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Digitalization of manufacturing in Africa and Latin America: A foundational capability analysis

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Digitalization of Manufacturing in Africa and Latin America: A foundational capability analysis

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Abstract

In this paper, we examine the readiness for the digitalization of manufacturing in Africa, and Latin America, and the Caribbean. The analysis builds on applying a novel methodology that introduces a set of three foundational capabilities for digitalization and one related to the ability of firms to engage with advanced digital production technologies. We analyse the presence of these capabilities at the country level based on three criteria: a country's positioning within the region, its performance relative to the average of its respective income group, and whether progress was made across capability dimensions over the period 2015-2021. The country analysis identified specific strengths of several economies in one or more capability dimensions. Our findings also provide insights into the readiness for the digitalization of manufacturing based on a multidimensional picture of progressing layers of capabilities. By identifying capability gaps, we expect to inform policy interventions geared to address those and accelerate progress in the structural transformation required for the digitalization of manufacturing in the regions under study.

Key words: digitalization of manufacturing, capabilities, Africa, Latin America, and the Caribbean.

JEL codes: L6, O14, O33, O54, O55

1. Introduction

The uptake of advanced digital production (ADP) technologies fundamentally reshapes manufacturing production processes globally. Such technologies can create vast opportunities for expanding production capacities and innovation in the sector (UNIDO 2019). Moreover, trends towards digitalization of manufacturing should transform the sector's role as a driver of economic development (UNIDO 2019), thereby enhancing its ability to contribute to social prosperity and environmental sustainability (Ferrannini et al., 2021).

Despite the potential developmental implications of this fast-paced wave of technological change in manufacturing, there needs to be more intelligence on practical approaches to policymaking to promote digital transformation in manufacturing. The scope for such intelligence is notable in developing countries, which need to catch up in adopting ADP technologies. There is a need for empirically tested role models to inform digitalization agendas and industrialization efforts articulated with long-term national development strategies (Santiago, 2018). To address such a gap, this paper explores factors that determine readiness for digitalization of manufacturing in two developing regions, namely Africa and Latin America and the Caribbean. The emphasis is on determining capability gaps hindering the pace of digitalization of manufacturing in these two regions.

Interest in these regions responds to the several opportunities and challenges they face to endorse digitalization of manufacturing. Firstly, there is the paucity of industrialization, which results in general backwardness in manufacturing capabilities, particularly in Africa (Whitfield and Zalk, 2020) and the Caribbean, combined with a steady pace of premature de-industrialization in several African and Latin American economies (UNIDO 2023). Secondly, overall levels of digitalization at the firm level still need to improve, especially with regards to the adoption of more sophisticated ADP technologies. The technological capabilities required to adopt ADP technologies, and their applications, is heavily concentrated in a handful of countries in each region (UNIDO 2019; Santiago, Freire, and Lavopa, 2023). Thirdly, with few exceptions, the pace of digital transformation of manufacturing in the most advanced countries in each region tends to trail the dynamic industrializing Asian economies (UNIDO 2019; UNCTAD 2021b; World Economic Forum 2018). Finally, according to (UNIDO, 2021), the rapid rebalancing of global manufacturing capabilities towards Asia might further widen the manufacturing development gap in Africa, and Latin America and the Caribbean.

Policymakers in the regions under study are anything but blind to both the opportunities and threats that the trends toward digitalization of manufacturing can –and are– bringing to their

countries. There is little question regarding the urgency to develop relevant strategies. However, generally, policymakers are unclear about how to create the best enabling conditions required to encourage uptake of ADP technologies amongst manufacturing firms, and thus, how to design adequate blueprints (Santiago 2018; Lee et al., 2019). Which factors constrain the ability of Africa and, Latin America and the Caribbean to harness digitalization of manufacturing? What capability gaps should policymakers in these regions address to help domestic firms tap into the digital transformation in global manufacturing? In addressing these questions, this paper aims to identify possible policy initiatives that could help African, Latin American, and Caribbean countries, respectively, address their capability gaps. If left unaddressed, such gaps may compromise these regions' ability to leverage manufacturing as a driver of prosperity.

Without substantive evidence to inform decision-making and priority-setting on strategies to support digitalization in the manufacturing sector, policymakers may easily overlook areas whose attention is crucial to solving the more significant digital transformation puzzle. In this paper, we offer a framework to identify a suitable set of dimensions and illustrative indicators for several of the underpinnings of digital transformation in manufacturing.

The remainder of this paper proceeds as follows. Section 2 introduces the analytical framework used for the analysis. We draw on the notion of foundational capabilities proposed by Andreoni, Chang, and Labrunie (2021), which we interpret as determinants of countries' readiness to adopt ADP technologies. Readiness for digital transformation emerges from a complex set of technological capabilities, which enable the diffusion, adoption, and mobilization of ADP technologies in manufacturing. Hence, capability building is of essence for the digitalization of manufacturing. Section 3 presents the methodology for collecting and analyzing statistical data, drawing from publicly available international data sources. The methodology builds on a novel analytical diagnostic tool developed by UNIDO and GIZ (2024) to assess readiness for digitalization at the country level. The methodology proposes a multidimensional framework which translates each dimension of foundational capabilities into a set of 17 indicators. Section 4 provides the core of this paper. It splits into two main sections. Firstly, the findings for Africa are discussed. Secondly, we present the case of Latin America and the Caribbean. Section 5 concludes by drawing some general observations from each of these regions and some specificities for each. The section provides some relevant policy implications as well.

2. Digitalization of manufacturing: From readiness to capability building

In this paper, we adopt UNIDO's (2019) definition of ADP technologies as technologies that result from combining three main components –hardware, software and connectivity. ADP technologies

can be grouped into three main clusters: (1) AI, data analytics, and cloud computing; (2) Robotics, Cyber-Physical Systems, and Additive Manufacturing; and (3) IoT and network technologies. These ADP technologies describe multipurpose technology clusters integrating software, hardware, and connectivity with applications in various areas of production, which underpin smart manufacturing production systems. This implies a narrow understanding of the digitalization of productive activities and tasks shaping manufacturing systems and closely related digital infrastructures supporting such activities. Hence, this definition is close to the notion of Industry 4.0.

2.1. A readiness perspective

Like previous technological revolutions, the digitalization of manufacturing brings opportunities and challenges at different levels (Perez, 2001; 2010). While windows of opportunity open up for firms, industries, and countries (UNCTAD, 2021b), each of these entities differs in their readiness, or individual ability to leverage on rapid advances in digital technologies and their application in manufacturing.

Significant efforts to understand the extent of readiness to adopt ADP technologies in manufacturing firms involve the development of diagnostics, toolkits, indexes and tailor-made blueprints (Santiago, 2018; Kupilas et al., 2019). By looking at their relative positioning according to a given readiness index, firms can identify some opportunities and challenges to progress in their digitalization journey. Micro-level diagnostic tools also aim to inform policy initiatives to foster digital transformation in firms (MITI, 2018; Singapore Economic Development Board, 2023). Thus, several readiness frameworks exists that seek to categorize firms and describe the levels of their technological capabilities, depicting how to initiate and achieve digital transformation along a technology maturity ladder (Peerally et al., 2021; Kupilas et al., 2019).

