde, 2018). There is a need to develop relevant skills and other capabilities in many countries to enable the deployment of industry 4.0 technologies (UNCTAD, 2021a). For example, Kenya is implementing a comprehensive capacity-building programme based on experiential learning, to prepare a skilled workforce for industry 4.0; and South Africa aims to increase the number of youth and adults with skills for employment, decent jobs and entrepreneurship, by providing relevant skills required for the digital world, and also aims to mitigate the potential number of job losses due to automation and to achieve the targets outlined in its national development plan and under the Sustainable Development Goals (box 1). Other countries have also promoted the development of digital skills.

Box 1

Preparing skills for industry 4.0

Kenya: The next generation workforce will be taken up by those that seize the opportunities provided by frontier and digital technologies in health, agriculture, housing, manufacturing and environmental issues at the community level. Accordingly, training and mentoring a technology-savvy workforce will require a collaborative effort between training institutions and industry to introduce the next generation STI workforce to underlying principles of technology development and the ethical implications of frontier technologies such as artificial intelligence, quantum computing, machine learning and cybersecurity. Capacity-building through experiential learning is being undertaken at all levels starting with basic education. Kenya focuses on competency-based education and training at the pre-primary, primary, secondary and university levels and in technical and vocational education and training. Students are trained and skilled labour is developed to thrive in the industry 4.0 environment. Kenya is combining and integrating the physical, digital and biological spheres and reskilling and upskilling to achieve a human-centred revolution.

South Africa: To produce a globally competitive workforce, South Africa plans to develop a super smart society that leverages big data, the Internet of things, artificial intelligence and robotics to deliver services that enhance the quality of life of all citizens. South Africa plans to create a resilient and digital skilled population that can adapt rapidly to the future digital world. Through investing in research and development activities to provide solutions to national socioeconomic challenges, STI is expected to serve as an enabler that can be harnessed to overcome the digital divide and provide equal access that could result in better employment opportunities among vulnerable groups, as well as stimulate economic growth. Funding for digital research in South Africa has concentrated on building capabilities in science, technology, engineering and mathematics. Over the years, South Africa has built capacities in physics, earth sciences, mathematics, computer science, engineering, big data, supercomputing, cybersecurity, electronic science and electronic research through a variety of postgraduate teaching and training programmes in space sciences and cyberinfrastructure. Through these projects, students develop skills that are essential for industry 4.0. Investments in data science and mobile application laboratories, to support access to training and skills development for the future digital world, have contributed to inclusive development.

Source: Contributions from the Governments of Kenya and South Africa.

Countries need to build and attract a skilled workforce while minimizing or reversing human capital flight comprising those with disruptive skills. Policymakers should consider introducing incentives to retain skilled professionals or attract skilled expatriates. For example, in Latvia, the Government has designed and implemented innovation vouchers and support for the attraction of highly qualified specialists.[9]

Developing national strategies for industry 4.0

A national strategy for industry 4.0 is critical in guiding innovation efforts towards developing and deploying industry 4.0 technologies in manufacturing. Such a strategy should identify the investment needed in physical infrastructure and human capacity, including training in the new digital skills required; key sectors requiring strengthened capacity; and aspects of the regulatory environment requiring changes in order for firms to adopt and adapt the technologies. Such a strategy could take many forms and could be a stand-alone national strategy or form part of national strategies for industrialization and manufacturing or STI. It is critical to align innovation and industrial policies, to harness industry 4.0 for manufacturing. A focus on increasing productivity growth requires various innovation and industrial policies, including more collaborative projects. Aligned STI and industry policies should draw firms into the core of frontier technology development, resulting in improved levels of labour productivity (UNCTAD, 2021a). This would enable traditional production sectors to access industry 4.0 technologies, benefiting from multiple channels of technology diffusion, including FDI, trade, intellectual property rights, patents and the exchange of knowledge and know-how (UNCTAD, 2021a). Experiences in countries with national strategies for adopting advanced manufacturing show that they have sought to deploy industry 4.0 technologies to maintain or increase manufacturing competitiveness (box 2). Many countries aim to be among the leaders in the new production regime. The changing skills requirements of the new systems have received attention, with an emphasis on technician-level training and on broadening skills in science, technology, engineering and mathematics. The opportunity to spread new manufacturing jobs across unequal regions is part of most plans. National strategies for industry 4.0 could also direct innovation to address social challenges. Technology and Innovation Report 2021 presents examples of such strategies in the context of climate change, of ageing populations, such as in Japan, and of addressing regional disparities, such as in Mexico and South Africa.

[9] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c06_I_Latvia_en.pdf.

Box 2
Examples of national and regional strategies for industry 4.0

Brazil: In 2019, the Government set up Camara 4.0, or Chamber 4.0, an initiative of the Ministry of Science, Technology, Innovation and Communications, the Ministry of Economy and the National Federation of Industries. The Chamber has set up an action plan to introduce concepts and practices related to industry 4.0 to companies, including SME, to increase competitiveness and productivity and contribute to the insertion of Brazil into GVCs. The initiative also aims to ensure the following: stability and volume of resources at an adequate cost to implement initiatives for industry 4.0; development of industry 4.0 solutions suitable for companies in Brazil; and coordination to avoid overlapping individual efforts by public and private institutions to address needs and industry 4.0 demands in Brazil. The Chamber has been following the path provided under other governmental plans, including Pro Futuro, the plan for advanced manufacturing, and the National Internet of Things Plan.

China: Made in China 2025 is the first 10-year action plan focused on promoting manufacturing. The strategy aims to transform China into a global leader in key high-end manufacturing sectors, drive innovation and lead to competitive advantages by 2049. The following nine tasks are priorities: improving manufacturing innovation; integrating technology and industry; strengthening the industrial base; fostering brands from China; enforcing green manufacturing; promoting breakthroughs in 10 key sectors; advancing restructuring of the manufacturing sector; promoting services-oriented manufacturing and manufacturing-related service industries; and internationalizing manufacturing. The 10 key sectors are as follows: new information technology; high-end numerically controlled machine tools and robots; aerospace equipment; ocean engineering equipment and high-end vessels; high-end rail transportation equipment; energy-saving cars and new energy cars; electrical equipment; farming machines; new materials, such as polymers; and biomedicine and high-end medical equipment.

Colombia: The national industrial policy seeks to promote the adoption and use of modern technologies to address social and economic disparities and contribute to higher levels of productivity and competitiveness in the economy. Under the policy, the Government is delivering programmes and action plans for the adoption of new technologies, such as the launch of the centre for the fourth industrial revolution, to ease the adoption of artificial intelligence, the Internet of things, big data, blockchain and smart cities; and the Banco de Retos initiative, to promote matchmaking between productive processes and local service providers. In addition, Taxes Law 1955/2019 includes incentives for investment in STI and there are credit lines for innovation included in the strategy to use royalties under the science, technology and innovation fund.

Mexico: The national 2016 road map for industry 4.0 focuses on the automotive, aerospace and chemical industries, which account for over 900,000 jobs, and the road map envisions the growth of jobs in new sectors, including new Internet of things businesses, talent development for design and engineering, big data analysis and digital solutions. Training for both engineers and technicians is also included, along with regional development; the road map recommends identifying six states with the potential to implement industry 4.0 ecosystems and developing plans for industry 4.0 clusters in those states.

Portugal: The national strategy for industry 4.0, Portugal i4.0, launched in 2017 and updated in 2019, has the objective of disseminating and boosting the adoption of advanced technologies and smart production in domestic industrial sectors. A particular focus is on the qualification of the workforce in a greater number of companies in the digital technologies associated with smart technological production.

Thailand: National Strategy 2018–2037 is the core national development strategy, including plans to establish and increase competitiveness in the following 10 industries: new generation automotive; smart electronics; affluent, medical and wellness tourism; agriculture and biotechnology; food for the future; manufacturing robotics; medical hub; aviation and logistics; biofuels and biochemicals; and digital. Industry 4.0 Strategy 2017–2036 of the Ministry of Industry aims to move the country towards smart industries and strengthen links to the global economy.

European Union: Vision 2030 sets out a vision of industry in the European Union in 2030 as a global leader, responsibly delivering value for society, the environment and the economy. The strategy aims to build the competitive advantage of Europe in cutting edge and breakthrough technologies, respect for the environment and biodiversity, investment in people and smart European and global alliances. Based on collaboration and common values, the plan seeks to provide a new industrial model to help to make Europe a role model for the rest of the world. The strategy is to promote cutting edge technologies and the automation and digitalization of manufacturing, products and data-driven services, based on sound ethical values, to transform European industry. Progress in artificial intelligence, the Internet of things, robotics, automation, biotechnology and three-dimensional printing is considered essential, to bring about technology-led transformations across all industries in Europe.

Source: UNCTAD, based on Camara 4.0, 2022, China State Council, 2015, European Union, 2019, and contributions from UNIDO and the Governments of Brazil, Portugal and Thailand.

To develop a strategy for industry 4.0, Governments should consider the potentially disruptive effects in the years ahead, which requires a strategic vision and intelligence in the form of technological foresight and assessments. Such assessments extract knowledge and evidence from various stakeholders about the industrial growth areas that match a country's strengths to commercial opportunities (UNCTAD, 2021a). There are several examples of institutions and programmes for conducting technological foresight and assessments, including the following: the Centre for Strategic Studies and Management in Brazil; a special programme of technology foresight in Peru; the technology foresight centre under the Asia-Pacific Economic Cooperation forum; and a distributed competence centre on foresight within the Joint Research Centre in the European Union.[10] Technology assessments can also contribute to shaping public and political opinions on the social aspects of science and technology, including potential risks and opportunities, while helping policymakers identify effective, pragmatic and sustainable policy options. Newer types of technological assessments build on a broader range of inputs and can catalyse social, political and inter-institutional debates on the benefits, drawbacks and associated uncertainties of alternative directions. For example, in 2021, UNCTAD launched a project on technology assessment in the energy and agricultural sectors in Africa to accelerate progress on STI, aiming to build capacity in three selected countries to carry out technology assessments to consider how new technologies can contribute to solving social problems such as those particularly affecting women and girls. The project will also investigate how technologies applied within these sectors can support improved resilience to pandemics and significant short-term shocks and help the beneficiary countries in building for the future.

Fostering multi-stakeholder collaboration

Governments, business sectors, academia and other stakeholders should work together to drive the deployment of industry 4.0 in each country in a coordinated manner and aimed at national development goals such as structural transformation, economic diversification and job creation. Many countries could benefit from creating institutional spaces or mechanisms to bring together all relevant partners to develop a shared vision for industry 4.0 and coordinate the implementation of related technologies. The smooth functioning of a national innovation system is often linked to a good governance structure and the involvement of national and regional Governments and actors representing businesses, academia and research organizations. In countries with significant regional disparities, creating a multilevel governance structure can help distribute socioeconomic growth at the within-country regional level. A national innovation system governance structure is important in allowing government agencies to work closely together to develop technological standards (as in Egypt, for example) or to introduce complex policy and legal and regulatory changes (as in Thailand).

[10] See https://www.cgee.org.br/; https://portal.concytec.gob.pe/index.php/programas-especiales-de-soporte-de-cti/programa-especial-de-prospectiva-y-vigilancia-tecnologica; http://www.apecctf.org/; and https://ec.europa.eu/jrc/communities/en/node/2/article/ec-competence-centre-foresight.

Note: All websites in references were accessed in March 2021.

An example of a multi-stakeholder mechanism for industry 4.0 is Camara 4.0, or Chamber 4.0, in Brazil, created in 2019 to bring together government actors and representatives from industrial and academic sectors under the coordination of the Ministry of Science, Technology and Innovation and the Ministry of Economy, to formulate and implement initiatives to boost national industrial development through the adoption of industry 4.0 technologies, the promotion of increased productivity, competitiveness and economic development. In Switzerland, the private initiative Industrie 2025, founded by various industry associations, brings together stakeholders to drive digital transformation in the national manufacturing sector.

Building international partnerships

Many developing countries can benefit from including an outward-looking dimension in national strategies for industry 4.0. Transnational knowledge, information exchanges and collaborations can offer invaluable opportunities to build new, and participate in existing, regional and continental value chains. For example, the African Continental Free Trade Area can help countries in Africa to develop and utilize regional value chains to promote the adoption of frontier technologies in critical areas such as transportation and logistics, financial technology, potable water and sanitation, smart cities, affordable housing and low-cost, high-quality health care (UNCTAD, 2021a). There are several examples in this regard. The Dominican Republic, as part of the national strategy, is collaborating with Spain on industrial digitalization, including four training courses at the School of Industrial Organization aimed at professionals in the Dominican Republic, as well as agreements signed by the Ministry of Industry and Commerce of the Dominican Republic and the Ministry of Industry, Commerce and Tourism of Spain, to promote digitalization in the industrial sector, focusing on increasing industrial added value, qualification of employment in the sector and development and deployment of digital solutions for the industry; and a joint committee on industry 4.0 has been created to implement measures and approve joint projects and study their evolution.[11] In Egypt, international partnerships are considered key in order to mobilize resources and provide technical assistance with regard to tools for varying the current policy mix and incentivizing industry 4.0 adoption at the firm level, as well as retaining and developing talent.[12] In 2019, the Government of Peru launched the Prospecta Americas initiative, in cooperation with the Inter-American Commission on Science and Technology of the Organization of American States, to promote the use of transformative industry 4.0 technologies, including prospective studies and technological surveillance of Industry 4.0; infrastructure development in centres of excellence of a continental scope in various countries, specialized in each of the technologies; and the high-level training of researchers specialized in these technologies, using both existing infrastructure and those being created within the framework of this initiative.

B Fostering the adoption of industry 4.0

Raising awareness among businesses

Developing countries need to raise awareness of industry 4.0 in various sectors and the positive impacts of related technologies.[13] Governments should consider incentivizing businesses, especially SME, to recognize the importance of digital adoption and start the process of digital transformation. To raise awareness, Governments can set up meetings and activities to promote the benefits of industry 4.0. Governments can also help by promoting industrial transformation with relevant stakeholders in each sector. For example, in the Dominican Republic in 2019, several institutions held a conference on industry 4.0 to promote industrial transformation as part of a technological transformation strategy for the national industrial system. Governments could also arrange for demonstration initiatives in science parks, incubators, accelerators and innovation laboratories (UNCTAD, 2018b; UNCTAD, 2019b). For example, in the Islamic Republic of Iran,

[11] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c30_IU_DomRep_en_es.pdf.

[12] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c03_I_Egypt_en.pdf.

[13] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c04_I_ESCWA_en.pdf.

this is one of the pillars of related policies, aimed at catching up with regard to industry 4.0 by promoting faster commercialization of advanced digital and production technologies through digital hubs and accelerators. As part of demonstration initiatives, Governments should encourage academia, research organizations and civil society to work closely with the private sector to deploy new technologies (UNCTAD, 2021a). For example, Belarus has put in place the Republican Centre for Technology Transfer to promote the transfer of technologies developed both in the country and abroad, to ensure the sustainable growth of the national economy and increase the competitiveness of national industry and agriculture.[14] Kenya has established a national university and industry collaborations committee to harness the national industry innovation ecosystem.[15] In the Philippines, the Government is implementing a small enterprise technology upgrading programme to encourage and assist SME to adopt technological innovations to improve operations and boost productivity and competitiveness.[16] In the Russian Federation, the Government has established Innovative Science and Technology Centres to combine efforts related to science, education and business, facilitate the transfer of scientific competencies from universities to business practice and assist technology companies and start-ups.[17] The private sector can also drive this process. For example, in Kenya, as part of national policy efforts, a masterplan for establishing science and technology parks has been developed; Dedan Kimathi University is constructing a government-funded science and technology park and Chuka University is constructing a second science and technology park in collaboration with the Government of the Netherlands. In Portugal, the industry 4.0 platform project of the Business Association for Innovation aims to strengthen industry 4.0 technological capabilities among SME to accelerate digital maturity and contribute to productivity and competitiveness gains.[18] Finally, Governments can also use science parks, innovation hubs, model factories and other similar platforms to facilitate technology and innovation learning through demonstrations. For example, in Turkey, the Government has established eight model factories to provide consultancy and training solutions for businesses to complete their lean digital transformation.[19]

Investment

An increasing number of countries worldwide are introducing policy measures and setting targets to attract technology-oriented investment to support the development and uptake of industry 4.0 technologies. To attract such investment, countries should introduce dedicated policy measures and promotion and facilitation efforts. In particular, developing countries should consider formulating industry 4.0 promotion strategies to put in place investment promotion and facilitation in line with national industry 4.0 investment development plans. A good industry 4.0 investment plan can be built by resetting priorities for investment promotion, targeting diverse investment activities and business functions and facilitating green and digital investors (UNCTAD, 2020b). Such investment plans can also be part of national strategies for industry 4.0. There are several examples in this regard among CSTD members, as follows: the Government of Brazil has established the Cesta 4.0, or Basket 4.0, initiative, which identifies industrial and technological segments of industry 4.0 for investment in and promotion of industry 4.0; Latvia has designed and implemented the green channel initiative, eliminating administrative burdens on high value added investment (ICT, bioeconomics, smart materials, photonics, biomedicine and smart energy are among the priority industries); the Philippines has implemented the Inclusive Innovation-led Industrial Strategy, aimed at removing obstacles to growth, to attract investment; South Africa, under the programme Digital Advantage 2035, guides the implementation of the national ICT research, development

[14] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c29_IU_Belarus_ru.pdf.