At a macro level, interest in the determinants of readiness for the digitalization of manufacturing is evident. For example, in a couple of reports, the World Economic Forum attempts to characterize the level of readiness for the future of production at the country level (WEF and A.T. Kearney, 2018; World Economic Forum, 2017). The reports present data for 100 countries, representing more than 96 percent of global manufacturing value addition and global Gross Domestic Product (GDP). Framing the analysis within the notion of the Fourth Industrial Revolution (4IR), the reports look into current production baselines –Structure of Production, and the presence –or lack– of the key enablers expected to assist countries capitalize on emerging technologies and transform production systems –the Drivers of Production. The studies find that no country –not even the most industrialized– has reached the frontier of readiness. The analysis

uncovered a mixed picture; most countries are just starting to create the conditions necessary to endorse the 4IR in production. Moreover, the 25 leading countries, the most high-income economies, concentrate in Europe, North America and East Asia. Confronted with these findings, the question is how to help countries "not only understand how ready they are for the future of production but to act on that understanding and build out the relevant strategies and policies that will enable them to take advantage of the opportunities that lie ahead" (World Economic Forum, 2018).

The preceding discussion suggests that despite progress made in understanding the drivers to adopt ADP technologies by manufacturing firms, readiness to endorse digital transformation is only part of a more comprehensive story. Increased attention should be given to understanding the underlying capabilities needed to successfully uptake and implement those technologies at the micro and the macro-levels (UNCTAD, 2021b; Peerally et al., 2021). Indeed, at the micro-level, Peerally et al. (2021) point out the lack of proven capability frameworks that present a refined set of micro-level human and organizational activities and resources (i.e., knowledge, skills, experience) that underpin readiness for digital transformation in manufacturing firms. Without this intelligence, manufacturing firms will continue to struggle to identify the technological capabilities needed to progress in their digital transformation journeys. At the macro level, while debates focus on how much developing countries can access ADP technologies, successful latecomer experiences show the importance of building and developing foundational capabilities (Park et al., 2021).

In this context, UNIDO (2019) documents the cumulative nature of the digitalization journey and the challenges that emerge for policymakers, particularly in developing countries. Success generally depends on the local industrial sector's absorptive capacity, which results from a country's engagement with manufacturing over time. Important is consideration of factors external to the firm, including investments in skills and infrastructure development, the adoption of supportive industrial policies, and the maintenance of healthy business environments.

The preceding discussion leads to conclude that the challenges of digital transformation go beyond fostering diffusion, access, and uptake of ADP technologies and related services by manufacturing firms. Macro-level conditions regarding infrastructure, regulations, human resource development, and innovation are required for firms to endorse trends towards the digitalization of manufacturing. This paper advances a framework for identifying of relevant macro-level dimensions influencing digital transformation in manufacturing.

2.2. Capability building to endorse digitalization of manufacturing

The possible tensions in development outcomes that can be associated with advances in digital technologies have been documented (Mansell and Wehn, 1998; UNCTAD, 2021b). Digitalization can exacerbate structural inequalities regarding productive and innovative capabilities, ultimately widening development gaps (Foster and Azmeh, 2023). If left unattended, capability gaps affecting specific segments of firms and industries, even in highly competitive economies, may result in missed opportunities to leverage the positive development dynamics offered by innovation in ADP technologies (UNIDO 2019; UNCTAD 2021b).

Capability building necessary to uptake ADP technologies in manufacturing is a complex, non-linear process (UNIDO 2019). Firms, particularly those in developing countries, must engage in a gradual process of learning how to create and accumulate the capabilities necessary to adapt, compete, and thrive within the context of a technological paradigm characterized by an active presence of digital technologies in manufacturing (Peerally et al., 2021; UNIDO, 2019). Andreoni, Chang, and Labrunie (2021) argue that while countries may be able to acquire digital technologies, the meaningful deployment of these will be determined by the extent to which a country has the necessary capabilities to adopt and adapt such technologies to the local context. Developing countries cannot leapfrog from a low industrial base and skip the fundamental stages of learning and experience required to adopt digital technologies and capitalize on the ongoing technological revolution (UNIDO 2019). Moreover, digital transformation implies technological upgrading in contexts where different technological generations coexist across firms and within countries (Andreoni and Anzolin, 2019).

The capabilities required for digitalization still need to be distributed across regions and within countries. For example, UNIDO (2019) finds an intense concentration of intellectual property rights that govern access to ADP technologies –additive manufacturing, CAD-CAM, Robotics, and Machine learning– associated with the recent wave of digitalization and innovation in manufacturing. Only about ten countries –the frontrunners[1]– account for 90 percent of all global patents and 70 percent of all exports directly associated with these technologies. Another 40 countries –the followers[2]– actively engage in these technologies, though with less intensity. The rest of the world either shows very little activity (the latecomers) or fails to contribute to the global

[1] UNIDO (2019, 6) defines *frontrunners* as "Economies with 100 or more global patent family applications in ADP technologies (average value for all economies with some patent activity in this field)". In alphabetical order, this group includes China, France, Germany, Japan, the Republic of Korea, the Netherlands, Switzerland, Taiwan, the United Kingdom and the United States.

[2] UNIDO (2019, 6) defines *followers in use* as "Economies with at least 20 regular patent family applications, or ten global patent family applications in ADP technologies (average values for all economies with some patent activity, once frontrunners are excluded)."

creation and use of ADP technologies (the laggards). This concentration of technological capabilities in a few countries is consistent with the findings of Daiko et al. (2017), who identified aggressive strategies to take patents on advanced digital technologies by the 2000 firms most active in the performance of R&D globally.

Recent work by UNCTAD captures similar concerns about the underlying capabilities underpinning the adoption of digital technology (UNCTAD, 2021b; 2018). UNCTAD (2021b), in particular, proposes an index that assesses national capabilities to equitably use, adopt, and adapt frontier technologies, including those generally associated with the 4IR.[3] The index comprises five building blocks: (i) ICT deployment, (ii) skills, (iii) R&D activity, (iv) industrial activity, and (v) access to finance. The first three building blocks are consistent with national-level technological capabilities such as physical investment, human capital, and technological effort. Industrial activity is related to the assumption that the development of technological capabilities is path-dependent and is based on research on economic complexity. In contrast, the pattern of a country's industrial activity influences its likelihood of adopting frontier technologies.

The preceding discussion lends support to some of the conclusions by Mansell and Wehn (1998), who, in a study on the role of information and communication technologies as drivers of "innovative *"knowledge societies"*"[4], conclude that the goal should be to ensure *"That the capabilities for using these technologies creatively are embedded in new policy measures and firm strategies"* (Mansell and Wehn, 1998, pp. 1–2). Transposed to today's debates, capability building at different levels –but particularly among users of ADP technologies a necessary condition for developing countries to endorse the digital transformation of manufacturing (UNIDO, 2019; Peerally et al., 2021; UNCTAD, 2021b; Andreoni, Chang, and Labrunie, 2021).

2.2.1.Identifying foundational capabilities

Sustained investments in what Andreoni, Chang, and Labrunie (2021:334) identify as "Foundational capabilities" should enable firms *"To learn new technical and organisational solutions, integrate them into production, organise and commit resources over time for the effective deployment of these new solutions."* Foundational capabilities go beyond those enabling the uptake of individual digital technologies such as robots or AI. Some foundational capabilities are transversal, essential for all sectors of the economy. In other cases, they sustain more sector-

[3] The index considers eleven frontier technologies: Artificial Intelligence (AI), Internet of Things (IoT), big data, blockchain, 5G, Additive manufacturing (3D printing), robotics, drones, gene editing, nanotechnology, and solar photovoltaics (PV).
[4] Emphasis on the original by the authors.

specific applications. The combination of capabilities will ensure that a country has the conditions to develop digital transformative processes.

This complex nature of foundational capabilities means that policymakers confront the challenge of assessing the level of such capabilities already present and the opportunities they offer for developing specific sectors. This level of awareness should help identify gaps, set priorities and advance the formulation of digital agendas connected with industrialization. Andreoni, Chang, and Labrunie (2021) propose three elements that characterize the foundational capabilities that underpin progress in the digital transformation journey:

Enabling Infrastructure: The backbone of the digital economy is access to a reliable and affordable national network of electricity and digital infrastructure. Infrastructure quality and affordability are fundamental to using ADP technologies in productive activities (Ndung'U and Signé, 2020). Without adequate energy and digital infrastructure, firms will be reluctant to make large investments in technology (UNIDO, 2019). In particular, widespread internet penetration and connectivity quality are key to consolidating digital infrastructure and an instrumental factor to enable the use of digital technologies in the industrial and other productive sectors. This layer of capabilities considers indicators for *energy availability and reliability*, as well as *access and quality of digital connectivity*, as part of the enabling infrastructure towards digitalization.

Production Capabilities enable the adoption of new technologies to foster innovation and expand manufacturing production (UNIDO 2019). Adopting ADP technologies in manufacturing implies the deployment of 'smart production' processes, which rely as much on connectivity as on the pre-existing conditions to implement technological change. In this sense, this layer of capabilities points at indicators for *basic production capabilities*, which look at the long-term investment in fixed capital as well as the level of basic education skills and *intermediate production capabilities*, that aim to capture firms' capabilities in terms of their operational capacity and efficiency, and their engagement with foreign-developed technologies as a proxy for technological absorption.

Innovation capabilities build from the production capabilities and show the extent to which firms in a given country can adopt and adapt ADP technologies to the local context, for example, through retrofitting and redesigning imported technologies by training and upskilling the workforce in line with the demands of digitalization (Andreoni and Anzolin, 2019; Peerally et al., 2021). This layer of capabilities distinguishes between efforts and outputs of innovation activities, considering a set of indicators that capture the primary efforts to form the conditions to create innovation (advanced and specialized skills and research investment) throughout the development

of intermediate innovation outputs (scientific and technical publications, patents and receipts for intellectual property rights). Such a distinction aims to illustrate the level of preparedness to effectively engage with adopting and adapting ADP technologies.

UNIDO and GIZ (2024) propose a fourth layer of more advanced capabilities, which provides insights into the readiness for digital transformation based on the countries' exposure and adoption of digital technologies.

Digital capabilities: The final layer of capabilities captures *digital capabilities*, which hint at the readiness for digital transformation based on the countries' exposure and adoption of ADP technologies. Hence, it reflects domestic firms' ability to absorb and adapt sophisticated technologies crucial for transitioning manufacturing systems toward smart production (UNIDO, 2019). Access to foreign digital technologies is a proxy of the ability to learn and implement those technologies as part of the digitalization of production processes. In this case, a distinction is made between exposure to production technologies with digital potential[5] (PTDP), and imported ADP technologies. As firms, and thereby countries, uptake and gain experience in the use of ADPs, they may also increasingly enter the market as producers and exporters of those technologies or related components, which implies a cumulative process of building competitiveness in the markets for those technologies.[6]

The notion of digital capabilities captures the extent to which firms in a specific country have or do not:

- absorbed and have been exposed, via import from abroad, to different types of PTDP;
- directly imported ADP technologies, including parts and instrumentation;
- become exporters of ADP technologies, hence have gained some levels of *industrial competitiveness* in digital technologies; or,
- engaged with digital services via the import and export of computer and information services.[7]

[5] According to Andreoni and Anzolin (2019), PTDP refers to a wide range of machine tools, tooling, and complementary productive equipment whose coordinated and synchronized operations can be potentially enhanced through digital retrofitting such as sensorization, automation, and network integration.
[6] The ability to become producers and exporters of ADP technologies is only a way to capture firms' mastery of such technologies. Several firms may remain users of ADP technologies, developing new products or process innovations and gaining increased market presence, productivity, and efficiency. Without data on these firms, we cannot look into those that can develop capabilities to engage with ADP technologies as producers.
[7] Due to data limitations, the dimension of computer and information services is excluded from our analysis.

3. Methodology

In this paper we present an application of the methodology developed by UNIDO and GIZ (2024), which offers a multidimensional approach to exploring countries‘ conditions and efforts toward digitalizing industry.

For the analysis, the regional groupings are as follows. The analysis of Africa includes all 54 countries in the region. Latin America and the Caribbean are examined as two sub-regions. This considers their specific context, structural characteristics and dynamics, and data availability. The analysis covers 33 countries from the 42 countries comprised in the regional classification from the World Bank. Latin America refers to Mexico and the Central- and South American countries. At the same time, the Caribbean considers the independent states of the sub-region: Antigua and Barbuda, The Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

To measure the extent to which a country exhibits the four capabilities in Andreoni, Chang, and Labrunie (2021), it is necessary to translate these concepts into quantitative indicators. UNIDO and GIZ (2024) break down the capabilities into dimensions and assigns indicators that can proxy for each. By using such indicators in cross-country comparisons and time-series analysis, it is possible to shed light on the degree of countries' readiness based on different capability dimensions. To identify suitable indicators per UNIDO and GIZ (2024), we searched for publicly available indicators for several countries, including the most developing countries, from open-access international databases.

Table 1 provides an overview of the capability dimensions and 17 suggested indicators about each capability. An in-depth evaluation of all 17 indicators included in the analysis differs from this paper's objective. Instead, the aim is to understand how ready a country is for digital transformation in the manufacturing sector building on several macro-level indicators that allow measuring national performance across capability dimensions.

To analyze advanced digital capabilities, we built the pertinent indicators based on a *Digital Technologies Classification proposed* by UNIDO and GIZ (2024), using trade data from UN COMTRADE. Building on trade data, three indicators are considered for digital capabilities:

1. Imports of production technologies with digital potential: HS 2017 – code 84-85, intersected with BEC 4 code 41 and 42.

2. Imports of ADP technologies: Selection of HS 2017 code 84-85-90, intersected with BEC 4 code 41-42; and,

3. Export of ADP technologies as a proxy of competitiveness in digital production: Selection of HS 2017 code 84-85-90, intersected with BEC 4 code 41-42.

Table 1. Dimensions and indicators per capability

Layers of capabilities	Dimensions	Indicators	Description
Enabling infrastructure	**Energy**	***Energy availability*** 1) Electric power consumption	A large energy coverage is instrumental for the use of digital machines and equipment
		Electrical reliability 2) Percentages of firms experiencing outages	Digitalization requires widespread and reliable electrical energy
	Digital	***Access to connectivity*** 3) Fixed broadband subscriptions	Access to wired broadband internet connectivity is an enabling factor for digitalization
		Quality of connectivity 4) Mean download speed (Mbps)	Digital technologies, especially the more advanced ones require high-speed, low-latency and reliable internet connectivity
Production capabilities	**Basic**	***Productive investment*** 5) Share of manufacturing in Total Gross Fixed Capital Formation	Proxy for investments made to upgrade the manufacturing structure
		Productive skills 6) Mean years of schooling	Average number of completed years of education (population ≥25 years)
	Intermediate	***Operational efficiency*** 7) ISO 9001 certificates	Firms with good productive and organizational capabilities can obtain the standard certification for quality management
		Technological absorption 8) Intellectual property rights payments (royalties)	Proxy for firms' level of technological capabilities
		Advanced skills	Broad base of university-level knowledge is needed

Innovation capabilities	**Basic: innovation effort**	9) Enrollment ratio in tertiary education:	for the absorption, diffusion, and development of advanced digital technologies
		Specialized skills 10) Percentage of STEM graduates	Level of specialization of the tertiary education system
		Research effort 11) Gross Expenditure in R&D as a share of GDP:	Larger R&D investments indicates capabilities to carry out research and innovation activities
	Intermediate: innovation outputs	***Research output*** 12) Scientific and technical journal articles per million people	Impact on digitalization directly through research areas or indirectly by creating innovation capabilities
		Innovation output (patents) 13) Total patents in force per 100 billion USD GDP	Patents are a common measure for a country's level of innovation capabilities
		Innovation outputs (property rights) 14) Intellectual property rights receipts	Proxy to measure how technologically advanced a country is (licensing of locally developed technologies to other countries)
Digital capabilities	**Absorption and exposure**	***Production technologies with digital potential (PTDP)*** 15) Imports of production technologies (automation, sensorization and Internet of Things)	Measures the engagement with production technologies with digital potential
	Deployment and adaptation	***Advanced digital production (ADP) technologies*** 16) Imports of ADP technologies (automated and/or with embedded digital systems)	The value comprises production technology, parts or components, and technology instrumentations
	Industrial competitiveness	***Competitiveness in ADP technologies*** 17) Exports of ADP technologies	It is cautiously assumed that if the country exports those products, it has digital-related capabilities.