[15] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c32_IU_Kenya_en.pdf.

[16] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c34_IU_Philippines_en.pdf.

[17] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c35_IU_Russia_ru_en.pdf.

[18] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c07_I_Portugal_en.pdf.

[19] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c10_I_Turkey_en.pdf.

and innovation strategy and seeks to ensure more comprehensive and transparent investment monitoring; and the Government of Thailand, as part of Industry 4.0 Strategy 2017–2036, aims to attract investment in future industries and services.

Financing deployment

In several developing countries, a persistent lack of finance for research and development programmes continues to be a challenge.[20] Better access to finance could accelerate the use, adoption and adaption of industry 4.0 technologies. A challenge in this regard is that many areas associated with industry 4.0 are new to firms and financial intermediaries, and those seeking and providing finance may express caution. For example, there are difficulties in proving business cases and returns on investment and ensuring that the new emerging applications of such technologies perform according to expectations. In this regard, innovation and technology funds financed by the public sector, international donors or development banks, could become important instruments for innovation in developing countries, as they may be introduced relatively quickly and are flexible in design and operation. Developing countries could use these funds to support strategic goals and target particular industries, activities or technologies (UNCTAD, 2021a). For example, in the Islamic Republic of Iran, the establishment of specialized funds and accelerators for building an industry 4.0 innovation ecosystem forms part of the policies for catching up with regard to industry 4.0. In Malaysia, Bank Pembangunan, one of the first development financial institutions in the country, has allocated RM3 billion to aid manufacturers in adopting industry 4.0 technologies through an industry digitalization transformation fund.[21] In Peru, the Pro Innovate Programme funds and provides technical support for the generation of innovative industry 4.0 projects and strengthening of actors in the national innovation system. In Turkey, the SME Development Organization provides funds for SME investment projects focusing on high value added manufacturing products in the medium-high and high-technology sectors.[22] Some activities may be supported by procurement programmes and financing mechanisms involving local sovereign wealth funds, pension funds, institutional investors and guarantee instruments (UNCTAD, 2021a). In the Philippines, Republic Act 11377, or the Innovative Start-up Act, includes the provision of partial or full subsidies on the use of facilities, office space and equipment or services by start-ups provided by the Government or private enterprises and institutions, as well as grants for research, development, training and expansion projects.[23] In the Russian Federation, a set of measures is being implemented, aimed at supporting projects at any stage of technological readiness, ranging from concept or prototype development and start-up acceleration to fully-fledged production and scaling-up of the best domestic solutions. Following competitive calls in 2020, authorities will support grants of Rub 2.8 billion for a total of 254 innovative small business start-ups developing and commercializing information technology solutions; a further 12 pilot information technology projects were approved to receive up to Rub 750 million; a further Rub 1 billion was allocated in grants for 10 other digital technology projects; and a programme of subsidized loans has been launched to stimulate the digital transformation of business processes, with up to 15 banks selected for the programme (and another 40 willing to participate) that, encouraged by the Ministry of Digital Development, compiled a loan portfolio for 25 projects, seeking Rub 34.5 billion, and nine projects have received approval to date.[24]

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[20] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c04_I_ESCWA_en.pdf.

[21] See https://belanjawan2021.treasury.gov.my/manfaat/index.php/en/ind-digi-trans-en.

[22] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c10_I_Turkey_en.pdf.

[23] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c34_IU_Philippines_en.pdf.

[24] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c35_IU_Russia_ru_en.pdf.

C Protecting workers and easing workforce transitions

The adoption of industry 4.0 in specific sectors and countries could lead to the displacement of workers in the same or other sectors in the same or other countries. Policymakers in developing countries should be particularly attuned to rapid technological changes in GVCs in which the countries participate and how these changes could affect the workforce. Some policymakers state that a loss of jobs in traditional areas will be followed by jobs in areas associated with industry 4.0 and that there is a need to upskill and reskill citizens whose jobs may be affected by the deployment of industry 4.0 technologies. For example, Kenya is developing building blocks towards industry 4.0 to ensure that the next generation workforce can take advantage of opportunities provided by frontier technologies and, accordingly, training and mentoring of a technology-savvy workforce will require a collaborative effort between training institutions and industry to introduce the next generation STI workforce to key principles of technology development.[25]

From a labour market policy perspective, the guiding question is how to enable labour markets to deal with structural change in general and more recent phenomena such as industry 4.0 in particular. For example, in a country at the technological frontier such as Switzerland, the following elements are of particular interest in a phase of rapid change: promoting a business environment conducive to growth and job creation; ensuring that the supply of skills is permanently adapted to changing labour market needs; recognizing that the adaption of skills (including digital skills) will be an issue for youth but more often for older persons as well; and noting that the protection of workers against labour market risks should go together with incentives and support to find new jobs.

Workers who cannot be trained or retrained and who may lose their jobs should be able to rely on stronger social protection mechanisms (UNCTAD, 2021a). By making social transfers such as unemployment benefits, Governments can reduce the risk of people falling into poverty, as social protection systems can support workers during labour market disruptions (Milanovic, 2016).

There is a renewed importance placed on labour unions, to defend worker rights and legitimate concerns about jobs, given the increasing automation of tasks. They should play a critical role in tackling new challenges in the relationship between workers and employers in the context of industry 4.0. Many of these challenges are related to collecting and using worker data, requiring new rights in the digital transformation era, such as the right to defined levels of privacy at work and at home (Industriall Global Union, 2017). To remain relevant, labour unions need to strengthen and update collective bargaining agreements to cover the impact of industry 4.0 and devise new strategies for addressing the potential adverse effects of smart production on the well-being of workers. It may be useful to conduct studies and forecasts about future trends and the potential impact of automation on production systems and labour demand. Labour unions could also try to include isolated workers, such as many workers in the gig economy. At the same time, employer organizations can contribute to the dialogue between different stakeholders and to the development of more targeted education and training to prepare workers for labour market changes and needs. Governments should also play a role, supporting the social dialogue between employers and labour unions to deal with industry 4.0. With policy support and regulatory and legal reforms, collective bargaining could protect vulnerable workers from precarious employment, substandard conditions and marginalization.

[25] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c04_I_ESCWA_en.pdf.

VII. International collaboration

In harnessing industry 4.0 for inclusive development, developing countries should be able to rely on technical and financial support through international cooperation and official development assistance. International cooperation is essential in supporting developing countries in building capacities to properly identify ways to harness industry 4.0, aligned with national development objectives and the Sustainable Development Goals; formulate coherent policies; and design appropriate policy instruments to promote industry 4.0. International cooperation is also critical in building an international institutional framework to harness industry 4.0 technologies for the Goals and address potential unintended consequences.

In this regard, the areas noted in the following sections require attention through international cooperation.

A Sharing knowledge and information and conducting research

Governments and other stakeholders should be aware of the benefits of industry 4.0 and how firms can absorb the associated new technologies to bridge the productivity gap. International cooperation helps raise awareness in developing countries through the sharing of knowledge and information. For example, UNIDO provides for a multi-stakeholder knowledge-sharing platform to create awareness of industry 4.0 and of opportunities and challenges in pursuing inclusive and sustainable industrial development in developing countries. The platform enables the sharing of available tools and methods for innovation management; information on training curricula for new workforce skills requirements; methods and best practices to support digital transformation among SME and on bridging the gender digital divide; and information on new infrastructure, standards and policies that need to be developed or mainstreamed for the deployment of industry 4.0 technologies.[26]

Convening power is a crucial element of international cooperation, to gain the widest possible range of expertise, exchange and agreement on sustainable industrial development actions. In this regard, CSTD acts as a forum for strategic planning and the sharing of lessons learned and best practices, providing foresight about critical trends in STI in key sectors of the economy, the environment and society, and drawing attention to new and emerging technologies. Other platforms and forums also help share knowledge of and information on industry 4.0. For example, the Global Manufacturing and Industrialization Summit, a joint initiative of UNIDO and the Government of the United Arab Emirates, has convened advanced technology actors to pursue the achievement of an inclusive and sustainable fourth industrial revolution.[27]

The World Summit on the Information Society serves as a platform for sharing national strategies, policies, laws, programmes and initiatives concerning industry 4.0. Its stocktaking database, coordinated by ITU since 2004, has collected more than 40 ICT-related national strategies, policies, laws, programmes and initiatives that have reflected upon or contributed to the development of industry 4.0, with some recognized through prizes offered at World Summit on the Information Society forums.[28]

The international community also helps to provide developing countries with new data on and analysis of the development and impact of industry 4.0 technologies. For example, UNCTAD Technology and Innovation Reports have explored how to harness frontier technologies such as artificial intelligence and robotics for sustainable development and have critically examined the possibility that such technologies could widen existing inequalities and create new ones (UNCTAD, 2018b; UNCTAD, 2021a). The reports focus on low- and middle-income developing countries and

[26] See https://www.unido.org/unido-industry-40.

[27] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c12_I_UNIDO_en.pdf.

[28] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c31_IU_ITU_en.pdf.

the least developed countries, as well as the most vulnerable segments of societies, in addition to discussing effects in high-income countries as part of the broader context and as they are significant drivers of frontier technologies.

To analyse the situation of industry 4.0 and discuss its opportunities and challenges for the Arab region, the Economic and Social Commission for Western Asia (ESCWA) prepared a study on the impact of the fourth industrial revolution on development in the Arab region (2019) and Arab Horizon 2030: Innovation Perspectives for achieving Sustainable Development Goals in the Arab Region, which identified the five most relevant emerging technologies for the region, namely, artificial intelligence, the Internet of things, big data, blockchain and three-dimensional printing (ESCWA, 2020).

B Helping design policies and strategies and implement initiatives

Governments in developing countries may encounter difficulties in designing and implementing policies, strategies and initiatives concerning the development and deployment of new technologies. In this regard, the international community has assisted Governments in developing industry 4.0 to ensure that they receive the benefits while avoiding the potential adverse effects of this technological wave.

For example, ESCWA has assisted member States in developing policies and strategies related to the fourth industrial revolution, such as the following: artificial intelligence and cloud computing policies, Jordan; artificial intelligence strategy, Lebanon; digital transformation strategy, Syria; and artificial intelligence policy and big data readiness assessment, State of Palestine.[29] The UNCTAD programme of STI policy reviews assists countries in aligning STI policy with development strategies, providing information on how Governments can harness industry 4.0 technologies in traditional sectors and for economic diversification. UNIDO supports policy development, programmes and initiatives in beneficiary countries concerning industry 4.0 to ensure inclusive and sustainable industrial development. Its activities complement national strategies from developed countries such as Alliance du Futur in France and Industrie 4.0 in Germany; and developing countries, such as Digital India and Vision 2030 in Kenya.[30] Such activities help build awareness among policymakers and industry associations of new infrastructure, standards and policies that need to be developed or mainstreamed to benefit from industry 4.0. For example, one activity involves establishing multi-stakeholder knowledge-sharing platforms to mainstream industry 4.0 opportunities for pursuing inclusive and sustainable industrial development in developing countries.[31]

There is a high level of demand among Governments in developing countries for policy advisory services concerning industry 4.0 and related technologies such as artificial intelligence. The international community should increase resources for scaling up industry 4.0-related advisory services provided through the United Nations system and other international organizations that provide support for developing countries and the least developed countries. It is also key for developing countries to obtain assistance in the development of policies for industry 4.0, to ensure they receive the benefits (e.g. increased productivity, less consumption of resources and decreased costs) while avoiding the potential negative impacts (e.g. related to cybersecurity, electronic waste and lack of data privacy).[32]

[29] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c04_I_ESCWA_en.pdf.

[30] See https://www.plattform-i40.de/IP/Navigation/EN/Home/home.html, http://www.industrie-dufutur.org/, https://www.digitalindia.gov.in/ and https://vision2030.go.ke/.

[31] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c12_I_UNIDO_en.pdf.

[32] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c31_IU_ITU_en.pdf.

C Helping capacity-building

The development and deployment of industry 4.0 technologies require all actors in national innovation systems to build new capabilities and skills. These range, for example, from new digital skills in the workforce and work in a data-rich environment assisted by artificial intelligence to the capacity of policymakers to explore new policy instruments and good practices to support digital transformation. International cooperation supports tailored programmes that help support digitalization and upskilling and increase capacity to develop policies and strategies, for developing countries to benefit from the rapid progress of the digital technologies associated with industry 4.0. In this regard, the international community has helped firms and people in developing countries develop digital skills and use new technologies. For example, UNIDO supports SME in Azerbaijan and Belarus in technological learning, smart manufacturing and innovation related to industry 4.0 and supports capacity-building in specific technologies in Kenya, such as strengthening capacity for operation and maintenance related to Internet of things technologies.[33] In addition, several United Nations entities work to build the capacity of policymakers in policy design to support the deployment of industry 4.0. For example, ESCWA has cooperated with national entities in Morocco, Qatar and the State of Palestine to build policy capacity in dealing with the deployment of artificial intelligence, big data, blockchain and the digital transformation.[34] The international community should continue to advocate and support human resources development to prepare for an industry 4.0-ready economy and society.

D Promoting technology transfer

To enable developing countries to take advantage of industry 4.0, the international community should pursue new innovative partnership approaches for promoting technology transfer related to industry 4.0, addressing market, innovation system and capability failures related to the uptake of new technologies and business models. There is also a need to complement technology transfer and facilitate and promote the transfer of innovation capabilities, that is, the ability to use a particular technology or set of technologies to generate value in the socioeconomic, material and natural context to which the technology is transferred, which involves more than the transfer of technological knowledge. International cooperation should also help developing countries absorb frontier technologies and overcome potential challenges associated with industry 4.0. International political dialogue and technical cooperation initiatives are essential in disseminating good practices and knowledge-sharing to increase the competitiveness of national industries and insertion into GVCs. The international community should take practical actions and implement tailored solutions based on the local needs and absorption capacities of countries. International organizations should leverage and build on solutions developed within a country whenever possible, for example, through innovation hubs.

E Helping to set legal frameworks, guidelines, norms and standards

Countries, individually and through concerted international efforts, need to guide the development and deployment of industry 4.0 to support sustainable development and leave no one behind. From the outset, it is essential to establish ethical frameworks and regulations for such technologies. Technology and Innovation Report 2021 lists 167 ethical frameworks concerning artificial intelligence, prepared mainly by private sector firms and some academics, with inconsistencies and contradictions between them. This shows the importance of international, multi-stakeholder efforts, with the participation of stakeholders from developing countries.

In this regard, a dedicated ITU study group is working to address the standardization requirements

[33] See https://open.unido.org/projects/AZ/projects/190347; https://open.unido.org/projects/BY/projects/; and https://unctad.org/system/files/non-official-document/CSTD2021-22_c12_I_UNIDO_en.pdf.

[34] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c04_I_ESCWA_en.pdf.

related to Internet of things technologies, with an initial focus on Internet of things applications in smart cities and communities. It is developing a series of standards and guidelines on security, privacy, trust and identification for the Internet of things, which offer a more comprehensive, interlinked, secure and holistic approach to manufacturing. ITU has also established several focus groups on industry 4.0 technologies and their environmental impacts, including on environmental efficiency for artificial intelligence and other emerging technologies; artificial intelligence for autonomous and assisted driving; and autonomous networks. A dedicated study group is responsible for studies on methodologies for evaluating ICT effects on climate change and publishing guidelines for using ICTs in an eco-friendly manner. Under its environmental mandate, the study group is also responsible for studying design methodologies to reduce the adverse environmental effects of ICTs and electronic waste, for example, through the recycling of ICT facilities and equipment.[35] ITU has published international standards related to industry 4.0 and associated technologies such as the Internet of things. These standards are available free-of-charge for downloading and use in developing countries. The focus on the availability of free standards allows developing countries to have the information needed to create and implement the infrastructure required for industry 4.0. In addition, ITU organizes events in different regions that enable countries to obtain new knowledge and works with developing countries to bridge the standardization gap and assist them to become more involved in standardization activities.

At the regional level, ESCWA is analysing the legal framework of some States, including Jordan, Libya and Morocco, to identify needed amendments to deal with the requirements of industry 4.0 technologies.[36]

[35] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c31_IU_ITU_en.pdf.

[36] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c04_I_ESCWA_en.pdf.

VIII. Conclusions and recommendations

This study has examined how developing countries can harness industry 4.0 in manufacturing for inclusive development. Industry 4.0 in manufacturing entails smart production, that is, integrating and controlling production using sensors and equipment, including traditional machinery and robots, cobots and three-dimensional printers, connected to digital networks supported by artificial intelligence. Many firms that have adopted smart production have increased productivity and reduced environmental impacts. The impact of such technologies on jobs has been of concern, particularly in developed countries, yet empirical evidence shows that the use of industry 4.0 technologies may create more jobs than it replaces. Reshoring, a significant concern among developing countries, is also not expected to be a significant effect of industry 4.0.