Source: Adapted from (UNIDO and GIZ. 2024)

3.1. The Digital Readiness Dashboard

The first step in the analysis was to create a Digital Readiness Dashboard (DRD), which was proposed by UNIDO and GIZ (2024). The DRD presents, in a single exhibit, the four dimensions of capabilities for digitalization of manufacturing: enabling infrastructure, production capabilities, innovation capabilities, and digital capabilities.

A global DRD, including 218 countries, was constructed as it is required to calculate global income group averages for each indicator as part of the country benchmarking analysis. A global dashboard offers various other advantages, such as extracting regional averages and enabling comparison with countries from outside the region of interest. The DRD includes the most recent available data per country and indicator over the period 2015-2021.[8] The results provide a general overview of the level of readiness for digital industrialization per country, allowing for cross-country comparison in the two regions. The global dashboard created a DRD for Africa (Annex 1), and Latin America and the Caribbean (calculations Annex 2)

Criteria for country comparison

Three criteria were used to compare overall performance across countries and capabilities. These criteria intend to complement each other, looking at the countries' position across capabilities, their performance relative to other countries with the same income level, and the temporal trend of each indicator during the period 2015-2021.

Criteria 1: Performance relative to the region

The first criterion identifies the region's top performers according to the countries' position across the 17 indicators in the DRD. Countries were ranked for each indicator and assigned a score, with the best-performing country receiving the highest score. The scores were then aggregated and normalized from 0 to 1. This was necessary to ensure we assign equal weight to each capability, which is otherwise not given due to the varying number of indicators per capability.

Criteria 2: Performance relative to income level

The second criterion relativizes a country's average performance to its respective level of development. We do so by counting the number of indicators per capability where the value of

[8] Data coverage is incomplete for certain indicators, such as percentage of firms experiencing electrical outages, mean years of schooling, or the share of graduates in STEM. Furthermore, missing data hinders computation of growth rates for several indicators.

the country is above the global average of the respective income group as per the World Bank's definition.[9]

Criteria 3: Trends

The third criterion captures trends across indicators, thereby helping identify dynamic country performances across different capabilities. Results for this criterion consider only the number of indicators where a country shows a positive change during the period of analysis, which is generally between 2015 and 2021. We overcame missing data issues by including data points outside this time range.

A country's overall readiness for digitalization in manufacturing is calculated as the sum of each criterion across all capabilities. This results in the theoretically achievable maximum value of 4 for criteria 1, 17 for criteria 2, and 16 for criteria 3.[10] Table 2 presents an overview of these criteria.

The analysis for Africa, and Latin America and the Caribbean presented below includes several tables and graphics with findings according to the three aforementioned criteria. For the sake of clarity of the presentation, countries are ranked according to the scores given by the first criteria, which shows the performance relative to their respective region, i.e., Africa, or Latin America or, the Caribbean. For visualization purposes, the higher scores of the first criteria and the highest number of indicators of the second and third criteria are reflected with the darkest shade of *green.*

[9] World Bank Classification: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups, accessed 19.05.2023.

[10] Methodological changes at the source, M-Lab, made it challenging to conduct trend analysis to indicate the quality of connectivity, and mean download speed.

Table 2. Criteria for regional comparative analysis

Criteria	Description	Methodology steps	Highest possible score
Criteria 1 (CR1)	***Performance relative to the region***	▪ Countries were ranked, with the best performing country receiving the highest score (i.e. 54 for Africa, 17 for Latin America and 16 for the Caribbean, if all countries reported) ▪ *The scores are aggregated per capability and* normalized from 0 to 1, with 1 being the best performer	1.00
Criteria 2 (CR2)	***Performance relative to income level***	▪ The count of indicators where a country outperforms the global average of its income group	▪ Enabling infrastructure: 4 ▪ Production capabilities: 4 ▪ Innovation capabilities: 6 ▪ Digital capabilities: 3
Criteria 3 (CR3)	***Trends***	▪ The count of indicators where a country shows a positive trend between 2015 and 2021[b].	▪ Enabling infrastructure: 3 ▪ Production capabilities: 4 ▪ Innovation capabilities: 6 ▪ Digital capabilities: 3
Overall performance by country		▪ The sum was taken of each criterion across all capabilities	▪ Criteria 1: 4 ▪ Criteria 2: 17 ▪ Criteria 3: 16

Note: a) The country's position for each indicator is limited by data availability. b) The period 2015-2021 was covered for most indicators. In the case of Africa, Annex 1 specifies countries where years deviate from this period. For Latin America and the Caribbean, deviations are indicated as notes under the respective graphs.

Source: Authors' elaboration

4. Main findings by region

4.1. Africa

This section presents the key findings from the analysis of the DRD for Africa. The findings are discussed per capability. Each subsection begins with a regional overview of the capability before undertaking the cross-country analysis, where selected countries that stand out based on our criteria are discussed. A summary table of the top performers per criteria is included to help legibility. Countries that perform well based on criteria 1 (regional comparison) or 2 (global income group comparison) and have made progress in the majority of indicators (criteria 3) are marked in bold. The final subsection presents the overall digital readiness of countries, displaying the aggregate results of all four capabilities. Annex 1 shows the complete DRD for Africa.

4.1.1. Enabling infrastructure

Access to electricity varies significantly across Africa. While over 99 percent of North Africans have access to electricity, the share is significantly lower in Sub-Saharan Africa, as low as 4.4 percent, 7.8 percent, and 8.7 percent in the Central African Republic, Chad and the Democratic Republic of Congo, respectively (IEA, 2022). Regarding energy consumption per capita, as a proxy for the energy supply, our data shows figures in the order of 680 kWh in Africa, roughly half the average value of lower-middle-income countries.

The literature documents the challenges that African countries face in securing suitable energy provisions for productive purposes. For example, the 2019 World Bank Enterprise Survey reveals that African firms, especially medium-sized firms, consider electricity a significant constraint for their operation (UNECA 2020). Similarly, a study by the Center for Global Development conducted on 37 Sub-Saharan African countries finds that power outages cause up to an estimated 31 percent of loss in firms' sales (Ramachandran, Shah, and Moss, 2018). The hardest-hit firms suffered over 200 hours of blackouts per month, while the least-affected firms report over 10 hours each month (Ramachandran, Shah, and Moss 2018). Generally, our data tend to support several of these considerations.

Digital infrastructure remains a challenge for many countries in the region. According to a recent ITU report, while 33 percent of the African population is using the internet, this figure contrasts significantly with the shares of 80 percent for both Europe and the Americas (ITU 2022). A significant obstacle is the cost of the internet. A global league table of mobile data costs[11] reveals that five of the ten countries where the internet is most expensive are in Africa. In these countries,

[11] https://www.cable.co.uk/mobiles/worldwide-data-pricing/ Accessed 12.9.2023

Internet costs are more than 250 times more expensive than the country with the cheapest internet (Israel), significantly impacting economic competitiveness. Large projects are underway in both energy and digital connectivity. However, with significant improvements in these and other necessary infrastructures, firms will be more willing to make large investments in digital technologies (UNIDO, 2020).

Notwithstanding this somewhat gloomy picture in Africa as a whole, our analysis indicates that North African lower-middle income countries such as Morocco, Tunisia, or Egypt are among the best performers in the region in terms of enabling infrastructure. These countries are relatively well positioned compared to others in the same income bracket (Table 3). Economies with higher income levels, such as Seychelles and South Africa, are also among the top five performers in the region. However, their stance could be stronger when compared to peers in their respective income bracket. Regarding temporal dynamics, six low-income and lower-middle-income African countries have improved on all infrastructure-related indicators where change can be measured.

Table 3 Scoring of African countries in terms of enabling digital and energy infrastructure

Ranking (CR1)	Economy	Income group	Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)
			Relative to region	Relative to income group average	Trend
			Score	# of indicators above global average (total: 4)	# of indicators with positive growth rates (total: 3)
1	Morocco	Lower Middle Income	1.00	3	3
2	Seychelles	High Income	0.95	1	2
3	Tunisia	Lower Middle Income	0.95	3	2
4	Egypt, Arab Rep.	Lower Middle Income	0.95	3	2
5	South Africa	Upper Middle Income	0.93	2	1
6	Mauritius	Upper Middle Income	0.88	1	2
7	Cabo Verde	Lower Middle Income	0.76	2	2
8	Kenya	Lower Middle Income	0.74	1	2
9	Zimbabwe	Lower Middle Income	0.74	1	2
10	Côte d'Ivoire	Lower Middle Income	0.73	1	2
11	Libya	Upper Middle Income	0.72	1	1
12	Algeria	Lower Middle Income	0.69	2	2
13	Congo, Rep.	Lower Middle Income	0.69	1	2
14	Gabon	Upper Middle Income	0.69	0	1
15	Mozambique	Low Income	0.68	3	1
16	Botswana	Upper Middle Income	0.67	0	1
17	Lesotho	Lower Middle Income	0.66	1	1
18	Ghana	Lower Middle Income	0.65	1	2
19	Eswatini	Lower Middle Income	0.64	0	2
20	Zambia	Low Income	0.64	2	2
21	Namibia	Upper Middle Income	0.63	0	0
22	Tanzania	Lower Middle Income	0.61	1	2
23	Senegal	Lower Middle Income	0.58	0	2
24	Angola	Lower Middle Income	0.58	0	2
25	Liberia	Low Income	0.56	2	2
26	Cameroon	Lower Middle Income	0.53	0	1
27	Rwanda	Low Income	0.50	2	3
28	Mali	Low Income	0.50	2	2
29	São Tomé and Prír	Lower Middle Income	0.49	0	2
30	Madagascar	Low Income	0.45	1	1
31	Burkina Faso	Low Income	0.42	1	2
32	Mauritania	Lower Middle Income	0.42	0	2
33	Nigeria	Lower Middle Income	0.40	1	1
34	Uganda	Low Income	0.39	1	1
35	Comoros	Lower Middle Income	0.36	0	1
36	Togo	Low Income	0.35	1	1
37	Equatorial Guinea	Upper Middle Income	0.30	0	0
38	Djibouti	Lower Middle Income	0.27	0	0
39	Malawi	Low Income	0.27	1	1
40	Ethiopia	Low Income	0.25	0	2
41	Sudan	Low Income	0.25	1	1
42	Gambia, The	Low Income	0.25	0	1
43	Guinea	Low Income	0.25	1	2
44	Eritrea	Low Income	0.24	0	1
45	Congo, Dem. Rep.	Low Income	0.23	0	2
46	Somalia	Low Income	0.20	1	2
47	Niger	Low Income	0.19	0	1
48	Benin	Lower Middle Income	0.17	0	0
49	Sierra Leone	Low Income	0.13	1	1
50	Chad	Low Income	0.13	1	1
51	Burundi	Low Income	0.12	0	2
52	Guinea-Bissau	Low Income	0.12	0	2
53	South Sudan	Low Income	0.03	0	2
54	Central African Re	Low Income	0.00	0	0

Source: Authors' calculations

Morocco stands out in the continent (Table 4), as it outperforms the average of lower-middle-income countries in three of the four indicators. In addition, it has improved on all three indicators where growth can be measured. Morocco is particularly strong in the reliability of its energy supply. The number of firms reporting to have experienced power outages in the previous year was 21 percent, which is lower than the average of high-income countries (26 percent).

Table 4 African countries with perceived strongest level of readiness in terms of enabling digital and energy infrastructure

Top performers relative to region	Top performers relative to income group:	Top performers: Positive change
Morocco (LMI) Seychelles (HI) Tunisia (LMI) Egypt (LMI) South Africa (UMI)	**Morocco (LMI)** Tunisia (LMI) Egypt (LMI) Mozambique (LI)	**Morocco (LMI)** Rwanda (LI)

Source: Authors

Seychelles, the only high-income country on the continent, is the second-best performer in enabling infrastructure. It has the highest level of electricity consumption (a proxy for energy availability) in the region, and the value continues to increase, despite still falling short of the global average for high income countries, 6,100 kWh compared to 8,100 kWh per capita. Regarding Internet access, almost 39 percent of the population features a fixed broadband subscription, the highest in the region, and well above the global income group average of 32.6 percent. Despite this, the mean download speed, 12.04 Mbps recorded in 2021, is only a fraction of the average 58.8 Mbps in high-income countries and lies between the lower and upper-middle-income global averages.

Mozambique is the best-performing low-income country in this capability dimension. It outperforms the global average for its income bracket on three of the four indicators: energy availability, energy reliability, and the speed of internet connection. The country performs particularly well regarding energy reliability, where the share of firms that have experienced power outages is at par with the average of lower-middle-income countries. Despite its relatively strong position compared to low-income African countries, Mozambique has only seen improvements in one indicator: fixed broadband subscriptions.

Finally, Rwanda deserves a mention. While the country outperforms the average low-income countries in two of the four indicators on enabling infrastructure, namely energy reliability and internet connection quality, it has recorded positive dynamics on all indicators where change can be measured. While electricity consumption is far below the average of low-income countries, Rwanda must almost triple its value to reach the average. Power outages are not a significant burden to firms. On the continent, only Morocco and Egypt offer more reliable electricity supply when measured by the share of firms that experienced power outages in the year before the survey.

4.1.2. Production capabilities

Despite being "the most important determinant in adopting new technological progress innovations," according to an analysis of 13 African and four South Asian economies (UNIDO, 2019, p.p. 111), production capabilities are generally "scarce and unevenly distributed" in developing countries (UNIDO, 2019, p.p. 110). This is particularly true in Africa, where most manufacturing firms are small, informal, and heavily dependent on local markets (AfDB, 2022). While countries such as Ethiopia, Ghana, Tanzania, Zambia, and Mozambique have significantly improved their manufacturing performance (IGC, 2023), several African countries have failed to leverage on manufacturing to boost their economic performance. Several even experience premature deindustrialization (Grabowski, 2015; Tafinreyika, 2016). International competitiveness remains a distant target. The region's share in global manufacturing has contracted to less than 2 percent. Moreover, a study by Arana, Allur, and Heras-Saizarbitoria (2014) highlights the extent to which the continent struggles with operational efficiency, as measured by the share of firms obtaining ISO 9001 certificates. The authors find that Africa's share of global GDP is over five times higher than its share in ISO 9001 certificates worldwide.