At the same time, in developing countries, with less diversified economies and in which firms mainly use technologies from the second industrial revolution, most firms are not yet utilizing industry 4.0 technologies. There cannot be an industry 4.0 without industry in the first place; developing countries need to further industrialize before they can broadly benefit from industry 4.0. They should not miss the windows of opportunity that industry 4.0 offers for increasing productivity and sustainability. Therefore, developing countries need to implement a dual strategy of continuing to diversify their economies and foster competitive manufacturing while, at the same time, creating the conditions for the emergence and diffusion of industry 4.0 in their production bases.

In this regard, developing countries may wish to consider the following courses of action:

- Foster economic diversification and manufacturing competency. Developing countries, particularly low-income countries and the least developed countries, should consider placing economic diversification at the centre of national development strategies, implementation of which should be supported by a whole-of-government approach
- Facilitate an enabling digital infrastructure. Governments in developing countries should create the conditions for affordable, high-quality digital infrastructure that supports the competitiveness of the private sector. This requires the mobilization of investment in ICT infrastructure, both public and private, and the creation of a regulatory environment that provides for sound competition in the telecommunications sector
- Develop national strategies for industry 4.0. Governments should prepare and launch a national strategy and programme or initiatives for the most relevant industry 4.0 technologies for the country. Such a strategy should articulate a unified vision and deep understanding of the measures needed to harness industry 4.0 effectively and should clearly define the direction of diffusion of industry 4.0 within the economy, define priorities and identify actions for future development and the results to be achieved
- Foster multi-stakeholder collaboration to create an industry 4.0 ecosystem. Governments should create institutional spaces or mechanisms that bring together all relevant partners to develop a common vision for industry 4.0 and coordinate its implementation. Interventions should enable an industry 4.0 innovation ecosystem to emerge by linking academia and the private sector, including manufacturing and the digital and ICT sector. This ecosystem should be conducive to the development of quality infrastructure for industry 4.0. All stakeholders should collaborate closely. Inputs from private sectors and labour unions can assist government sectors in launching effective policies and measures. In addition, policy implementation requires active cooperation from the private sector and labour unions
- Conduct foresight exercises. Policymakers should consider conducting foresight exercises and bringing together key agents of change and sources of knowledge to explore possible scenarios and develop strategic visions and intelligence to shape the future. Such assessments should pay particular attention to how the diffusion of industry 4.0 can affect different sectors

and impact men and women differently. Countries should consider creating or reinforcing national capacities in technological assessment and foresight to help policymakers identify and exploit the potential of industry 4.0 for sustainable development

- Build workforce skills for industry 4.0. Governments should promote initiatives to qualify and retrain the workforce and promote industry 4.0 technologies in production chains. They should undertake skills assessments in the manufacturing sector to determine existing and required skills and skills shortages and develop specific and comprehensive strategies to close identified gaps. Training and retraining should pay particular attention to the different impacts of automation on men and women workers. In this context, the role of labour unions is significant in supporting training processes and enabling new skills to meet the needs of industry 4.0
- Raise the awareness of the private sector. To help developing countries benefit from industry 4.0 technologies, Governments can set up meetings and activities to promote the benefits of industry 4.0. Such activities should build awareness of the modernization and skills needed in production and how these need not pose additional, high costs, but are necessary for competitiveness
- Promote technological upgrading in manufacturing. Governments can help by promoting the industrial transformation to stakeholders in this sector. Governments could support the sharing of good practices, training in digitalization and making people aware of the new opportunities available to solve business problems more effectively. In addition, they could promote the development of cooperation platforms that help promote digital solutions in the business processes of companies, providing consultations and offering support tools
- Foster innovation in industry 4.0 technologies. Governments should provide incentives for the private sector, including SME, and entrepreneurs to use and develop applications using industry 4.0 technologies, including by facilitating the acquisition of hardware, software and tools needed for industry 4.0 solutions. In addition, policy instruments should aim to create an enabling environment for the emergence of markets for industry 4.0 solutions. For example, they could encourage the development of new projects through competitions or financing
- Build international partnerships. International partnerships are crucial in mobilizing resources and providing technical assistance on policy and an effective policy mix, incentivizing the adoption of industry 4.0 technologies at the firm level and retaining and developing talent. In addition, international collaborative projects on digital technologies can facilitate the development of industry 4.0 technologies. They may play a decisive role in boosting the acquisition and assimilation of new knowledge, systems and solutions. In this context, demonstration projects involving companies showing technological maturity may be an effective tool in paving the way for capacity-building

To support developing countries in harnessing industry 4.0 for inclusive development, the international community may wish to consider the following courses of action:

- Collect and share success stories, including successful business cases, demonstrating the impact of industry 4.0 technologies on inclusive and sustainable development. In particular, the international community should disseminate examples and information that help guide how women and girls and those in marginalized communities can benefit from such technologies. CSTD can play a pivotal role in disseminating knowledge and best practices, establishing partnerships and sharing knowledge of success stories in various development contexts for the benefit of States
- Exchange knowledge and experience. The international community should facilitate the exchange of knowledge, research, experiences, success stories and best practices with leading policymakers, innovators and regulators in developed and developing countries. Such exchanges could be through forums or events and platforms for knowledge and experience-sharing. In this regard, CSTD plays a critical role in gathering and disseminating quality information about experiences in countries

- Help design and implement national policies, strategies and programmes related to industry 4.0. The international community should support Governments in formulating national strategies and programmes for industry 4.0. It should help guide how to prioritize investments in STI capacity-building and technology development and adaptation that address challenges and take advantage of opportunities afforded by frontier technologies such as artificial intelligence, the Internet of things, big data, blockchain, robotics, cloud computing and three-dimensional printing, while existing technologies continue to be mastered. Technical assistance in this regard should include systematic efforts to involve a broad range of stakeholders to allow for benefits from industry 4.0 without creating unintended and adverse socioeconomic effects and negative environmental externalities
- Promote infrastructure development. The international community should support national infrastructure development that allows for the deployment of industry 4.0 technologies in production processes, such as digital infrastructure
- Support pilot programmes. The international community should support developing countries in designing and implementing pilot programmes and initiatives to apply industry 4.0 technologies in priority sectors
- Scale-up capacity-building activities; and contribute to capacity-building activities at national and regional levels on industry 4.0 technologies, including creating online and hybrid training programmes for professionals and the general public
- Network. The international community should support the participation of actors in the innovation system of Member States in international networks and programmes, to build capacity in innovation for industry 4.0
- Promote knowledge and technology transfer. The international community should support the transfer of knowledge and technology between developed and developing countries on industry 4.0 technologies; and encourage South–South cooperation to exchange knowledge and best practices. Support could be in the form of knowledge exchange and transfer, research and development projects and business matching and joint ventures. In addition, integration into international networks such as digital innovation hubs in Europe could contribute to the digitalization of firms in developing countries
- Create joint programmes. The international community could help identify markets or market segments with greater demand for joint technological development. Such joint programmes can help facilitate technological and commercial exchanges, particularly with countries leading in such technologies
- Increase investment in education in science, technology, engineering and mathematics. Developed countries should consider increasing investment in such education in developing countries through targeted programmes, for example, by supporting the education of girls in science, technology, engineering and mathematics.[37] Developed countries can facilitate the training of students from developing countries in science, technology, engineering and mathematics by supporting exchange or visiting programmes hosted by universities in the former
- Support technological upgrading. The international community should support the upgrading of digital and non-digital industries to increase high-technology production and exports; and assist in benchmarking domestic industry firms against international firms that have achieved the transformation to industry 4.0
- Develop ethical frameworks and guidelines. The international community should strengthen international cooperation to develop ethical frameworks and guidelines for the adoption of industry 4.0 technologies. Innovation management standards have great potential to help developing countries and economies in transition to leapfrog into industry 4.0. Such guiding frameworks could be relevant for all types of organizations, including SME

[37] See, for example, https://www.usaid.gov/what-we-do/gender-equality-and-womens-empowerment/addressing-gender-programming/promoting-gender.

Annex A
Experiences with industry 4.0 among member States of the Commission on Science and Technology for Development

National strategies, policies, laws, programmes and initiatives related to industry 4.0 of selected CSTD member States are presented in this annex, along with information on key sectors and actors of the innovation ecosystem for industry 4.0. The information is based on contributions from Governments in response to an UNCTAD questionnaire sent to CSTD member States in July 2021.

Belarus[38]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

The State body responsible for the organization and implementation of the digital transformation of the national economy is the Ministry of Communications and Informatization. Regulation of the processes of implementation of elements of industry 4.0 at the sectoral level is carried out by ministries and departments. The most important document implemented in the last five years has been the State programme for the development of the digital economy and information society for 2016–2020 (approved by Resolution No. 235 of the Council of Ministers, 23 March 2016), aimed at ensuring the development of ICTs and their effective application in all spheres and industries. To ensure favourable conditions for the development of the information technology industry and the formation of the competitive advantages of Belarus in the creation of the digital economy, Decree of the President No. 8, 21 December 2017, on the development of the digital economy was adopted. The State programme Digital Development of Belarus 2021–2025 (approved by Resolution No. 66 of the Council of Ministers, 2 February 2021) is being implemented, the purpose of which is to ensure the introduction of ICT and advanced production technologies in the national economy and society. Tasks under the programme include the following:

- Development of digital economy tools in various sectors of the national economy, providing for the use of advanced production technologies in the production and processes of foreign economic activity and the formation of the necessary conditions for maintaining and increasing the competitiveness of enterprises from Belarus in the world market
- Increasing the comfort and safety of the population through the creation and implementation of smart city technologies, including systems for remote monitoring and accounting of housing stock, energy consumption, the state of the environment, video analytics and others
- The National Academy of Sciences is the custodian of Digital Development of Belarus 2021–2025. Within the framework of this programme, the National Academy of Sciences participates in the implementation of the following scientific support event activities:
- Creation of an integrated system of digital cataloguing of goods (products) of Belarus for the formation of a single market among member States of the Eurasian Economic Union
- Implementation of the complex project Smart Cities of Belarus; creation of a typical regional State digital Smart City (Region) platform

Scientists of the National Academy of Sciences, together with representatives of interested government bodies and other organizations, developed the strategy Science and Technology 2018–2040 (approved by Resolution No. 17 of the Presidium of the National Academy of Sciences, 26 February 2018). The main provisions of the strategy were approved by Congress II of scientists in Belarus, taking into account the provisions of the report of the President of Belarus, speeches of delegates, proposals and recommendations from sections of the Congress. The purpose of the strategy is to determine priorities for the long-term development of science and technology, a set of tools and mechanisms for improving the scientific and technical sphere, aimed at high growth rates and increasing the competitiveness of the national economy and its integration into the global innovation space, while ensuring national security and sovereignty. The strategy defines the key features of the future intellectual economy and the new contours of its production system; basic foundations, goals, objectives and priorities for the development of the scientific and technological sphere; the main directions of State policy in science and innovation and tools to stimulate the scientific and technological development of the national economy for the period up to 2040; and expected results of the implementation of the strategy. The strategy is the basis for the development of forward-looking policy documents for the medium and long term. In accordance

[38] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c29_IU_Belarus_ru.pdf.

with the strategy, formation of a model intellectual Belarus is planned, which includes the following three key elements:

- Full-scale introduction of digital technologies that form the technological core of the intellectual economy; core components are as follows: powerful centralized and distributed computing resources (super and quantum computers; cloud and edge computing); software based on artificial intelligence systems and involving machine learning; network resources of a new generation that combine big data and the principles of building neural networks. Creation of a nationwide cluster of information technology companies, development and implementation of software and hardware complexes, formation of a nationwide network that unites government bodies, business entities and specific consumers, to ensure the implementation of the concept of Belarus-information technology-country
- A developed neo-industrial complex (production of goods, works, services) that meets the challenges of the fourth industrial revolution and is built on the basis of the latest technological package (nano, bio, information technology and additive technologies, composite materials with specified properties). The main characteristics of the complex are as follows: widespread use of artificial intelligence systems; widespread robotization and the use of sensors; introduction of technologies of the Internet of things and industrial Internet of things; supercomputer processing of big data in order to optimize production processes and market turnover; and intellectualization of transport and logistics systems. An important component of the neo-industrial complex is smart energy (New Industry 2040)
- A highly intelligent society in which the needs of each person are harmonized with the needs of the entire society to maximize public goods

The main direction is the formation of the industry 4.0 platform. It involves the transition from centralized to decentralized digital production, informatization of assembling and moving components under control and the communication of machines with each other. Digitalization will make it possible to make significant improvements in production processes, design and development work and the use of raw materials and materials, as well as in the processes of supply chain management and the regulation of product life cycles, to obtain a wide range of products in required volumes, while maintaining the efficiency of mass production and the flexibility of pilot production. Intensive informatization will lead to the formation of new digital markets and smart platforms. In particular, the New Industry 2040 complex will be formed in the industry. The most important components that must be created in Belarus for the implementation of New Industry 2040 are as follows:

- A set of standards and solutions for network architecture
- Algorithms and tools for managing complex systems
- A full-scale broadband Internet network integrated into the world's network resources
- An integrated system of security and protection against external influences and access, as well as identification methods
- Creation of national standards, ensuring metrological traceability of new technologies, automation of metrology and its integration into production processes
- A system of personnel training for the neo-industrial complex based on continuous professional development, including new approaches in the organization and planning of labour
- A new regulatory legal framework for creating and developing production networks and integrated structures based on information technology

In parallel, interactions and constructive exchanges of experience of scientists from Belarus and practitioners with countries implementing initiatives such as industry 4.0 should be developed.

Priority technical and technological areas of New Industry 2040 are as follows:

- Network technologies and technologies of radiofrequency identification based on the industrial Internet and the Internet of things
- Works and services based on supercomputers and cloud technologies
- Digital production technologies, including additive technologies
- Mechatronic systems and technologies; robotic complexes with intelligent control systems
- Creation of a nationwide network of big data, software and supercomputers to ensure end-to-end interaction of enterprises of the real economy, as well as systems for the identification and traceability of goods
- Serial production of electric vehicles, including autonomous vehicles and related components (electric drives, batteries, supercapacitors and equipment for charging)
- Accelerated development of photonics (optics, laser technology, thermal imaging equipment and other equipment, including dual use)
- In the field of microelectronics, production of matrices for information processing systems of spacecraft, production of semiconductor devices for high-voltage electronics, high-frequency chips and microsystems
- In instrumentation, creation of the production of optoelectronic equipment on the basis of thermal imaging, laser systems with the use of electro-optical transducers and high-frequency optical components, semiconductor generators and induction plants for heating metal for plastic deformation and heat treatment
- Production of new structural materials for mechanical engineering, construction, medicine (carbon fibre, cermet, metal plastics, growing crystals for microelectronics, etc.)
- Combination of traditional design and production technologies with the principles of the formation of living organisms and natural objects

Implementation of the strategy will make it possible to form high-technology sectors of the national economy and to bring the structure of the economy of Belarus closer to the structure of the economy of developed countries.

Key sectors and actors of the innovation ecosystem for industry 4.0

One of the key participants in the national innovation ecosystem associated with industry 4.0 is the Republican Centre for Technology Transfer, the goal of which is to promote the transfer of technologies developed both in Belarus and abroad to ensure the sustainable growth of the national economy and increase the competitiveness of the industry and agriculture of Belarus and the methodological guidance of national technology transfer centres. Since 2015, the Centre has been the coordinator of the project “Creation of the Belarusian Business Innovation Centre of the European Network for Support of Technology Transfer, Entrepreneurship Development and Establishment of Partnerships in the Field of Scientific Research”, the purpose of which is to promote technology transfer, business cooperation and the establishment of partnerships in scientific research among SME and scientific organizations of Belarus and the European Union, aimed at increasing their competitiveness.

Brazil[39]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

The Chamber 4.0 brings together the Government, the business sector and academia to drive digital transformation in the country in a coordinated way. Action Plan 2019–2022 of the Chamber established initiatives through its four working groups on technological development and innovation; human capital; productive chains and the development of suppliers; and regulation, technical standardization and infrastructure.

The implementation of Action Plan 2019–2022 has already achieved important results in the productive sector in Brazil, such as the following:

- Modernization of labour regulations related to safety at work in production equipment, facilitating human and machine interactions for industry 4.0
- Monitoring the general law of personal data protection, with legal provisions on data protection and granting of telecommunications services; and elaboration of a handbook to advise enterprises on how to apply the law
- Establishment of the centre for the fourth industrial revolution, affiliated with the World Economy Forum
- Constitution of Cesta 4.0 (Basket 4.0), which indicates industrial and technological segments of industry 4.0 that can serve as a reference for investment in and promotion of this industry
- Creation of the digital platform Mapeamento 4.0 (Mapping 4.0), in which public and private institutions register industry 4.0 initiatives
- Identification of soft skills capacities required among instructors, teachers, professors and students that work with industry 4.0 technologies and processes
- Offers of courses related to industry 4.0 on digital platforms through distance learning methods
- Support for the Fábricas do Futuro (Future Factories) initiative, which fosters testbeds for companies and institutions in Brazil to create real environments to test innovative industry 4.0 solutions
- Creation of the Nucleo de Apoio a Gestao da Inovacao digital programme, which constitutes a support network for innovation management, to improve methodologies, with a focus on digital transformation
- Creation of the Brazil Plus Economy 4.0 programme, which supports the development of and accelerates the implementation in SME of industry 4.0 technologies such as artificial intelligence, the Internet of things, blockchain, machine learning and fifth-generation Internet applications
- Funding for companies entering the industry 4.0 ecosystem, through tools such as FINEP Inovacred 4.0, BNDES Finame Máquinas 4.0, Rota 2030 and FINEP Internet of things, as well as public calls such as MCTI/FINEP Tecnologias 4.0
- Issuance of the Standardization 4.0 Road Map proposal; and issuance of studies related to the identification of segments or niches with greater potential for national technological development

Key sectors and actors of the innovation ecosystem for industry 4.0

The key industries with a high level of potential to increase competitiveness with the deployment of industry 4.0 technologies are automotive, oil and gas, pharmaceuticals, textiles, chemicals, food and beverages, agroindustry and aerospace and defence, according to a study issued in 2020. The national ecosystem of innovation is robust, involving many science and technology institutions, science parks, universities, firms and innovation agencies. The Chamber of Industry 4.0 seeks to involve most of the actors.