Productive investment, measured in terms of gross fixed capital formation as a share of GDP in Africa, is also low compared to other regions (UNECA, 2020), with a slow rate of progress (AfDB, 2019a). Access to long-term finance is essential for manufacturing firms to expand productive capacities. However, the banking sector in Africa needs to be more fit to invest in long-term innovation projects (UNECA, 2020). The World Bank Enterprise Survey 2019 reveals that access to finance was among the largest constraints for firms –and the largest for small firms (UNECA, 2020).

The current wave of digitalization in manufacturing and the associated changes in production structures demand a labour market that can quickly adapt to the rapidly changing needs of African firms with competitive potential (Ndung'U and Signé, 2020). However, the ability to respond to such demand is constrained by the relatively low shares of STEM graduates in Africa. Pervasive issues plague Africa's educational and training systems, including insufficient funding, deficient teacher development programs, restricted availability of electricity and internet connectivity, and insufficient infrastructure for the teaching and learning of STEM disciplines in particular (United Nations, 2022a). These issues impact the number of people who attend STEM programmes, significantly hindering the quality and timeliness of the acquired skills and causing severe challenges to manufacturing firms hoping to incorporate digital technologies.

Data limitations regarding productive skills (only 13 African countries report data on mean years of schooling between 2015 and 2021 in the UNESCO UIS database) mean we are unable to include this dimension in the analysis of several African countries. Although the region has adopted a regional education strategy (Continental Education Strategy for Africa 2016-2025), and many African governments are making significant efforts to improve education performance, approximately 20 percent of children of primary school age are absent from educational settings, while nearly 60 percent of adolescents are currently not enrolled in school (UNESCO and African Union, 2023). This should significantly affect how manufacturing sectors across the continent can equip themselves for adopting ADP technologies.

Table 5 presents the results for all African countries regarding production capabilities, while Table 6 lists the top performers across the three different criteria used for the analysis. Overall, the findings show that similar to enabling infrastructure, most African countries with the most robust production capabilities are located either in North Africa or Southern Africa. Senegal is the sole exception as a West African, francophone country. Somewhat different from enabling infrastructure, more low-income countries that outperform the average for their income groups. In particular, Zambia, a low-income country, stands among the ten countries with the most substantial level of readiness.

Table 5 Scoring of African countries according to performance in production capabilities

Ranking (CR1)	Economy	Income group	Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)
			Relative to region	Relative to income group average	Trend
			Score	# of indicators above global average (total: 4)	# of indicators with positive growth rates (total: 4)
1	Algeria	Lower Middle Income	1.00	2	0
2	Botswana	Upper Middle Income	0.98	2	2
3	Morocco	Lower Middle Income	0.93	3	3
4	South Africa	Upper Middle Income	0.89	2	1
5	Senegal	Lower Middle Income	0.86	1	4
6	Mauritius	Upper Middle Income	0.85	1	1
7	Tunisia	Lower Middle Income	0.78	1	3
8	Eswatini	Lower Middle Income	0.78	2	3
9	Zambia	Low Income	0.75	3	1
10	Angola	Lower Middle Income	0.74	1	0
11	Nigeria	Lower Middle Income	0.73	1	3
12	Egypt, Arab Rep.	Lower Middle Income	0.71	2	2
13	Côte d'Ivoire	Lower Middle Income	0.71	0	3
14	Ghana	Lower Middle Income	0.71	1	2
15	Kenya	Lower Middle Income	0.69	0	0
16	Seychelles	High Income	0.68	0	1
17	Djibouti	Lower Middle Income	0.67	1	0
18	Madagascar	Low Income	0.66	3	1
19	Tanzania	Lower Middle Income	0.64	1	2
20	Lesotho	Lower Middle Income	0.61	1	0
21	Mauritania	Lower Middle Income	0.59	1	2
22	Cabo Verde	Lower Middle Income	0.56	1	1
23	Namibia	Upper Middle Income	0.54	0	0
24	Comoros	Lower Middle Income	0.54	1	1
25	Benin	Lower Middle Income	0.53	1	2
26	Cameroon	Lower Middle Income	0.51	0	2
27	Rwanda	Low Income	0.51	3	4
28	Uganda	Low Income	0.51	2	2
29	Togo	Low Income	0.51	2	1
30	Gabon	Upper Middle Income	0.49	0	0
31	Mozambique	Low Income	0.49	2	0
32	Congo, Rep.	Lower Middle Income	0.48	0	2
33	Ethiopia	Low Income	0.44	1	1
34	Gambia, The	Low Income	0.43	1	1
35	Congo, Dem. Rep.	Low Income	0.39	2	3
36	São Tomé and Prír	Lower Middle Income	0.37	0	1
37	Burkina Faso	Low Income	0.36	1	3
38	Guinea-Bissau	Low Income	0.36	1	1
39	Malawi	Low Income	0.30	1	1
40	Niger	Low Income	0.30	1	0
41	Zimbabwe	Lower Middle Income	0.30	1	2
42	Libya	Upper Middle Income	0.30	0	0
43	Mali	Low Income	0.26	1	2
44	Burundi	Low Income	0.19	0	4
45	Somalia	Low Income	0.17	0	2
46	Guinea	Low Income	0.16	0	1
47	Equatorial Guinea	Upper Middle Income	0.15	0	1
48	Chad	Low Income	0.14	0	0
49	Sierra Leone	Low Income	0.13	0	2
50	Sudan	Low Income	0.09	1	0
51	Central African Re	Low Income	0.09	0	1
52	Liberia	Low Income	0.07	1	1
53	South Sudan	Low Income	0.00	0	0
54	Eritrea	Low Income		0	0

Source: Authors' calculations

Algeria is the country on the continent with the highest overall score in production capabilities. It outperforms the average of lower middle-income countries in productive investments –measured by the share of GFCF in GDP– and in intellectual property rights payments, indicating a certain level of technology absorption. Still, despite the country's overall solid performance, it has been unable to see improvements in any of the dimensions throughout the analysis.

Botswana, the second highest performer in production capabilities, exhibits the same relative strength as Algeria: It records stronger productive investments and higher expenditures on intellectual property rights as a share of GDP than the average of upper-middle-income countries. The country spends almost twice as much on intellectual property rights, in terms of GDP, relative to the average income group, and as any other African country.

Both countries' relatively high expenditure levels on fixed assets and intellectual property suggest an ability to make larger, long-term investments and absorb technology. This is an essential prerequisite for digitalization, often done by retrofitting already available production technologies (Andreoni, Chang, and Labrunie 2021). A quick glance into these countries' performance in innovation capabilities (see 4.1.3) reveals that they are among the top 10 performers, with Algeria somewhat stronger than Botswana.

Table 6 African countries with perceived strongest level of readiness in terms of production capabilities

Top performers relative to region	Top performers relative to income group:	Top performers: Positive change
Algeria (LMI)	**Morocco (LMI)**	**Rwanda (LI)**
Botswana (UMI)	Zambia (LI)	**Senegal (LMI)**
Morocco (LMI)	Madagascar (LI)	Burundi (LI)
South Africa (UMI)	**Rwanda (LI)**	**Morocco (LMI)**
Senegal (LMI)		

Zambia has the highest level of production capabilities among low-income African countries. It scores above the average low-income country in all three indicators for which it reported data. After the Gambia and Malawi, it also records the second-highest share of productive investments in GDP and intellectual property right payments among low-income African countries. Zambia outperforms the average of lower-middle-income countries in operational efficiency and technology absorption.