[39] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c02_I_Brazil_en.pdf.

Dominican Republic[40]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

In August 2021, Action Plan 2021–2024 of Digital Agenda 2030 was presented and launched. This includes a list of 100 projects to be executed during the period, taking into account the COVID-19 context. Components encompass the following six main areas: governance and regulatory framework; connectivity and access; digital government; education and digital capabilities; digital economy; and cybersecurity and technological innovation.

In May 2021, the Ministry of Industry, Trade and Microenterprises and SME launched the First National Strategy for the Export of Modern Services, which seeks to enhance the value chains of non-traditional sectors with significant export potential. Five working groups were created with actors from the public and private sectors to carry out actions in the short, medium and long terms on statistics, logistics and transport, professional services, the creative industries (orange economy) and ICT. The strategy involves the technologies associated with industry 4.0 as essential tools for advancing and developing national service exports. The strategy is supported by Action Plan 2021–2024, which creates a synergy of joint work for the support of all productive sectors in the Dominican Republic. Some of the initiatives with a direct impact on the diffusion of industry 4.0 in the manufacturing sector include the review of the legal and fiscal framework of the digital goods and services industry and the programme for strengthening firms in the industrial sector, comprising knowledge transfer, technical assistance with regard to business issues, strengthening of quality and the transfer of technologies for the development of digital products and services.

As part of a national strategy, the Dominican Republic is collaborating with Spain in industrial digitalization. This collaboration will be strengthened with four training courses aimed at professionals from the Dominican Republic that will be taught at the School of Industrial Organization. The Ministry of Industry and Commerce of the Dominican Republic and the Ministry of Industry, Commerce and Tourism of Spain have signed several agreements to promote digitalization in the industrial sector. The memorandum of understanding includes reference to different areas of cooperation to increase industrial added value, the qualification of employment in the sector and the development and deployment of digital solutions for industry. A joint committee on industry 4.0 was created to implement measures and approve joint projects and study their evolution.

The Organic Law of the National Development Strategy 2030 and its implementing regulations 134-15 constitute the national sustainable development plan. Additionally, a portal has been created to monitor national sustainable development.

Key sectors and actors of the innovation ecosystem for industry 4.0

The primary industries that lead innovation are free zones, public administration, the education sector, ICTs and creative industries. According to Action Plan 2021–2024, the main actors are as follows:

- Ministries: Ministry of Public Administration; Ministry of Industry, Trade and Microenterprises and SME; Ministry of the Presidency; Ministry of Economy, Planning and Development; Ministry of Finance; Ministry of Public Health; Ministry of Women; Ministry of Education; Ministry of Higher Education, Science and Technology; Ministry of Foreign Affairs; Ministry of the Interior and Police; Ministry of Public Works; Ministry of Tourism; Ministry of Agriculture
- National entities: National Competitiveness Council; National Statistics Office; National Department of Investigations; National Institute of Transit and Land Transport; National Police; National Health Service; National Institute of Public Administration; Institute of Telecommunications; Institute of Professional Technical Training; General Directorate of Ethics and Government Integrity; Government Office of Information and Communications

[40] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c30_IU_DomRep_en_es.pdf.

Technologies; Central Bank; Entities of the National Cybersecurity Council; Office of Social Policy; Presidential Commission for the Promotion of Innovation; Superintendency of Banks; Superintendency of Securities; Pro Competencia; Pro Consumidor; Consejo Nacional de Promoción y Apoyo a la Micro, Pequeña y Mediana Empresa

- Universidad Auténoma de Santo Domingo
- Private sector telecommunications companies

The Institute of Telecommunications is a key pioneer of industry 4.0 innovation in the country. As addressed in various activities, industry 4.0 is a new era with a quantitative and qualitative leap in the organization and management of value chains. This new phase involves greater automation, connectivity and globalization. The interrelation between different areas, such as products, processes and business models, has penetrated the industrial world, leading to the Internet of things and the world of big data and analytics. The Technological Institute of Santo Domingo is one of many universities promoting and researching the benefits of Industry 4.0 and, along with Loyola Specialized Institute for Higher Studies, has published a scientific investigation that considers a generic approach based on the philosophy of holonic systems and modern techniques of cyberphysical systems, as well as the use of components of industry 4.0, such as digital twins represented through systems at discrete events that allow for the monitoring and managing of desired behaviour in a production system.

Egypt[41]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

Vision 2030 is the national agenda that reflects the long-term strategic plan of the State, to achieve sustainable development principles and objectives in all areas. Under its third objective, the vision outlines the ambition of Egypt to achieve knowledge-based economic growth and digital transformation, to increase the resilience and competitiveness of the economy, promote employment and improve the business environment. Under its fourth objective, the value of innovation and scientific research as key pillars of development are noted. Similarly, the recently launched National Structural Reform Programme has industry 4.0 as one of its main pillars. The Programme focuses on expanding the relative weight of three leading sectors, namely, manufacturing, agriculture and ICT.

In 2017, a high-level interministerial committee was formulated to elaborate a national digital transformation strategy. The committee was tasked with identifying the sectors that would benefit the most from science and technological development, assessing respective technological gaps and defining needed interventions.

Digital Egypt ICT 2030 Strategy and National Artificial Intelligence Strategy, developed by the Ministry of Communications and Information Technology, have guided the upgrading of digital connectivity by mobilizing more than $1.6 billion since the mid-2018s to modernize ICT infrastructure, including efforts to replace copper cables with fibreoptic cables and investing in fifth-generation infrastructure. Regulatory frameworks (Electronic Payments Law No. 18/2019 and personal data protection law, 2020) have been addressed and the establishment in 2020 of the National Centre for Telecommunications Services Quality Monitoring has been supported, to provide detailed reporting on services. The National Telecommunications Regulatory Authority has established a road map for investing in research and development programmes for technological regulatory and standardization work on industry 4.0 that aims to finance joint research and development initiatives and partnerships.

To foster digitalization in firms, the Government provides start-ups and other businesses with guidance and resources to develop industry 4.0 technologies, such as laboratories, testing facilities and co-workspaces in six innovation clusters (Mansoura, Menoufia, Minya, Sohag, Aswan and South Valley (Qena)). The Information Technology Development Agency, under the Ministry of Communications and Information Technology, is setting up a dedicated industry 4.0 competence centre that can conduct assessments and demonstrate best use cases. The National Telecommunications Regulatory Authority has launched challenges with regard to robotics and autonomous vehicle research and has set up a financial technology fund of funds of approximately $64 million, managed by the central bank. Fiscal incentives of up to 10–20 per cent of exported value added digital services have also been introduced. The Ministry of Communications and Information Technology provides a full chain of support for ICT-related firms, from seed capital to incubation services, business consultancies and networking opportunities. Some of these are directed in particular at boosting industry 4.0 technologies, electronics design, industry 4.0 manufacturing and Internet of things systems. Through the "Our opportunity is digital" initiative, the Ministry of Communications and Information Technology is also setting aside at least 10 per cent of public digital transformation projects for SME and start-ups, boosting demand. In addition, the Ministry has introduced numerous initiatives to increase the availability and financing of training for basic digital skills and advanced courses in information technology among youth. Egypt has various platforms and initiatives for training in digital skills, such as "future work is digital" (training in web, data and digital marketing for youth); "next technology leaders" (45 advanced digital technologies for students, university staff and professionals); "Mahara technology" (training in information technology fields for youth) (Ministry of Communications and Information Technology, Information Technology Development Agency, Information Technology Institute and occasional private sector

[41] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c03_I_Egypt_en.pdf.

partners); and the Internet of Things Academy for training through the Mahara technology platform). Advanced training is also offered through the applied innovation centre, which fosters research and development and skills development through international partnerships in artificial intelligence; the train the trainers initiative for digital technology, managed by the National Telecommunications Institute and Huawei; and the advanced training centre for automation, the Internet of things and other industry 4.0 technologies, which offers vocational training. A digital platform was established by the Microenterprises and Small and Medium-Sized Enterprises Development Agency in 2018 to facilitate information-sharing with regard to the various services (e.g. financing and training) provided to microenterprises and SME.

Key sectors and actors of the innovation ecosystem for industry 4.0

Digital Egypt ICT 2030 Strategy aims to accelerate the pace of digitalization as a vehicle for development. It seeks to increase the ICT share of GDP, enhance the export capacity of Egypt from outsourcing services and create new job opportunities. This will be particularly manifested in the manufacturing and agricultural sectors. Automation and digital solutions will be promoted in the engineering, textiles, food, agribusiness and pharmaceutical industries, in addition to agricultural applications. The digitalization of the finance and energy sectors is also highlighted as an important enabler to facilitate the transition to industry 4.0 in Egypt.

Islamic Republic of Iran[42]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

Smartness, digitalization and sustainability are at the core of future scenarios for societies and economies. In the coming years, the world will change significantly. Industry 4.0 is a crucial driver of these changes and will converge many advanced technologies, especially digital ones, to boost productivity and disrupt business models. As in other developing countries, the State understands the opportunities and great potential of industry 4.0 for achieving competitive advantages.

The five pillars of national policies to catch up in industry 4.0 are as follows:

- Promote faster commercialization of advanced digital and production technologies through digital hubs and accelerators
- Reduce demand-side shortages for products and technologies of the industrial revolution by encouraging large industries to launch industry 4.0 projects. Many heavy and chemical industries, such as steel, petrochemicals and automotive, have launched programmes to digitize processes
- Upgrade skills for advanced production by organizing boot camps and start-up weekends
- Provide consultation services for digitalization through maturity models and transition road maps
- Establish specialized funds and accelerators for building an industry 4.0 innovation ecosystem

Key sectors and actors of the innovation ecosystem for industry 4.0

Heavy industries such as steel and large petrochemical plants are pioneers in using industry 4.0 in the Islamic Republic of Iran. The transformation of these energy-intensive industries is vital, to increase their competitiveness and achieve sustainability by reducing energy and water consumption.

The key actors are the Ministry of Industry, Mine and Trade; Ministry of Communications and Information Technology; Ministry of Energy; and Vice-Presidency for Science and Technology.

[42] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c37_IU_Iran_en.pdf.

Kenya[43]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

Kenya focuses on competency-based education and training at the pre-primary, primary, secondary and university levels and in technical and vocational education and training. Students are trained and skilled labour is developed to thrive in the industry 4.0 environment, the main platforms of which are artificial intelligence, the Internet of things, blockchain, data science (big data and analytics), cloud computing and cybersecurity. Kenya is combining and integrating the physical, digital and biological spheres and reskilling and upskilling to achieve a human-centred revolution.

Kenya is also promoting manufacturing by increasing FDI, reducing the cost of doing business and improving the ease of doing business. The country is also leveraging low-hanging fruit by enhancing its global competitiveness in exports of processed agroproduce.

Key sectors and actors of the innovation ecosystem for industry 4.0

To harness the national ecosystem of innovation related to industry, Kenya established a national university and industry collaborations committee with the following terms of reference:

- Assist public universities in setting up highly influential university and industry partnerships
- Meet the challenges of a knowledge-based economy
- Spearhead the development of policy issues of joint concern to universities and industry
- Help define the kinds of skills needed by graduates, such as academic depth and critical ability, flexibility, high-level transferable skills, problem-solving skills, communications skills and the ability to quickly learn on the job
- Ensure university facilities for production plants, workshops and laboratories generate income for universities
- Enhance the quality and quantity of university research through grants or contract funding
- Support initiatives for cooperation, business development and the dissemination of scientific research results
- Promote the commercialization of intellectual property, including innovations

[43] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c32_IU_Kenya_en.pdf.

Latvia[44]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

The following policy documents have been approved for the planning period 2021–2027:[45]

- National Development Plan 2021–2027
- National Industrial Policy Guidelines 2021–2027
- Guidelines for Science, Technology Development and Innovation 2021–2027
- Research and Innovation strategy for smart specialization. Latvia is planning to restructure its economy with the aim of facilitating productivity growth and the export of knowledge-intensive goods and services (smart reindustrialization). It will be focused on the following key areas: knowledge-intensive bioeconomy; biomedicine, medical technologies and biopharmacy; smart materials, technologies and engineering systems; smart energy; and ICT
- Freedom of Information Law
- Digital Transformation Guidelines 2021–2027. The guidelines provide for action in five directions and cover all key aspects of the digital societal breakthrough, including digital skills and education; digital security and credibility; access to telecommunications services; digital transformation of the economy (including public administration); ICT innovation development; and commercialization, industry and science
- Space Strategy 2021–2027
- Open data portal

Latvia has also designed and implemented several support programmes and initiatives, as follows:[46]

- Digitalization support
- Innovation motivation programme
- Business incubators
- Start-up support programmes
- Innovation vouchers and support for the attraction of highly qualified specialists
- Support for the commercialization of the results of scientific projects
- International competitiveness development
- Green channel (to relieve administrative burdens for high value added investments)

Key sectors and actors of the innovation ecosystem for industry 4.0

The main industries engaged in industry 4.0 are telecommunications, electronics, logistics, smart mobility and biotechnology.

44 See https://unctad.org/system/files/non-official-document/CSTD2021-22_c06_I_Latvia_en.pdf.

45 See https://www.pkc.gov.lv/sites/default/files/inline-files/NAP2027__ENG.pdf, https://www.em.gov.lv/lv/media/4157/download, http://polsis.mk.gov.lv/documents/7053, https://www.izm.gov.lv/en/smart-specialisation-strategy, https://likumi.lv/ta/en/en/id/50601-freedom-of-information-law, https://likumi.lv/ta/id/324715-par-digitalas-transformacijas-pamatnostadnem-20212027-gadam, https://www.varam.gov.lv/en/article/latvian-digital-transformation-guidelines-2021-2027-accellation-digital-capacities-future-society-and-economy, https://www.izm.gov.lv/en/space-policy and https://data.gov.lv/lv.

46 See https://www.em.gov.lv/lv/digitalizacija, https://www.liaa.gov.lv/lv/programmas/inovaciju-motivacijas-programma, https://www.liaa.gov.lv/lv/programmas/biznesa-inkubatori, https://www.liaa.gov.lv/lv/programmas/jaunuznemumu-atbalsta-programmas, https://startuplatvia.eu/innovation-voucher, https://www.liaa.gov.lv/lv/programmas/atbalsts-petniecibas-rezultatu-komercializacijai, https://www.liaa.gov.lv/lv/programmas/skv and https://www.liaa.gov.lv/en/article/minister-economics-latvia-new-fast-track-green-channel-will-significantly-contribute-latvias-economic-breakthrough.

Several networks are involved in the industry 4.0 innovation ecosystem. Some of the key networks are as follows:[47]

- Information technology cluster
- Information and Communications Technology Association
- European Digital Innovation Hubs, of which Latvia will have two
- Annual Fifth-Generation Techritory, the leading fifth-generation ecosystem forum in Europe

Some of the companies that are part of the innovation ecosystem are as follows:[48]

- Latvia State Forests. Innovative logistics system; implementation of geospatial information technology products and services, drones and robots
- Latvia Mobile Telephone. Introducing fifth-generation technology and autonomy of autonomous aircraft; connecting fifth-generation industry players to enable the development of new solutions for connected and automated mobility; virtual call management platform developed for use in mobile networks, replacing traditional, voice over Internet protocol and cloud-based private branch exchanges with a single solution. Sparta is one of four European Union projects aimed at strengthening the region's resilience and capabilities in cybersecurity; using artificial intelligence to transform urban data into valuable information that ensures increased road safety and traffic optimization; powering drones with artificial intelligence and sensors to enhance the success of rescue missions such as search operations, during forest fires and others; and the cross-border electronic solution with regard to the United Nations Conference on the Carriage of Goods by Sea will significantly ease exchanges of cargo information between countries and benefit transit speed
- SAF Tehnika. Accumulated experience, world-class intellectual capacity and a team of like-minded suppliers are the essential assets behind customized microwave solutions. The commitment to an industry-rare capability to design, develop and produce hundreds of supported, customer-tailored product variations, as well as numerous specific, user-adapted application techniques and features for products, linked by a feature-rich SAF network management system
- Conelum. A biotechnology start-up using artificial intelligence in microbiological testing and measuring cell clusters. Solutions help reduce the risk of product recalls, save products and reputations, enable reacting on time and minimize negative consequences of unlikely events of outbreaks
- Mikro Tik. Provides hardware and software for Internet connectivity in countries around the world
- Mobilly. Convenient and user-friendly billing system for mobile telephones. The Mobilly application allows users to make payments for car park fees, Jurmala entry fees, taxi services, postage, train and bus tickets, supplement Bite cards, Helio interactive television codes, donations and other goods and services
- Dots. Strives to take a different approach by using the latest advancements in cloud and machine learning to solve challenges related to efficiency, mobility and security
- Tilde. Drives innovation in European language technologies, provides worldwide award-winning language technology, translation and localization services; provides localization services; develops custom machine translation systems; and offers online terminology tools for a wide range of languages

[47] See https://www.itbaltic.com/, https://likta.lv/en/home-en/, https://likta.lv/platina-pele/, https://digital-strategy.ec.europa.eu/en/activities/edihs and https://www.5gtechritory.com/.