Senegal is particularly interesting. It is the best performer among lower-middle-income Sub-Saharan African countries, the fifth best performer regionally, and it has experienced growth in all dimensions of production capabilities. The country's relative strength lies in productive investments, the only indicator where it surpasses the average for its income group.

Rwanda is one of the other few African countries that record positive change in all four indicators for production capabilities. It is the third highest low-income performer in Africa after Zambia and Madagascar, and it has exceeded the average for low-income countries in terms of productive investments, productive skills, and operational efficiency.

Of the 13 countries that reported mean years of schooling at any point between 2015 and 2021, South Africa stands out as the best performer. In South Africa, people over 25 have completed an average of 11.4 years of schooling, near high-income levels –the continent at large struggles with providing foundational years of education for all.

4.1.3.Innovation capabilities

Regarding research efforts as the basis for innovation, African countries spend a significantly lower share of GDP on R&D (0.33 percent in total Africa and 0.22 percent in Sub-Saharan Africa) than the target of 1 percent (United Nations, 2022b), limiting the potential for innovation. Low innovation efforts result in weak innovation outputs. Regarding patents, for example, in addition to the low number of applications stemming from Africa (0.5 percent of the world's patent applications in 2019), less than a fifth of the continent's applications correspond to residents in the continent (18.6 percent) (United Nations, 2022b). To some extent, this may be explained by the complexity and high costs involved in registering patents in some African countries (United Nations, 2022b).

Despite these gloomy figures, technology hubs have been thriving across the region, increasing by more than 50 percent between 2016 and 2018 alone and reaching 442 in the later year (AfDB 2019b). Networks connect many of these hubs, with Afrilabs[12] standing out as the most extensive network, uniting 150 innovation centres in 40 countries throughout the continent. However, various constraints weaken the potential of these centres to accelerate innovation dynamics in the region, from a lack of adequate specialized knowledge and insufficient collaboration with other innovation centres, universities, and the private sector to high dependency on funding from international donors (AfDB, 2019b).

[12] https://www.afrilabs.com/

Our analysis corroborates a generally low level of innovative capabilities among African countries; they score below average across income brackets. North and Southern African countries seem to be the strongest performers in the continent (Table 7 and Table 8). Still, only Tunisia and Algeria score above the average for lower-middle-income countries. By contrast, according to our second criterion, no low-income African country outperforms the average for this income group in more than half the indicators (Table 7). While the development of innovation capabilities remains challenging for many African countries, some progress exists in several countries in the region (Table 8).

Considering innovation capabilities by country, Tunisia is the best positioned in Africa. In most indicators in this capability dimension, the country's performance is above average for lower-middle-income countries. The exception is total patents in force, an indicator of innovation output. Interestingly, Tunisia boasts a share of STEM graduates well above any other income group average and scores higher than any other African economy. Notwithstanding these positive findings, Tunisia has only experienced positive growth in half of the indicators, namely R&D expenditure (research effort), scientific and technical journal articles published (research output), and number of patents in force (innovation output). Growth in the latter is significant for the country, as it would need to more than quadruple its current value to reach the average for lower-middle-income countries.

Mauritius' innovation capabilities suggest a strong level of readiness for the digitalization of manufacturing. It is the second-best regional performer, with progress in all but one of six indicators in our analysis. It is exceptionally strong in the number of patents in force with a value four times over the average upper-middle income country. It has also surpassed the average of its income group in specialized skills –share of graduates from STEM programmes. The latter is also the only indicator where the country has been experiencing a stark fall over the reference period.

Seychelles and Morocco also show strong levels of innovation capabilities. Morocco outperforms the average of its income group in half of the indicators, namely those that measure advanced and specialized skills, and scientific and technical journal articles published. Seychelles, in turn, is particularly strong in the number of patents in force and intellectual property rights receipts –two innovation output indicators. Both countries have improved in most indicators.

Table 7 Scoring of African countries according to performance in innovation capabilities

Ranking (CR1)	Economy	Income group	Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)
			Relative to region	Relative to income group average	Trend
			Score	# of indicators above global average (total: 6)	# of indicators with positive growth rates (total: 6)
1	Tunisia	Lower Middle Income	1.00	5	3
2	Mauritius	Upper Middle Income	0.92	2	5
3	South Africa	Upper Middle Income	0.92	3	3
4	Seychelles	High Income	0.86	1	4
5	Morocco	Lower Middle Income	0.79	3	4
6	Algeria	Lower Middle Income	0.77	4	2
7	Egypt, Arab Rep.	Lower Middle Income	0.76	3	4
8	Botswana	Upper Middle Income	0.71	0	3
9	Namibia	Upper Middle Income	0.71	0	4
10	Zimbabwe	Lower Middle Income	0.60	1	3
11	Senegal	Lower Middle Income	0.57	2	5
12	Kenya	Lower Middle Income	0.57	1	3
13	Cabo Verde	Lower Middle Income	0.56	0	5
14	Rwanda	Low Income	0.56	3	4
15	Ghana	Lower Middle Income	0.55	1	3
16	Eswatini	Lower Middle Income	0.52	0	2
17	Lesotho	Lower Middle Income	0.46	0	3
18	Cameroon	Lower Middle Income	0.46	0	2
19	Sudan	Low Income	0.45	3	3
20	Gabon	Upper Middle Income	0.45	0	1
21	Madagascar	Low Income	0.43	2	3
22	Burkina Faso	Low Income	0.42	1	4
23	Congo, Rep.	Lower Middle Income	0.42	0	3
24	Benin	Lower Middle Income	0.41	0	2
25	Burundi	Low Income	0.39	1	4
26	Uganda	Low Income	0.39	2	3
27	Mauritania	Lower Middle Income	0.38	1	4
28	São Tomé and Prín	Lower Middle Income	0.37	0	3
29	Ethiopia	Low Income	0.35	3	4
30	Malawi	Low Income	0.34	2	3
31	Nigeria	Lower Middle Income	0.33	0	3
32	Tanzania	Lower Middle Income	0.29	0	3
33	Côte d'Ivoire	Lower Middle Income	0.26	0	3
34	Togo	Low Income	0.26	2	3
35	Mali	Low Income	0.26	0	1
36	Liberia	Low Income	0.26	1	2
37	Mozambique	Low Income	0.24	1	3
38	Zambia	Low Income	0.22	1	1
39	Sierra Leone	Low Income	0.22	0	1
40	Congo, Dem. Rep.	Low Income	0.21	1	4
41	Niger	Low Income	0.21	0	3
42	Eritrea	Low Income	0.21	1	2
43	Libya	Upper Middle Income	0.20	0	0
44	Chad	Low Income	0.19	1	2
45	Central African Re	Low Income	0.19	1	1
46	Guinea-Bissau	Low Income	0.18	2	2
47	Gambia, The	Low Income	0.17	1	0
48	Guinea	Low Income	0.16	0	1
49	Angola	Lower Middle Income	0.16	0	3
50	Djibouti	Lower Middle Income	0.08	0	0
51	Somalia	Low Income	0.05	0	1
52	Comoros	Lower Middle Income	0.04	0	1
53	Equatorial Guinea	Upper Middle Income	0.01	0	0
54	South Sudan	Low Income	0.00	0	2

Source: Authors' calculations

Table 8 African countries with perceived strongest level of readiness in terms of innovation capabilities

Top performers relative to region	Top performers relative to income group:	Top performers: Positive change
Tunisia (LMI)	Tunisia (LMI) (5)	**Mauritius (UMI) (5)**
Mauritius (UMI)	Algeria (LMI) (4)	Senegal (LMI) (5)
South Africa (UMI)		Capo Verde (LMI) (5)
Seychelles (HI)		
Morocco (LMI)		**Morocco (LMI) (4)**
		Seychelles (HI) (4)
		Egypt (LMI) (4)
		Rwanda (LI) (4)
		Ethiopia (LI) (4)
		Burkina Faso (LI) (4)
		Burundi (LI) (4)
		Mauritania (LMI) (4)
		Congo, Dem. Rep. (LI) (4)
		Namibia (UMI) (4)

Together with Mauritius, Senegal, and Cape Verde, record positive change in five of six indicators. This finding suggests that while these countries face weaknesses in innovation capabilities relative to other capability dimensions, they are in an upward trend. Senegal outperforms the average of lower-middle-income countries in two fronts: R&D expenditure as a share of GDP, (its share is above the average of upper-middle income countries); and intellectual property rights receipts.