[48] See https://innovations.lmt.lv/solutions/, https://www.saftehnika.com/en/about#, https://www.conelum.com/about_us.html, https://mikrotik.com/aboutus, https://mobilly.lv/en/about-mobilly/, https://www.wearedots.com/en/about-us and https://www.tilde.com/.

Peru[49]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

There are several initiatives in each sector of the Government, whether in transport and communications, production, energy and mines, education, health, foreign trade or agriculture, among others. The Government has also implemented several standards, strategies and programmes related to industry 4.0, as follows:

- Supreme Decree No. 015-2016-PCM, approves the National Policy for the Development of Science, Technology and Technological Innovation
- Supreme Decree No. 345-2018-PCM, approves the National Competitiveness and Productivity Policy
- Supreme Decree No. 255-2019-EF, approves the National Policy of Financial Inclusion and modifies Supreme Decree No. 029-2014-EF, which creates the Multisectoral Commission for Financial Inclusion and approves the National Policy of Financial Inclusion
- Emergency Decree No. 006-2020, creates the National Digital Transformation System
- Urgency Decree No. 007-2020, approves the Digital Trust Framework and provides measures for its strengthening
- Legislative Decree No. 1412, approves the Digital Government Law
- Supreme Decree No. 029-2021-PCM, approves the Regulation of Legislative Decree No. 1412, which approves the Digital Government Law. It establishes provisions on the conditions, requirements and use of electronic technologies and media
- National Digital Transformation Policy, the priority objectives of which have been presented and are in the process of approval
- National Artificial Intelligence Strategy, which was presented at the national level, with comments received until 4 June 2021, and is now in the review process for approval by supreme decree[50]
- National Data Governance Strategy, which was presented at the national level and received comments from the public until 17 September 2021, to be analysed and incorporated, with a final review carried out for approval by supreme decree[51]
- National Strategy for Security and Digital Trust, which was presented at the national level and is now in the process of review for approval by supreme decree[52]
- National Digital Talent Strategy, the design of which has begun, with a committee of experts[53]

National Science, Technology and Innovation Policy 2021–2030 is also being completed, including the mechanisms for adopting and developing 4.0 technologies.

Key sectors and actors of the innovation ecosystem for industry 4.0

The key industries in the use of industry 4.0 technologies are manufacturing, agribusiness, mining, banking and finance, commerce and telecommunications.

The key actors are universities (National University of Engineering, National University of San Marcos, Universidad Peruana Cayetano Heredia, Pontificia Universidad Católica del Perú, Universidad

[49] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c33_IU_Peru_en.pdf.

[50] See https://www.gob.pe/13517-participar-de-la-estrategia-nacional-de-inteligencia-artificial and https://www.gob.pe/institucion/pcm/informes-publicaciones/1929011-estrategia-nacional-de-inteligencia-artificial.

[51] See https://www.gob.pe/institucion/pcm/informes-publicaciones/2046259-documento-de trabajo-para-la-Estrategia-nacional-de- government-of-data and https://www.gob.pe/14331.

[52] See https://www.gob.pe/institucion/pcm/informes-publicaciones/1998221-estrategia-nacional-de-seguridad-y-confianza-digital.

[53] See https://www.gob.pe/institucion/pcm/noticias/514817-pcm-inicia-diseno-de-la-estrategia -national-digital-talent-as-part-of-the-drive-for-digital-citizenship-in-the-country.

Nacional Agraria La Molina, among others), business groups (Grupo Breca, Intercorp and Belcorp, among others) and public entities specialized in innovation and technological development (network of productive innovation and technology transfer centres, Pro Innovate and Pro Ciencia programmes and National Science Council, Technology and Technological Innovation).

The public programmes described are essential in the development and promotion of industry 4.0. For example, the Pro Innovate programme is a strategic actor of the Government in strengthening specific actions concerning business innovation. Its mission is related to the objective of promoting industry 4.0 in the medium and long terms: "We manage funds for the generation of innovative projects, selecting, co-financing and technically accompanying those with the greatest potential, promoting productive development and strengthening the actors of the national business innovation system, which will be reflected in increasing business competitiveness and productivity in the country". Similarly, the Pro Ciencia programme captures, manages, administers and channels resources from national and foreign sources destined for National System of Science, Technology and Innovation activities. At the same time, universities generate large spaces for development in industry 4.0; taking into account their experience and infrastructure in terms of highly specialized major laboratory equipment, they carry out innovation, development and research work. They include the Centre for Innovation and Entrepreneurial Development of the Pontificia Universidad Católica del Perú; Incubator 1551 at the Universidad Nacional Mayor de San Marcos; Ventures, the accelerator of Universidad San Ignacio de Loyola; and Start-up Uni, the technology-based business incubator of the National University of Engineering.

Philippines[54]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

The President has signed a law aimed at harnessing innovation efforts to help the poor and marginalized and to enable microenterprises and SME to be part of domestic and global supply chains. Innovation Act, or Republic Act 11293, mandates the Government to promote local innovation through relevant provisions, which will push the country towards more significant progress. Enabling national microenterprises and SME with skills and technology to sustain their businesses also means propelling the country to rise with and above neighbouring countries in South-East Asia.

Another related law is Innovative Start-up Act, or Republic Act 11377, which aims to create initiatives that will provide benefits and incentives to start-ups and start-up enablers in the country. Its provisions include full or partial subsidies in the use of facilities, office space and equipment and services provided by the Government or private enterprises and institutions, as well as grants for research, development, training and expansion projects.

The Department of Trade and Industry, a government partner of the Department of Science and Technology (DOST) in innovative programmes and activities, is also at the forefront of the Inclusive Innovation-led Industrial Strategy. In 2017, the Government upgraded the Comprehensive National Industrial Strategy framework and released the Inclusive, Innovation-led Industrial Strategy. It retains goals from the former framework, that is, strengthening domestic supply chains, deepening participation in GVCs and removing obstacles to growth to attract investments. Building an inclusive innovation ecosystem is listed as an additional goal, underscoring the importance of innovation in the industrial strategy and ultimately in transforming the economy, especially in moving towards industry 4.0. Accordingly, the framework was revised, adding industry 4.0 as one of the external factors affecting industry growth. The fourth industrial revolution will lead to new challenges and opportunities, and to take part and survive, the Philippines must build an innovative ecosystem. The Government has therefore placed innovation at the centre of the industrial strategy.

DOST leads different initiatives to push forward the country's transition to industry 4.0. Through its attached agency, the Advanced Science and Technology Institute, DOST conducts various programmes and projects that are aligned with national priorities and the research and development agenda. One of the pillars is focused on increasing potential growth. In support of this, one of the outcomes identified in Development Plan 2017–2022 to address the country's potential growth is to build the foundation for a globally competitive knowledge economy in which accelerated technology adoption and stimulated innovation are at the forefront. This is an opportune time to embrace what industry 4.0 has to offer. The DOST Advanced Science and Technology Institute is not lagging behind its counterparts in Asia and the Pacific in terms of its efforts in deploying critical science and technology infrastructure and undertaking research and development in ICT and electronics that could effect change in society. The following three flagship programmes of the Institute are crucial in driving and spearheading the science and technology sector towards industry 4.0:

- Emerging research and applications
- Environment for extreme computing performance, networks and data
- Intelligent systems innovation for the Philippines

Other DOST initiatives in support of industry 4.0 include, but are not limited to, the following:

- Launching of DOST artificial intelligence programmes and technologies. Artificial intelligence for better normal development of capability-building efforts such as the learning at scale programme, AI Pinas and Sparta, since 2016, to increase the country's competitiveness

[54] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c34_IU_Philippines_en.pdf.

and ensure the maximum economic and social benefits of artificial intelligence. DOST is implementing programmes and initiatives to build capacity and upskill microenterprises and SME in industry, researchers and other communities

- Small enterprise technology upgrading programme. A nationwide strategy to encourage and assist SME to adopt technological innovations to improve operations and thereby boost productivity and competitiveness. The programme provides microenterprises and SME with equipment and technical assistance to enable them to increase sales and production, streamline and improve overall company operations, upgrade the quality of products and services, conform to national and international standards of excellence and be competitive in their respective fields. DOST is transitioning to small enterprise technology upgrading programme 2.0, to help microenterprises and SME in digitalization and automation aspects. DOST is enhancing the implementation of the programme to align with industry 4.0
- Science for change programme. Created to accelerate STI in the country to keep up with developments in which technology and innovation are game changers. Through the programme, DOST can significantly accelerate STI in the country and create a significant increase in investment in science and technology human resources development and research and development
- Niche centres in regions for research and development, to promote regional development
- Research and development leadership programme. Engages research and development experts to lead in strengthening the research capabilities of higher education institutions and research development institutions
- Collaborative research and development to leverage the Philippines economy programme. Creates a synergistic academia and industry relationship to invigorate research and development
- Business innovation through science and technology programme. Facilitates the acquisition of strategic and relevant technologies by companies in the Philippines to support research and development activities

Other different policies, laws, programmes and initiatives in the Philippines related to industry 4.0 are as follows:

- Advancing research and development. Republic Act 11035, institutionalizing the Balik Scientist Programme; DOST harmonized national research and development agenda; Republic Act 10055, Technology Transfer Act, 2009; Intellectual Property Act
- Connectivity. Republic Act 10844, ICT Development Agenda, 2015; National Broadband Plan; Republic Act 10173, Data Privacy Act, 2012; National Cybersecurity Plan; Republic Act 10173, Data Privacy Act, 2012
- Industrial policies. Electronic Commerce Act, 2008; Manufacturing Resurgence Programme; Comprehensive National Industrial Strategy; Inclusive Innovation-led Strategy; Republic Act 11032, Ease of Doing Business and Efficient Government Service Delivery Act, 2018; Republic Act 9485, Anti-Red Tape Act, 2007
- Fostering competition. Republic Act 10667, Competition Act, 2015
- Higher education. Republic Act 10931, Universal Access to Quality Tertiary Education Act; Republic Act 10647, Laddered Education Act, 2014; Executive Order 330, Expanded Tertiary Education Equivalency and Accreditation, 1996

Key sectors and actors of the innovation ecosystem for industry 4.0

The key industries that are pioneers in industry 4.0 innovation are smart manufacturing; tools, dies, iron and steel; additive manufacturing; shipbuilding; transport, logistics, construction and tourism; furniture, garments and creative; innovation and research and development; energy; climate change; smart agrifood, agribusiness and health; aerospace; mining and mineral processing; chemicals; automotive and automotive parts; pharmaceuticals; and electrical and electronics, including semiconductors.

Under the three flagship programmes of the DOST Advanced Science and Technology Institute, initially identified research areas are as follows:

- Emerging research and applications
- Space technology, wireless systems, industrial automation, embedded smart systems, autonomous and intelligent robotics and vehicle technology
- Environment for extreme computing performance, networks and data
- Advanced networks, high-performance computing, grid and cloud computing and data management and analytics
- Intelligent systems innovation for the Philippines
- Artificial intelligence in creative arts, computer vision, natural language, weather risk; Internet of things, quantum computing, edge artificial intelligence, intelligent application programming interface and blockchain for governance

The key actors of the ecosystem are the Government, such as through DOST, academia and education (e.g. State universities and colleges and the Technical Education and Skills Development Authority); industry (e.g. food microenterprises and SME; private electronics and manufacturing companies); financial institutions (e.g. DOST Small Enterprise Technology Upgrading Programme, start-ups, Land Bank of the Philippines and Development Bank of the Philippines); and regulators (e.g. government agencies such as the Department of Trade and Industry and the Food and Drug Administration).

- DOST also has innovation hubs as part of the key networks of the ecosystem, such as the following:
- DOST Food Innovation Centre
- DOST Modular Multi-Industry Innovation Centre
- DOST Advanced Manufacturing Centre
- DOST Advanced Mechatronics, Robotics and Industrial Automation Laboratory
- DOST One Store, One Expert and One Lab

Portugal[55]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

A national strategy for industry 4.0 was launched in 2017 and was updated in 2019 and titled Portugal i4.0. The strategy aims to disseminate and boost the adoption of advanced technologies and smart production in industrial sectors. The programme attaches particular importance to the qualification of human resources in the digital technologies associated with smart technological production.

The second phase of Portugal i4.0 is addressed to a larger number of companies, following the first phase of the demonstration of advanced technologies oriented towards industrial players with some technological intensity.

Key sectors and actors of the innovation ecosystem for industry 4.0

Industries that are pioneers include machinery, automotive, moulds, plastics and electronics.

Key actors are as follows:

- Public bodies: Agência para a Competitividade e Inovação; Agência Nacional de Inovação; Programa Compete 2020 (to be followed by a new programme towards 2030)
- Universities: Faculdade de Engenharia da Universidade do Porto; Instituto Superior Técnico, Universidade de Lisboa; Universidade do Minho
- Associate laboratories: Laboratório Associado de Sistemas Inteligentes (with the coordination of Faculdade de Engenharia da Universidade do Porto)
- Interface institutions: Institute of Systems and Computer Engineering, Technology and Science; Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial; DTX Digital Transformation Colab
- Business initiatives and associations: Associação Empresarial para a Inovação; Production Technologies Association
- Innovation platforms: Portugal i4.0

[55] See https://www.portugal.gov.pt/pt/gc21/comunicacao/noticia?i=20170130-mecon-industria-4.

Russian Federation[56]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

There are several Government regulations in specific areas of industry 4.0, including the following:

- National Strategy for the Development of Artificial Intelligence until 2030, enacted by Presidential Decree No. 490, 10 October 2019, defining the goals, key areas and mechanisms for the development of artificial intelligence
- Federal project on artificial intelligence, approved on 27 August 2020 by the Presidium of the Governmental Commission on the Use of Information Technologies for Improving Quality of Life and Business Environment, aimed at implementing the strategy
- Concept for the development of regulation of relations in the field of artificial intelligence technologies and robotics until 2024, enacted by Government Order No. 2129-r on 19 August 2020
- Government Decree No. 317 on the implementation of the national technology initiative, 18 April 2016, which is a long-term inter-agency public–private partnership programme, seeking to promote the development of new promising market sectors based on high-technology solutions that will drive the development of the global and Russian Federation economy within the next 10–20 years

The national technology initiative is focused on markets, emerging from a new technological paradigm, which developed countries are planning to shift to in the next 10–20 years. These markets either do not exist at present or are not yet mature enough. The initiative identifies the following nine key market sectors for development: air transport; automotive transport; maritime transport; neurocommunications; medicine; food; energy; industrial production; and security.

The mechanism of Innovative Science and Technology Centres was introduced in 2017. Pursuant to Federal Law No. 216-FZ, 29 July 2017, the Ministry of Economic Development is empowered to launch and develop Innovative Science and Technology Centres as an authorized federal executive body. The centres are an effective tool for combining the efforts of science, education and business. They are designed to arrange the transfer of scientific competencies from universities into business practice and to encourage students and researchers to develop technologies that are in demand in the market, as well as to assist technology companies and start-ups. The centres have special legal status for conducting scientific research and applying innovative solutions.

The leaders of industry 4.0 in artificial intelligence are member companies of the artificial intelligence alliance such as Sberbank, Yandex, Mail.ru Group, Gazprom Neft, MTS and the Russian Federation Direct Investment Fund.

The booming growth and spread of digital technology in recent years have significantly changed the face of key sectors of the economy and social sphere. Industry 4.0 envisions end-to-end digitalization of all physical assets and their integration into the digital ecosystem, together with partners involved in the value chain. Digital technology has become a key component in almost all areas related to the pandemic. This includes vaccine development, online learning, remote working and electronic commerce. However, given the current divide between those who have access to the Internet and those who do not, the digital gap may well become a new face of disparity. This is why the Government is making extensive efforts to provide all of the country's citizens with access to the Internet, understanding that the transition to electronic government and municipal services will contribute to improving both people's standards of living and the business environment. Electronic government applications reduce administrative barriers, save time and simplify the registration of businesses and the obtaining of approvals and clearances of all kinds.

As set forth in the mission statement of the Government, in 2020, one of the priority goals of the

[56] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c35_IU_Russia_ru_en.pdf.

Ministry of Digital Development was the introduction of digital technologies and platform solutions in the fields of public administration and services, including those in the interests of the public and SME, including individual entrepreneurs. Activities in this area resulted in a number of initiatives, such as the following:

- Super services. A new type of government electronic services that minimize the use of paper documents and the need to attend government offices
- Development of communications infrastructure
- Unified system of identification and authentication in infrastructure. This provides for the informational and technological interaction of information systems used for the provision of public and municipal services in electronic form. It is a federal Government information system designed to provide authorized access to information in governmental and other information systems
- Federal Register of State and Municipal Services. This federal government information system provides for the development of a subsystem to deliver State and municipal services (government services portal)

Industry 4.0 envisions the large-scale adoption of cyberphysical systems to satisfy people's common needs in day-to-day life, at work and in leisure time. End-to-end digital technologies are not linked to a single product or area of activity but can be applied to many industries, branches and sectors of the economy, for example, education, medicine, energy, construction, agriculture, engineering and others, thereby becoming one of the key elements of industry 4.0. Efforts to build an end-to-end digital environment have included activities in certain areas and already achieved results, in particular the following:

- Update of the federal project on digital technologies, aimed at ensuring the technological independence of the country, upgrading the capabilities of the national research and development system for the purpose of the commercialization of results and accelerating the technological development of companies in the Russian Federation to boost the competitiveness of their products and solutions in markets in the Russian Federation and abroad
- A comprehensive methodological and financial support system established as part of the federal project on digital technologies, to facilitate the digital technology development and digital transformation of companies

These efforts provide for a set of measures to assist methodologically in the development and implementation of corporate digital transformation strategies on the basis of Russian Federation information technology solutions, to spur technological start-ups in the Russian Federation, to offer grant support to small and large developers of information technology solutions in the Russian Federation and to co-finance the introduction of such solutions in domestic companies, provide venture funding to projects and subsidize borrowing and leasing initiatives. The set of measures is intended to support projects at any stage of technological readiness, ranging from concept or prototype development and start-up acceleration to fully-fledged production and scaling-up of best domestic solutions. In 2020, competitions resulted in the following: 254 innovative small business start-ups, developing and commercializing Russian Federation information technology solutions, received approval for grants of Rub 2.8 billion; 12 pilot information technology projects were approved to receive up to Rub 750 million; and a further Rub 1 billion was allocated in grants for 10 other digital technology projects. Other activities include the following:

- A programme of subsidized loans has been initiated to stimulate the digital transformation of business processes, with up to 15 banks selected for the programme (and another 40 willing to participate) that, encouraged by the Ministry of Digital Development, compiled a loan portfolio for 25 projects, seeking Rub 34.5 billion, and nine projects have received approval to date

- A methodology has been devised for companies to implement measures of digital transformation. For example, updates have been made to the methodical recommendations on digital transformation of State corporations and companies with State participation
- High-end technological advances that require centralized applied research and development of domestic equipment and machinery are making use of resources and competencies of the largest State-controlled technology companies through special agreements with the Government. Road maps have been approved, to give impetus to the development of innovations in the country, including in the fields of quantum computing, quantum communications, fifth-generation mobile networks, the Internet of things and distributed registry technologies

While taking anti-crisis measures in 2020, the Government continued its efforts to put the development of industry 4.0 in the country on a sustainable path. The Government signed a memorandum of intent with the State corporations Rosatom and Rostec to launch an end-to-end digital initiative called New Production Technologies. The agreement was concluded in fulfilment of the federal project on digital technologies of the digital economy national programme. The goal of the road map is to ensure the transition of industry in the Russian Federation to a digital platform that will incorporate both design and production in a common virtual environment. The central role in this technological loop should be played by digital tools for the planning, verification and modelling of industrial processes. The road map places particular emphasis on digital twin technology, which is an integrator of almost all end-to-end digital technologies and subtechnologies used in industrial applications worldwide.

South Africa[57]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

Digital Futures: South Africa Digital Readiness for the Fourth Industrial Revolution, in relation to the National Development Plan, sets out the mandate on industry 4.0, with national policy objectives of economic growth, job creation and inequality reduction. The policy perspective is critical, to ensure that the preconditions necessary to harness the benefits of the fourth industrial revolution are achieved, if the technologies are to serve developmental purposes with meaning, rather than intensify present social, economic and political inequalities.

One programme is Digital Advantage 2035, which operates through the Council for Scientific and Industrial Research to provide the capacity to implement the ICT road map developed by the Department of Science and Innovation in 2012. The ICT Research, Development and Innovation Implementation Road Map is a plan to guide the implementation of the national ICT research, development and innovation strategy. The road map is driven by the potential to deliver socioeconomic impacts and illustrates a good public and private investment in ICT research and development. Digital Advantage 2035 is intended to enable South Africa to become a significant player in the global ICT research, development and innovation arena through the following:

- Providing more targeted engagement with industry
- Focusing on international collaboration
- Accomplishing more comprehensive and transparent monitoring of investment
- Making an impact, such as through job and business creation, contribution to GDP, societal influence and positioning South Africa for strategic advantage

The Presidential Commission on the fourth industrial revolution presented its report in 2020. The report was a government-wide proposed strategy that highlighted key challenges, pillars and enablers for the fourth industrial revolution in South Africa. The Commission made recommendations spanning such strategic areas as the country's investment in human capital; artificial intelligence; advanced manufacturing and new materials; the provision of data to enable innovation; and future industries and fourth industrial revolution infrastructure. In 2017, the World Economic Forum launched the Centre for the Fourth Industrial Revolution Network, with the mission of ensuring that the revolution does not benefit a select few but all of society. The methodology is a human-centric approach that is agile and based on rapid iteration. The intent is for the network to serve as the following:

- A space for global cooperation. The Centre is dedicated to co-designing policy frameworks and governance protocols, including laws, regulations, norms and best practices that accelerate the application of science and technology in the global public interest
- A "do-tank". Partner Governments and companies will co-design and pilot frameworks and protocols for rapid iteration and scale. The Centre is not a think-tank but rather a "do-tank"
- A champion for ethics and values in technology. All policies, frameworks and regulations developed at the Centre will prioritize ethics and values

The Centre has established centres globally and begun its expansion into other regions through its affiliate centre model. An affiliate centre was established in South Africa, hosted at the Council for Scientific and Industrial Research.[58]

Key sectors and actors of the innovation ecosystem for industry 4.0

The National Advisory Council on Innovation mobilizes the National System of Innovation stakeholders and provides access to local and international experts who complement limited resources. The National System of Innovation is a network of institutions and resources in the

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[57] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c08_I_SouthAfrica_en.pdf.

[58] See https://www.c4ir-sa.co.za/.

public and private sectors that develop, share, support and promote science and technology innovations, knowledge, skills, performance and learning at the national level.

A major Department of Science and Innovation initiative, together with the National Research Foundation, is the multibillion-rand Square Kilometre Array, which is hosted in South Africa and Australia, and extends into eight countries in Africa. The Array will be the world's largest telescope and one of the largest scientific projects and multinational collaborations in the name of science. The amount of data being collected and transmitted by the Array means the project requires supercomputing power and big data management and analytics capabilities.

The Council for Scientific and Industrial Research has strengthened industrial development in the country, such as through the affiliate centre of the World Economic Forum Centre for the Fourth Industrial Revolution Network, joining China, India and Japan. The focus is on understanding and dealing with technology governance challenges that prevent innovation and the effective deployment of technologies. The centre will be a multi-stakeholder partnership, bringing together Government, business and other non-State actors to jointly assess technology governance challenges and develop arrangements that can address the requirements of different stakeholders. The key portfolios include artificial intelligence and machine learning, the Internet of things, robotics, smart cities and digital trade.

Switzerland[59]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

The Federal Council is addressing digitalization with the horizontal umbrella strategy Digital Switzerland. The strategy comprises various fields of action (economy, research and innovation, artificial intelligence, etc.) and an action plan with around 160 measures. The strategy is based on a multi-stakeholder approach and is updated regularly. In its current version, the focus is on environmental issues and data policy. There is no official strategy or programme regarding industry 4.0. Switzerland has an innovation policy that is not structured within the framework of a single comprehensive innovation strategy but rather in a decentralized manner and within several independent policy areas that are coordinated as needed. This gives individual actors in research and development and in the corporate world a high degree of autonomy. In addition, it enables tailored responses, to address new challenges and harness new opportunities. This bottom-up approach also applies in principle to industry 4.0 as a subarea of digitalization.

Switzerland is focused primarily on creating optimal framework conditions for various types of business models, including the digital economy. In connection with digitalization and/or industry 4.0, Switzerland does not provide targeted subsidies for industries and/or technologies. To fully exploit the economic potential of digitalization, Switzerland pays particular attention to framework conditions in the following areas: education and further education (digital skills, etc.); the research environment; data protection (legal security, trust); cyberrisks; and efficient and secure ICT infrastructure. In addition, necessary regulatory adjustments are addressed (e.g. financial technology) and digital government services are promoted.

The private initiative Industrie 2025 is the national initiative with the goal of driving forward the digital transformation in the manufacturing sector. It brings together stakeholders and deepens existing knowledge and experience and makes them freely available. It ensures the introduction, support and embedding of industry 4.0 concepts in added value networks and production companies. Industrie 2025 was founded in June 2015 by various industry associations.

From a labour market policy perspective, the guiding question is how to enable labour markets to deal with structural change in general, as well as more recent phenomena such as industry 4.0. In Switzerland, the following elements are of particular interest in a phase of rapid change:

- Promote a business environment conducive to growth and job creation. Competition is a driver of innovation and productivity growth. Labour market regulation should enable the reallocation of workers towards the most productive firms
- The supply of skills should be permanently adapted to changing labour market needs. In Switzerland, with its dual apprenticeship system, the link between education and industry is close. Cooperation between education and the business sector will be a cornerstone of successful skills policies in future
- The adaption of skills (including digital skills) will be an issue for youth but more often for older persons as well. Preparing the adult workforce to work with new technologies will be a key focus of skills policies in Switzerland in the coming years
- Protection of workers against labour market risks should go together with incentives and support to find new jobs

Key sectors and actors of the innovation ecosystem for industry 4.0

Economic actors organize themselves into numerous initiatives that deal directly or indirectly with the topic of industry 4.0, as follows: Industrie 2025; Swiss Smart Factory; Swiss Data Alliance;

[59] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c09_I_Switzerland_en.pdf.

Swiss Cognitive; Digital Switzerland; Crypto Valley; and Trust Valley.[60] In addition to these activities, companies pursue their own projects. With regard to artificial intelligence, they address aspects such as ethical guidelines, the responsible use of artificial intelligence or similar topics, to promote trust in products and services in which artificial intelligence is used.

Most higher education institutions, federal institutes of technology and universities of applied sciences are heavily involved in the subject of artificial intelligence, the Internet of Things, blockchain and robotics, from a wide variety of perspectives, including the following: Institute of Robotics and Intelligent Systems; Istituto Dalle Molle di Studi sull'Intelligenza Artificiale; Institut de recherche IDIAP; Swiss Data Science Centre; Datalab, the ZHAW Data Science Laboratory; UZH Blockchain Centre; and EPFL Centre for Intelligent Systems and Innovation Park.[61]

60 See www.industrie2025.ch, https://www.sipbb.ch/en/forschung/swiss-smart-factory/, https://www.swissdataalliance.ch/, https://swisscognitive.ch/, https://digitalswitzerland.com/de/, https://cryptovalley.swiss/ and https://trustvalley.swiss/en/.

61 See https://www.idsia.ch/, https://www.idiap.ch/fr, https://datascience.ch/, https://www.zhaw.ch/de/forschung/departementsuebergreifende-kooperationen/datalab/ and https://www.blockchain.uzh.ch/.

Thailand[62]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

National Strategy 2018–2037 is the core development strategy. Under the plan, the Thailand 4.0 initiative is implemented as a new economic model based on innovation, creativity, high-quality services and new technology employed for boosting the quality of life. The Thailand 4.0 initiative is a steppingstone in the advancement of the country's development, especially through future industries and services that can be key growth engines designed to push Thailand to become a developed country. The digital industry, including data technology and artificial intelligence, is one of the 10 strategic (S-curve) industries, through which to achieve the Thailand 4.0 policy.

Thailand has implemented a number of policies to harness the potential of the fourth industrial revolution, known as the Thailand 4.0 policy. Thailand 1.0 (1961) focused on agriculture and handicrafts. In 1982, Thailand moved to develop light industry (import substitution, consuming natural resources, low-cost labour) and in 1997, expanded to heavy industry (export-led, promoting FDI, importing high-technology). Thailand 4.0 is a concept that has been used since 2018. It is a visionary scheme with the aim of transforming the country into a value-based and innovation-driven economy. Thailand 4.0 is applied and implemented in conjunction with the twelfth national economic and social development plan and the 20-year national strategy, aimed at promoting an annual GDP growth rate of about 5 per cent, to become a developed country.

The 20-year industry 4.0 strategy (2017–2036) was written by the Ministry of Industry to drive the Thailand 4.0 policy under the vision of moving "toward the intelligence industrial and link to global economy". This strategy aims to promote an industrial GDP growth rate of at least 4.5 per cent per year, investment in industrial sector growth of at least 10 per cent per year, export growth of at least 8 per cent per year and total factor productivity growth of at least 2 per cent per year. This is the rate of expansion that will allow Thailand to move to a high-income country by 2036, according to the goals of the national strategy.

The Ministry of Industry is responsible for the national strategy and plan concerning industrial development. The revised National Industrial Development Plan 2017–2021 sets the vision for industry to be driven by innovation, eco-friendliness and the global economy by 2021. The plan outlines strategies in the following four areas:

- Enhance capacity and foster the growth of industry by promoting the use of STI and digitalization in product development and production efficiency improvement; developing the skills management, technology and innovation of entrepreneurs, workers and all players in the value chain; encouraging the value addition of domestic raw materials and effectively managing local supply to fulfil the demand for raw materials; improving product standards and inspection processes to enhance industrial competitiveness and provide consumer protection; increasing the efficiency of logistics and supply chain management; and elevating national target industrial clusters to Association of Southeast Asian Nations industrial clusters
- Strengthen an industrial ecosystem to support the transformation to industry 4.0 by creating a conducive legal and regulatory framework for businesses; developing economic and industrial intelligence for policy setting and early warning for industrial development; designing urban planning for industrial development; and establishing and strengthening design and inspection centres for industrial products and processes
- Promote responsible production by designing compliance and enforcement mechanisms; supporting the development of eco-industrial towns; establishing integrated industrial waste management systems with a focus on waste utilization; upgrading potential industrial clusters to eco-industry; promoting eco-efficiency and the creation of eco-friendly products; and advocating for environmental impact monitoring and management organizations with public engagement

[62] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c36_IU_Thailand_en.pdf.

- Improve the industry-related service efficiency of government agencies by promoting ethics, good governance and anti-corruption; improving process efficiency and ensuring adequate resources and information technology tools; strengthening human resource development; and striving to provide quality services

In line with the national strategy, the Ministry of Digital Economy and Society has launched the Digital Economy and Society Development Plan as a framework for utilizing digital technology as a key mechanism for national economy and social development. Within this context, the Digital Economy Promotion Agency, a government agency under the Ministry, has launched the Digital Economy Promotion Master Plan, focusing on transforming traditional industry to industry 4.0 through technology development and adoption on both the supply and demand sides. In particular, the agency aims to drive development in value-based industries such as high value added hardware and software, the platform economy and creative digital content, along with helping traditional hardware and software industries to adapt to the industry 4.0 era.

Key sectors and actors of the innovation ecosystem for industry 4.0

Ten newly targeted industries have been selected to serve as new and more sustainable growth engines and are divided into two segments, namely, five S-curved industries (new-generation automotive; smart electronics; affluent, medical and wellness tourism; agriculture and biotechnology; and food for the future) and five new S-curved industries or nascent high-technology industries slated to become significant long-term growth drivers (manufacturing robotics; medical hub; aviation and logistics; biofuels and biochemicals; and digital).

There is no regulatory body designated as the key actor of the innovation ecosystem for industry 4.0, as it is a national issue that requires cooperation between all stakeholders, including the public sector, the private sector, academic institutions and research centres, to drive industry in Thailand towards industry 4.0. At present, government agencies are key actors driving industry 4.0 and work closely with the education and private sectors to develop many important actions. The key steps can be divided into six activities, as follows:

- Promote research and development investment, social adoption and commercialization. Invest in research and development and technology in competent industries; invest in research and development and technology, resulting in a leap in growth; invest in research and development and technology for society to promote inclusive growth and quality of life; accelerate research and development and technology transfer to farmers, community enterprises and SME; develop the technology and market in Thailand for innovative product; and promote a world-class intellectual property system and national quality infrastructure
- Develop technopreneurs. Enhance entrepreneurs to play a key role in innovation and technology development and co-lead direction with the Government, academia, etc.; promote innovation, especially in design and technology development; promote a culture of intellectual property rights protection; facilitate start-up and SME access to capital and funds; and provide a proper environment for districts and communities to learn and develop creative thinking
- Develop a proper environment for the promotion of science, technology, research and innovation (develop human resources in science, technology, engineering and mathematics (increase human resources in education in science, technology, engineering and mathematics; enhance researcher capability; use tax incentives to attract specialists from abroad); science and technology infrastructure (improve effective research systems; promote quality infrastructure systems; accelerate government ICT; support new financial tools; promote the sharing of research and development facilities; encourage and accelerate regulatory reform); develop public management systems (restructure public organizations; improve government budgeting systems; launch a technology development road map; encourage knowledge exchanges))
- Attract investment in future industries and services
- Promote the Eastern Economic Corridor as a growth engine. Drive the country’s investment in

uplifting innovation and advanced technology for future generations

- Industry Transformation Centre. Enhance the productivity and capability of the industrial sector. The Centre is an integrated service centre that aims to develop the products, processes and people of industries in Thailand by connecting private manufacturers and SME with innovation and research and creating opportunities, especially by sharing knowledge of product development, business management and innovation. Currently, the network consists of 23 centres across the country, with the centre in Bangkok as headquarters. Among these are 11 regional industrial promotion centres

To drive towards industry 4.0, the Ministry of Digital Economy and Society is the key actor, providing both hard and soft infrastructure. The Ministry aims to enhance available, accessible and affordable broadband nationwide by rolling out broadband to every village. Soft infrastructure, such as the right regulatory framework, is also promoted by amending existing laws (i.e. Electronic Transactions Act and Computer Crime Act) or putting in place a new act to ensure the trust and confidence of both the public and business entities (i.e. Personal Data Protection Act).

The Digital Economy Promotion Agency has been assigned by law to focus on promoting the development of digital technology and innovation, the building of the digital ecosystem by supporting the supply side, such as digital providers and digital start-ups, and the adoption of digital technology or the digital transformation in all sectors (including industries and businesses), to achieve Thailand 4.0 goals in the economic aspect. In addition, the National Science and Technology Development Agency and the National Innovation Agency, under the Ministry of Higher Education, Science, Research and Innovation, are the main actors in supporting and promoting broad-based technology and innovation development. The private sector plays a role in complementing the ecosystem on both the demand side (i.e. Digital Council of Thailand) and supply side (i.e. Federation of Thailand Industries).

Turkey[63]

National strategies, policies, laws, programmes and initiatives related to industry 4.0

Turkey takes its place in the industry 4.0 era through the National Technology Initiative and Digital Turkey. All strategies, policies and programmes are based on this perspective. The General Directorate for National Technology was established under the Ministry of Industry and Technology on 14 April 2020 to make arrangements to pave the way for technology transformation. Some of the duties and powers of the Directorate are as follows:

- Contribute to the implementation of high-impact programmes and projects to improve the technological competence of Turkey within the scope of the National Technology Initiative
- Carry out activities for the development of individual competencies and social awareness and culture in technology development and the digital transformation of individuals and businesses in cooperation with relevant stakeholders in line with the objectives of the National Technology Initiative
- Take measures to increase the competencies of individuals and businesses in subjects such as big data and artificial intelligence, to develop and expand smart systems based on these technologies, to implement support and incentive programmes and to carry out programmes and projects
- Take the necessary measures in coordination and cooperation with the relevant public institutions and organizations for the development of digital economy applications and the growth of the ecosystem in this field to increase the economic benefit of digitalization and to contribute to the creation of legislation; carry out programmes and projects for the development of digital economy infrastructures and applications in parallel with digital technologies and trends
- Take the necessary measures and develop and carry out applications to ensure the development and competitiveness of the informatics and advanced technology sectors; keep the register of businesses operating in these sectors; harmonize the technical regulations regarding the products of the informatics and advanced technology sectors, excluding those used in the electronic communications sector; prepare and implement technical legislation and relevant standard lists; determine the qualifications of conformity assessment bodies and technical service organizations to be authorized within the scope of technical regulations, assign these bodies and temporarily suspend or cancel assignments when necessary

The SME Development Organization and the Scientific and Technological Research Council, which are organizations of the Ministry of Industry and Technology, have launched grant programmes to support the digital transformation of SME. The Eleventh National Development Plan 2019–2023, Industry and Technology Strategy 2023 and the Smart Production Systems Technology Road Map are the main policies and strategies concerning industry 4.0. Under the digital transformation and research and development and innovation sections of the strategy, policies and measures are provided, with the objective of boosting productivity and competitiveness in priority sectors by accelerating digital transformation and strengthening the research and development and innovation capability of the manufacturing industry to enable value added production and to increase the capacity for innovative product development and to provide an innovation-based structure. The Eleventh National Development Plan sets forth the long-term vision for economic and social development. It is the main road map for public policy, which leads all governmental institutions in the preparation processes of strategic and action plans. The plan sets out the main pillars of STI policies, emphasizing the need to develop capacity to produce and use knowledge and to focus research and development and innovation activities in both academia and the private sector that support high value added production, particularly through an efficient research and development and innovation ecosystem. The plan emphasizes entrepreneurship and commercialization activities tailored to different actors in industry (SME, large enterprises, etc.) and the transfer of

[63] See https://unctad.org/system/files/non-official-document/CSTD2021-22_c10_I_Turkey_en.pdf.

knowledge and technology (enabling the socioeconomic impacts of research and development results). In research and development and innovation, the primary goals are enhancing capacity for research and development and innovation capabilities, increasing value added production and the share of high-technology sectors in both manufacturing industry and exports and ensuring a convenient environment for innovation. To this end, support systems are evolved to an integrated structure from basic research to commercialization at every phase of research and development and innovation, and the distinctive structures and characteristics of medium-high technology and high-technology sectors are favoured. In this context, the following priority sectors are identified: chemicals; pharmaceuticals and medical devices; electronics; machinery and electrical equipment; and automotive and rail systems. Critical technologies, in which human resources are to be further supported, infrastructure to be established and road maps to be developed, are as follows: artificial intelligence; the Internet of things; augmented reality; big data; cybersecurity; energy storage; advanced materials; robotics; micro and nano-electromechanical systems; biotechnology; quantum technologies; sensors; and additive manufacturing technologies. Increasing competitiveness in priority sectors and improving research and development and innovation capacity, along with developing internationally competitive and high value added new sectors, products and brands in critical technologies are given the utmost importance under the plan.

Turkey has published Industry and Technology Strategy 2023 under the Ministry of Industry and Technology. The strategy has five pillars, namely, high technology and innovation, digital transformation and industrial move, entrepreneurship, human capital and infrastructure. Substrategies (namely, digital transformation of industry, national artificial intelligence strategy, fifth-generation and beyond technology strategy, mobility vehicles and technologies strategy, smart life, health products and technologies strategy, digital transformation of finance and commerce strategy) serving the umbrella strategy have been developed and are in the process of publication and implementation. The main purpose of digital transformation under Industry and Technology Strategy 2023 is to provide efficiency and self-efficacy, to increase the competitiveness of Turkey, with the following targets:

- Establishment of the proposed governance mechanism for the digital transformation programme of industry with the cooperation of the public and private sectors
- Completion of the development of tools that will ensure the management of the digital transformation of industry, monitoring its performance and efficient use of resources
- Announcement of the digital transformation support programme
- Completion of the infrastructure for digital transformation
- Gaining of new skills and competencies that will enable digital transformation for the existing and emerging workforce
- Development of competitive products and solutions in operational technologies
- Development of competitive products and solutions in information technologies
- Creation of competitive products and solutions in transactional technologies

Digital transformation in the manufacturing industry is considered critical. Through the coordination of the Scientific and Technological Research Council, under the framework of the Ministry of Industry and Technology, all sectoral stakeholders participated in the establishment of the smart production systems technology road map in 2016. In total, 29 critical products were identified in the context of eight critical technology areas determined in the road map, namely, big data and cloud computing, digitalization, cybersecurity, the Internet of things, sensor technologies, additive manufacturing, advanced robotics and advanced automation and control technologies. The critical products and technologies, identified as the priority research, development and innovation themes of smart production systems, are as follows:

- Development of algorithms and applications for a secure, smart and scalable end-to-end cloud service platform, which also enables the predictive maintenance of data

- Development of cybersecurity solutions for industry 4.0
- Simulation, modelling and virtualization technologies for industry 4.0
- Establishment of an interoperable, secure and reliable industrial Internet of things digital platform and development of high value added smart service applications
- Development of software and/or hardware for machine-to-machine, machine-to-human and machine-to-infrastructure communications
- Development of physical, chemical, biological, optical and micro and nano sensors for industrial use
- Development of smart manufacturing robots, equipment, software and executive systems that are competitive in global markets, easily accessible by SME
- Development of raw materials, production machines and required software and automation systems for additive manufacturing and additive manufacturing machines, materials and software
- Development of smart manufacturing execution systems and components and required middleware technologies

Since 2012, dedicated research and development and innovation support has been provided by the Scientific and Technological Research Council to universities, SME and large industrial organizations for the development of critical technologies serving digital transformation. To date, the leading areas, based on the distribution of the total budget for supported projects, have been sensors, electronic circuits and microelectromechanical systems, with a share of 21 per cent, followed by communications systems, with a share of 20 per cent. The following two areas, with a share of 15 per cent each, are artificial intelligence and robotic mechatronics. In fifth place, the area of data analytics has a share of 10 per cent.

A study of new research, development and innovation priority areas in 2020–2021, conducted by the Scientific and Technological Research Council, includes various technology-intensive subpriorities in the fields of ICT, health, food, energy, machinery and manufacturing and automotive. In this context, in the ICT sector, artificial intelligence, the Internet of things, big data and data analytics, image processing technologies, robotics, software technologies, cloud computing and broadband technologies are all considered priority technologies for the near future and are the basis of digitalization. Detailed contents and technological readiness levels have been prepared; 64 of the 154 research, development and innovation priority areas, or approximately 42 per cent of all research, development and innovation priority areas, are those related to ICT and digitalization.

Since 2020, the Scientific and Technological Research Council has been giving priority to research, development and innovation project proposals (if they concern at least one of the determined priority areas) within the evaluation phases of the following: Scientific and Technological Research Council 1001 scientific and technological research projects support programme; Scientific and Technological Research Council 1501: industry research and development projects support programme; and Scientific and Technological Research Council 1507 SME research and development start support programme. Projects dedicated to developing priority technologies and products are supported by the Scientific and Technological Research Council under the scope of research and development and innovation support programmes or through the Move Programme, under the scope of National Technology Move, by the Ministry of Industry and Technology. Some initiatives related to industry 4.0 are as follows:

- Model factories. Eight model factories (capability and digital transformation centres), established under a Ministry of Industry and Technology initiative, provide consultancy and training solutions for businesses, to complete their lean digital transformations. New model factories are planned to be established in different areas in coming years. Businesses that demand services from model factories can benefit from financial support through the SME Enterprises Development Organization and development agencies

- Fourth Industrial Revolution Centre. This is a multistakeholder initiative that supports global collaborations and develops new policies to accelerate the benefits of science and technology. The centre was launched in 2020 by the World Economic Forum, the Employers' Association of Metal Industries in Turkey and the Ministry of Industry and Technology; some notes about the organization are as follows: maximizing the benefits of science and technology for society; as of 2020, the seventh affiliate centre of the World Economic Forum; main working areas are the Internet of things, robotics, smart cities, artificial intelligence and machine learning; and active projects are in increasing the impact of the industrial Internet of things in SME, responsible use of artificial intelligence, human-oriented artificial intelligence for human resources and shaping future technology control: artificial intelligence and machine learning
- Accelerating the digital transformation of SME through the Internet of things. The Ministry of Industry and Technology is a stakeholder in this project, which is operated jointly by the Fourth Industrial Revolution Centre and the Management Sciences Institute. The aim of the project is to create a model for building a road map for companies. The project will be the pilot for the model and comprises the following steps: digital maturity assessments of SME; matching technology users and technology providers and creating a use case scenarios pool; and accumulating and keeping application scenarios in an industrial cloud
- D3A digital transformation assessment tool. Developed by the Boğaziçi University industry 4.0 platform. The Scientific and Technological Research Council and the Management Sciences Institute are to ensure the implementation of this assessment tool for SME. The tool focuses on SME (corresponding to 99 per cent of industry in Turkey) and the tool will provide road maps for them, focusing on the five dimensions of organization, customer, product development, supply chain and production management, and aiming to determine the needs of SME and to run their digital transformation processes smoothly

In addition to the actions of the Ministry of Industry and Technology, other ministries and presidencies make efforts in digital transformation, as follows:

- National Cybersecurity Strategy 2020–2023, under the Ministry of Transportation and Infrastructure. Addressing security criteria of new generation technologies such as artificial intelligence, the Internet of things, blockchain and fifth generation, will take place as a priority in the cybersecurity plans of the near future; areas of use of artificial intelligence and blockchain technologies for cybersecurity will be identified and the domestic and national technologies to be developed will be determined
- National Smart Transportation Systems Strategy Document and Action Plan 2020–2023, under the Ministry of Transportation and Infrastructure. States the strategies that aim to create a sustainable, productive, safe, efficient, innovative, dynamic and environment-friendly intelligent transport network that creates added value and integrates with all transport modes using the latest technology, while making use of national resources
- Digital Transformation Office of the Presidency. Aims to implement a digital transformation ecosystem by enhancing the performance of public institutions and increasing the efficiency and quality of their services in line with the goals, policies and strategies set by the President of Turkey

In addition to national policies implemented by the Ministry of Industry and Technology, regional policies are formulated and supported by development agencies and regional support programmes, as follows:

- SME Development Organization support programmes in industry 4.0. The organization announced two calls for proposals to support the digital transformation of SME in 2019. The first programme aims to support SME developing digital technologies applicable in industry.

The capabilities of digital technology developers are fostered by a project-based programme including YTL 1,000,000 ($115,000) in financial support. The second programme aims to support SME acting in the industry, with YTL 1,000,000 in financial support provided to industrial sector SME aiming to adapt digital technologies to their manufacturing and business processes. Calls for proposals (comprising eight smart digital technologies, namely, big data, the Internet of things, industrial robot technologies, smart sensor technologies, artificial intelligence, cybersecurity, smart and flexible manufacturing and virtual and augmented reality) were announced in 2019 and repeated in subsequent years. In total, 936 projects have been approved to date

- To encourage interaction between technology developer SME and industrial sector SME, an intent of purchase letter provided by industrial SME has been made obligatory for technology developer SME and prioritization rules have been defined for industrial sector SME that intend to procure digital technologies from technology developer SME
- Strategic product support programme. Provides funds for SME investment projects for manufacturing high value added products in the medium-high and high-technology sectors and increasing the production of critical products for the development of these sectors within the scope of the Move Programme of the Ministry of Industry and Technology. The programme offers up to YTL 6,000,000 in financial support with a 60 per cent grant ratio for projects of up to 36 months, aimed at production of the products mentioned in calls for proposals under the technology-oriented industry action programme

Machinery equipment, software, personnel, reference sample, knowledge transfer, test, analysis, calibration, training consultancy, design and other service procurement costs are eligible to be part of grant projects of SME. The Ministry of Industry and Technology publishes a list of privileged products and calls for specific areas based on this list. In 2021, three calls (mobility call, call for structural transformation in production and call for health and chemical products) were put into service for investments in 722 kinds of products. A digital transformation call will be published by the Ministry of Industry and Technology. The following products related to industry 4.0 are also on the list of investment to be financially supported through such calls: big data collection platform (validation, integrity, privacy, labelling, heterogeneous data support); Internet of industrial things platform; digital twin technologies; blockchain technologies (product traceability, digital product marketing, etc.) and infrastructure; advanced technology embedded sensor systems such as micro and nano-electromechanical systems and optical technologies to be used in Internet of things applications; extreme-proof sensors; wearable technologies that can send data to the cloud and receive commands, compatible with the Internet of things; cybersecurity technologies based on artificial intelligence and deep learning; system-on-chip technologies; robotic process automation technologies; autonomous and semi-autonomous industrial and service robots; and hybrid manufacturing systems.

Key sectors and actors of the innovation ecosystem for industry 4.0

The public sector aims to lead technological transformation with its actions. The automotive and manufacturing sectors are pioneer adopters of industry 4.0, to maximize production and minimize costs and work-related accidents. Generally, corporate companies, start-ups and technology transfer offices are the key actors in the ecosystem. For example, Koç Sistem and Turkcell are some of the service providers for industry 4.0 solutions. However, start-ups mostly focus on the digitalization of conventional machines. Since industry 4.0 is new in conventional sectors, there is significant potential for start-ups. Servis Soft, Hubbox and Bren Energy are examples of promising industry 4.0 start-ups. Technology transfer offices are another contributor to industry 4.0; they lead to the implementation of technology practices. The Industry and Business Association publishes reports on industry 4.0 and has launched the SD2 digital platform to bring together digital solutions.

In line with the importance given to the digital transformation of the industrial sector in the Eleventh

National Development Plan, the issue of digitalization in the manufacturing industry has been among the priority themes for the Government since 2019. SME in the industrial sector need to adapt to digital technologies for the value added production-oriented transformation of both industry and the industrial workforce. The digital transformation of industry as a strategic priority area leads to fundamental gains, such as increasing resource productivity and competitiveness in general. Industry and Technology Strategy 2023 aims at the digital transformation of the manufacturing industry and seeks to support this transformation through the National Technology Move programme. The model factory project, launched in 2015, is one of the critical initiatives of the Ministry of Industry and Technology in this area. Model factories, which provide applied training and consultancy services, especially for SME, have begun operating in critical industrial cities and their number will increase in the coming period. Key actors in both policymaking and the implementation of national strategies are the Ministry of Industry and Technology; chambers of industry and commerce; non-governmental organizations; international organizations (e.g. United Nations Development Programme) and the SME Development Organization, which manages financial support from the Government for manufacturing SME. These actors are involved in all processes, from policymaking to implementation. The Ministry is at the centre of policy networks and manages communications between stakeholders and actors as a high-level government agency. Model factories, also considered hubs of digitalization efforts, are coordinated at the national level and common technical experience is gained by sharing information between them.

Industry 4.0 covers a large variety of sectors; manufacturing and ICT seem to be pioneering sectors. The Ministry of Industry and Technology is the most active governmental body in the administration of efforts in industry 4.0; research and development are mainly supported by the Scientific and Technological Research Council. Research and development are conducted by universities, the private sector, technology parks and research and development institutes. The key success factor in this area is collaboration between the different actors. Various mechanisms are designed to increase such collaboration, including the Scientific and Technological Research Council industrial innovation networks mechanism, established in 2018. To strengthen industrial innovation networks, considering smart specialization in industrial innovation hubs, policy tools that are more target-oriented, collaborative, focused on the long term and directed to high value addition are being put forward, to strengthen aspects of smart specialization and inclusiveness in the local ecosystem. The objectives of the mechanism are to promote innovative network formations, leading to the creation of product road maps; form a network with other firms, especially those with research and development and product design centres, in the value chain of the targeted technology-based product, together with end users, technology development zones and universities; and enhance smart specialization activities in industrial innovation hubs, including firms, especially those with research and development and product design centres. The SME Development Organization, as a governmental organization, has a wide network of SME and field experience in supporting SME. These capabilities can be used to improve the industry 4.0 concept among SME.

Annex B
Questions for discussion

A set of questions for discussion are presented in this annex, to further the dialogue on harnessing industry 4.0 for inclusive and sustainable development.

Key issues in industry 4.0 and inclusive development

What challenges have Governments faced in promoting industry 4.0 to contribute to national development priorities and accelerate progress towards the Sustainable Development Goals?

Creating an ecosystem for industry 4.0 innovation

How can Governments better support the creation or strengthening of national and sectoral systems for industry 4.0 innovation?

What are policy instruments that Governments have used in this regard?

What are the most effective ways to support the improvement of skills levels for harnessing industry 4.0 for inclusive and sustainable development?

What should the private sector, labour unions and other stakeholders do in order that developing countries can benefit from such technologies?

Providing directionality for the sustainable and inclusive application of industry 4.0

What are examples of STI policies, projects and initiatives intended to promote and give directionality for industry 4.0 innovation to make it work for inclusive and sustainable development?

Dealing with unintended consequences

How can STI policies ensure that potential unintended consequences of industry 4.0 are addressed?

What are the policy instruments that Governments have used in this regard?

The role of partnerships and international and regional collaboration

What actions can the international community, including CSTD, contribute to maximizing the benefits associated with industry 4.0 and mitigating the risks?

What are success stories in this regard?

References

Acemoglu D and Autor D (2011a). Skills, tasks and technologies: implications for employment and earnings. *Handbook of Labour Economics*. Elsevier: 1043–1171.

Akerman A, Helpman E, Itskhoki O, Muendler M-A and Redding S (2013). Sources of wage inequality. *American Economic Review*. 103(3):214–219.

Alvarez J, Benguria F, Engbom N and Moser C (2018). Firms and the decline in earnings inequality in Brazil. *American Economic Journal: Macroeconomics*. 10(1):149–189.

Auerswald PE (2010). Entry and Schumpeterian profits. *Journal of Evolutionary Economics*. 20(4):553–582.

Automate (2020). Available at https://www.automate.org/case-studies/the-paradox-of-smart-manufacturing.

Autor DH (2013). The task approach to labour markets: An overview. *Journal for Labour Market Research*. 46(3):185–199.

Autor DH and Handel MJ (2013). Putting tasks to the test: Human capital, job tasks and wages. *Journal of Labour Economics*. 31(S1):S59–S96.

Autor DH, Dorn D and Hanson G (2015). Untangling trade and technology: Evidence from local labour markets. *Economic Journal*. (584):621–646.

Banga K and Te Velde DW (2018). *Digitalization and the Future of Manufacturing in Africa*.

Barth E, Bryson A, Davis JC and Freeman R (2016). It's where you work: Increases in the dispersion of earnings across establishments and individuals in the United States. *Journal of Labour Economics*. 34(S2):S67–S97.

Berriman R and Hawksworth J (2017). Will robots steal our jobs? The potential impact of automation on the United Kingdom and other major economies. Pricewaterhouse Coopers.

Bol T and Weeden KA (2015). Occupational closure and wage inequality in Germany and the United Kingdom. *European Sociological Review*. 31(3):354–369.

Brennen S and Kreiss D (2014). *Digitalization and Digitization: Culture Digitally*.

Brynjolfsson E and McAfee A (2016). *The Second Machine Age: Work, Progress and Prosperity in a Time of Brilliant Technologies*. WW Norton and Company. London.

Camara 4.0 (2022). A Câmara I4.0. Available at https://camara40.com.br/.

China State Council (2015). Made in China 2025 plan issued. Available at http://english.www.gov.cn/policies/latest_releases/2015/05/19/content_281475110703534.htm.

Cirera X, Comin D, Cruz M and Lee KM (2021). Firm-level adoption of technologies in Senegal. Working Paper. World Bank.

Cirera X, Comin D, Marcio C, Lee KM and Soares Martins-Neto A (2021). Firm-level technology adoption in Viet Nam. Policy Research Working Paper No. 9567. World Bank.

Dauth W (2014). Job polarization on local labour markets. Discussion paper No. 18. Research Institute, Federal Employment Agency, Germany.

Department of Economic and Social Affairs (2020). *World Social Report 2020*. United Nations publication.

De Stefano V (2018). Negotiating the algorithm: Automation, artificial intelligence and labour protection. Employment working paper. Employment Policy Department, International Labour Organization.

De Stefano V and Aloisi A (2018). *European Legal Framework for Digital Labour Platforms*. European Union, Luxembourg.

Devroye D and Freeman RB (2001). Does inequality in skills explain inequality in earnings across advanced countries? Working Paper No. 8140. National Bureau of Economic Research.

Ding L and Molina JS (2020). Forced automation by COVID-19? Early trends from current population survey data.

East D and Kaspar MG (2020). The impact of COVID-19 on manufacturing investments. Available at https://iap.unido.org/articles/impact-covid-19-manufacturing-investments.

Economic and Social Commission for Asia and the Pacific (2021). Available at https://www.unescap.org/blog/reaping-benefits-fdi-40-and-digital-fdi-sustainable-development.

Efficiency Vermont (2020). Available at https://www.efficiencyvermont.com/blog/your-story/how-did-simple-efficiency-solutions-help-husky-save.

Enterprise Insights (2018). Available at https://enterpriseiotinsights.com/20180102/smart-factory/three-smart-manufacturing-case-studies-tag23-tag99.

ESCWA (2019). *Impact of the Fourth Industrial Revolution on Development in the Arab Region*.

ESCWA (2020). *Arab Horizon 2030: Innovation Perspectives for achieving Sustainable Development Goals in the Arab Region*.

European Union (2019). A vision for the European industry until 2030: Final report of the industry 2030 high-level industrial round table. Available at https://op.europa.eu/en/publication-detail/-/publication/339d0a1b-bcab-11e9-9d01-01aa75ed71a1.

Fagerberg J and Verspagen B (2021). Technological revolutions, structural change and catching up. In Alcorta L, Foster-McGregor N, Verspagen B and Szirmai A, eds. *New Perspectives on Structural Change: Causes and Consequences of Structural Change in the Global Economy*. Oxford University Press.

Fernandes J, Reis J, Melão N, Teixeira L and Amorim M (2021). The role of industry 4.0 and BPMN[business process model and notation] in the arise of condition-based and predictive maintenance: A case study in the automotive industry. *Applied Sciences*. 11(8):3438.

Foster-McGregor N, Nomaler O and Verspagen B (2019). Measuring the creation and adoption of new technologies using trade and patent data. UNIDO.

Freire C (2017). Diversification and structural economic dynamics. Maastricht Graduate School of Governance Dissertation Series No. 191. United Nations University – Maastricht Economic and Social Research Institute on Innovation and Technology.

Freire C (2021). The impact of frontier technologies on inequalities across countries. Available at https://iap.unido.org/articles/impact-frontier-technologies-inequalities-across-countries.

Goos M, Manning A and Salomons A (2014). Explaining job polarization: Routine-biased technological change and offshoring. *American Economic Review*. 104(8):2509–2526.

Graetz G and Michaels G (2018). Robots at work. *The Review of Economics and Statistics*. 100(5):753–768.

Guadalupe M (2007). Product market competition, returns to skill and wage inequality. *Journal of Labour Economics*. 25(3):439–474.

Guerriero M (2015). The impact of Internet connectivity on economic development in sub-Saharan Africa.

Hartmann D, Guevara MR, Jara-Figueroa C, Aristarán M and Hidalgo CA (2017). Linking economic complexity, institutions and income inequality. *World Development*. 93:75–93.

Hjort J and Poulsen J (2019). The arrival of fast Internet and employment in Africa. *American Economic Review*. 109(3):1032–1079.

Huang R, Riddle M, Graziano D, Warren J, Das S, Nimbalkar S, Cresko J and Masanet E (2016). Energy and emissions saving potential of additive manufacturing: The case of lightweight aircraft components. *Journal of Cleaner Production*. 135:1559–1570.

Industriall Global Union (2017). The challenge of industry 4.0 and the demand for new answers.

International Labour Organization (2018). *Women and Men in the Informal Economy: A Statistical Picture* (Geneva).

International Labour Organization (2020). *The Future of Work in the Digital Economy*.

International Labour Organization (2021). *World Employment and Social Outlook Trends 2021*.

International Monetary Fund (2018). Gender, technology and the future of work. Staff discussion note.

International Trade Centre (2015). 2015: Connect, compete and change for inclusive growth.

International Trade Centre (2021). SME Competitiveness Outlook 2021: Empowering the Green Recovery.

ITU (2021). Connectivity in the Least Developed Countries: Status report 2021.

Juhn C, Murphy KM and Pierce B (1993). Wage inequality and the rise in returns to skill. *Journal of Political Economy*. 101(3):410–442.

Keep E, Mayhew K and Payne J (2006). From skills revolution to productivity miracle: Not as easy as it sounds? *Oxford Review of Economic Policy*. 22(4):539–559.

Krugman P (2021). Available at https://www.nytimes.com/2021/04/15/opinion/andrew-yang-automation.html.

La Porta R and Shleifer A (2014). Informality and development. *Journal of Economic Perspectives*. 28(3):109–126.

Leuven E, Oosterbeek H and Van Ophem H (2004). Explaining international differences in male skill wage differentials by differences in demand and supply of skill. *The Economic Journal*. 114(495):466–486.

Lin K-H and Tomaskovic-Devey D (2013). Financialization and United States income inequality, 1970–2008. *American Journal of Sociology*. 118(5):1284–1329.

McKinsey Global Institute (2018). Digitally enabled reliability: Beyond predictive maintenance. Available at https://www.mckinsey.com/business-functions/operations/our-insights/digitally-enabled-reliability-beyond-predictive-maintenance.

McKinsey Global Institute (2020). The future of maintenance for distributed fixed assets: Why people are key to successfully implementing technology-led maintenance transformations.

McMillan M, Rodrik D and Verduzco-Gallo Í (2014). Globalization, structural change and productivity growth, with an update on Africa. *World Development*. 63(C):11–32.

Michaels G, Natraj A and Van Reenen J (2013). Has ICT polarized skill demand? Evidence from 11 countries over 25 years. *The Review of Economics and Statistics*. 96(1):60–77.

Milanovic B (2015). Global inequality of opportunity: How much of our income Is determined by where we live? *Review of Economics and Statistics*. 97(2):452–460.

Milanovic B (2016). *Global Inequality: A New Approach for the Age of Globalization*. Harvard University Press.

Mueller HM, Ouimet PP and Simintzi E (2017). Wage inequality and firm growth. *American Economic Review*. 107(5):379–383.

Perez C (2002). *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Edward Elgar, Cheltenham, United Kingdom.

Perez C (2010). Technological revolutions and technological–economic paradigms. *Cambridge Journal of Economics*. 34(1):185–202.

Perez C (2013). Unleashing a golden age after the financial collapse: Drawing lessons from history. *Environmental Innovation and Societal Transitions*. 69–23.

Perez C (2015). 11. Capitalism, technology and a green global golden age: The role of history in helping to shape the future. *The Political Quarterly*. 86191–217.

Pietrobelli C and Rabellotti R (2011). Global value chains meet innovation systems: Are there learning opportunities for developing countries? *World Development*. 39(7):1261–1269.

Schwab K (2017). *The Fourth Industrial Revolution*. Penguin, London.

Shin N, Kraemer KL and Dedrick J (2012). Value capture in the global electronics industry: Empirical evidence for the “smiling curve” concept. *Industry and Innovation*. 19(2):89–107.

Song J, Price DJ, Guvenen F, Bloom N and Von Wachter T (2019). Firming up inequality. *The Quarterly Journal of Economics*. 134(1):1–50.

Timmer MP, Miroudot S and De Vries GJ (2019). Functional specialization in trade. *Journal of Economic Geography*. 19(1):1–30.

UNCTAD (2004). Electronic Commerce and Development Report 2004.

UNCTAD (2013). *Global Value Chains and Development: Investment and Value Added Trade in the Global Economy* (United Nations publication, Geneva).

UNCTAD (2017). Rising product digitalization and losing trade competitiveness.

UNCTAD (2018a). Available at https://worldinvestmentforum.unctad.org/wp-content/uploads/2018/03/Panel-2-Global-Value-Chains-the-Digital-Economy-and-the-New-Industrial-Revolution.pdf.

UNCTAD (2018b). Technology and Innovation Report: Harnessing Frontier Technologies for Sustainable Development (United Nations publication. New York and Geneva).

UNCTAD (2019a). Structural transformation, industry 4.0 and inequality: Science, technology and innovation policy challenges. TD/B/C.II/43. Geneva.

UNCTAD (2019b). Digital Economy Report 2019: Value Creation and Capture – Implications for Developing Countries (United Nations publication. Geneva).

UNCTAD (2020a). Available at https://unctad.org/system/files/official-document/CSTD2019-2020_Issues01_RapidTechChange_en.pdf.

UNCTAD (2020b). *World Investment Report 2020: International Production Beyond the Pandemic* (United Nations publication. Sales No. E.20.II.D.23. Geneva).

UNCTAD (2021a). *Technology and Innovation Report 2021: Catching Technological Waves – Innovation with Equity* (United Nations publication, Sales No. E.21.II.D.8, Geneva).

UNCTAD (2021b). *World Investment Report 2021: Investing in Sustainable Recovery* (United Nations publication, Sales No. E.21.II.D.13, Geneva).

UNCTAD (2021c). Global investment flows rebound in first half of 2021, recovery highly uneven, 19 October, Available at https://unctad.org/news/global-investment-flows-rebound-first-half-2021-recovery-highly-uneven.

UNCTAD (2021d). *Digital Economy Report 2021: Cross-Border Data Flows and Development – For Whom the Data Flow* (United Nations publication, Sales No. E.21.II.D.18, Geneva).

UNIDO (2017). *Accelerating Clean Energy through Industry 4.0*.

UNIDO (2019). A revolution in the making?

UNIDO (2020). *Industrial Development Report 2020: Industrializing in the Digital Age* (Sales No. E.20.II.B.49). Vienna.

UNIDO (2021a). *Impact Assessment of COVID-19 on Bangladesh's Manufacturing Firms*. Vienna.

UNIDO (2021b). *Impact Assessment of COVID-19 on Thailand's Manufacturing Firms*. Vienna.

UNIDO (2021c). Industrial analytics platform. Available at https://iap.unido.org/articles/what-fourth-industrial-revolution.

Van Reenen J (2011). Wage inequality, technology and trade: Twenty-first century evidence. *Labour Economics*. 18(6):730–741.

Vivarelli M (2014). Innovation, employment and skills in advanced and developing countries: A survey of economic literature. *Journal of Economic Issues*. 48(1):123–154.

World Bank (2016). *World Development Report 2016: Digital Dividends*. Washington, D.C.

World Economic Forum (2016). Available at https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.

World Economic Forum (2018). *The Global Gender Gap Report 2018*. Geneva.

World Economic Forum (2020). *The Global Gender Gap Report 2020*. Geneva.

World Trade Organization (2018). Electronic commerce and developing country SME participation in GVCs. Staff working paper, 13 November.

World Trade Organization (2019). *Global Value Chain Development Report 2017*.

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