Several other countries deserve mention here. Rwanda and Ethiopia are two low-income countries with significant progress in four indicators of innovation capabilities. Generally, they are stronger than the average country in their income bracket in three of the six innovation capability indicators. Both countries presented a stronger performance in R&D and publications than in the two innovation output indicators, where they fall short of the average low-income countries. Lastly, Burkina Faso –the fourth best-performing low-income country– has improved on all but the innovation output indicators. Its strongest indicator is scientific and technical journal articles published, where it outperforms its income group average.

4.1.4. Digital capabilities

Through ADP technologies, African economies expect to unlock numerous opportunities for manufacturing firms to enhance output and exports, reduce production costs, boost participation in global value chains and create vast employment opportunities (Banga and Willem te Velde, 2018). At the same time, the recent robot densification in the developed regions and simultaneous reshoring hint towards the start of a possible slippery slope for the region (Banga and Willem te Velde, 2018). If the continent fails to capitalize on the opportunities of meaningfully deploying digital technologies and the digital divide widens, it risks falling back further in global competitiveness (Chan, 2018).

The recently enforced African Continental Free Trade Area (AfCFTA) should help African firms leverage the absorption of ADP technologies to expand trade across the region and boost international competitiveness (Songwe, 2020). More broadly, digitalization stands out as a most potent instruments to realize the objectives of the 2030 Sustainable Development Agenda and Africa's Agenda 2063 (UNIDO, 2019; Songwe, 2020).

In this context, our analysis reveals that North African and Southern African countries (notably the island economies) have been engaging with digital technologies or technologies with digital potential, more strongly than other countries in the region. However, there is some variation. All other countries that outperform the average in their income group except for Tunisia are low-income countries. This suggests the difficulty of African countries to engage with digital technologies to the extent expected, given their level of economic development. Still, Namibia emerges among the five countries with the most substantial exposure to digital technologies in production. Two low-income countries, Mozambique and Rwanda, also appear among the top 10, ahead of countries such as South Africa and Botswana. Detailed findings are presented in Table 9 and Table 10.

Tunisia, Seychelles, and Morocco report the strongest performance regarding digital capabilities in Africa. Tunisia outperforms its income group average in all three digital capability indicators and even surpasses the average of upper-middle income countries. By contrast, Tunisia’s imports of digital production technologies have been declining in recent years.

Seychelles, the second strongest performer, has improved on both import-related indicators, meaning it is increasingly using technologies with digital potential and digital products. However, its values remain below those of Tunisia. It is also far from the average of its income group, namely high-income country.

Table 9 Scoring of African countries according to performance in digital capabilities

Ranking (CR1)	Economy	Income group	Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)
			Relative to region	Relative to income group average	Trend
			Score	# of indicators above global average (total: 3)	# of indicators with positive growth rates (total: 3)
1	Tunisia	Lower Middle Income	1.00	3	1
2	Seychelles	High Income	0.93	0	2
3	Morocco	Lower Middle Income	0.88	1	1
4	Namibia	Upper Middle Income	0.82	1	3
5	Mauritius	Upper Middle Income	0.81	0	1
6	Mozambique	Low Income	0.81	3	2
7	Rwanda	Low Income	0.80	3	
8	South Africa	Upper Middle Income	0.79	0	0
9	Lesotho	Lower Middle Income	0.78	2	1
10	Senegal	Lower Middle Income	0.76	0	2
11	Eswatini	Lower Middle Income	0.73	0	2
12	Botswana	Upper Middle Income	0.67	0	0
13	Mali	Low Income	0.62	3	3
14	Cabo Verde	Lower Middle Income	0.60	1	2
15	Zambia	Low Income	0.60	2	0
16	Angola	Lower Middle Income	0.59	0	3
17	Algeria	Lower Middle Income	0.58	1	
18	Madagascar	Low Income	0.48	3	2
19	Malawi	Low Income	0.48	2	0
20	Togo	Low Income	0.48	3	3
21	Congo, Rep.	Lower Middle Income	0.43	0	0
22	Zimbabwe	Lower Middle Income	0.41	0	3
23	Burkina Faso	Low Income	0.40	1	0
24	Burundi	Low Income	0.40	2	3
25	Uganda	Low Income	0.38	1	1
26	Egypt, Arab Rep.	Lower Middle Income	0.35	0	
27	Mauritania	Lower Middle Income	0.34	0	2
28	Côte d'Ivoire	Lower Middle Income	0.34	0	0
29	Kenya	Lower Middle Income	0.27	0	1
30	Ghana	Lower Middle Income	0.27	0	1
31	Congo, Dem. Rep.	Low Income	0.27	0	
32	Comoros	Lower Middle Income	0.27	0	3
33	Tanzania	Lower Middle Income	0.24	0	0
34	Sudan	Low Income	0.20	1	2
35	Ethiopia	Low Income	0.20	0	0
36	Libya	Upper Middle Income	0.14	0	
37	Benin	Lower Middle Income	0.13	0	3
38	Niger	Low Income	0.09	0	0
39	Cameroon	Lower Middle Income			
40	Gabon	Upper Middle Income			
41	São Tomé and Prír	Lower Middle Income			
42	Nigeria	Lower Middle Income			
43	Liberia	Low Income			
44	Sierra Leone	Low Income			
45	Eritrea	Low Income			
46	Chad	Low Income			
47	Central African Re	Low Income			
48	Guinea-Bissau	Low Income			
49	Gambia, The	Low Income			
50	Guinea	Low Income			
51	Djibouti	Lower Middle Income			
52	Somalia	Low Income			
53	Equatorial Guinea	Upper Middle Income			
54	South Sudan	Low Income			

Source: Authors' calculations

Table 10 African countries with perceived strongest level of readiness digital capabilities

Top performers relative to region	Top performers relative to income group:	Top performers: Positive change
Tunisia (LMI)	Tunisia (LMI)	**Mali (LI)**
Seychelles (HI)	Mozambique (LI)	**Togo (LI)**
Morocco (LMI)	Rwanda (LI)	Burundi (LI)
Namibia (UMI)	**Mali (LI)**	**Namibia (UMI)**
Mauritius (UMI)	Madagascar (LI)	Angola (LMI)
	Togo (LI)	Zimbabwe (LMI)
		Comoros (LMI)
		Benin (LMI)

Digital capabilities are Namibia's strongest asset underpinning readiness to digitalize manufacturing. It is the single country within the top five in digital capabilities in the region to record improvements on all three trade-related indicators. Still, Namibia performs below the average of its income group regarding imports and exports of ADP technologies, while it surpasses in terms of imports of PTDPs.

Among low-income countries, Mozambique and Rwanda exhibit the highest digital capabilities. However, Mali, Madagascar, and Togo also outperform their peers regarding income in all three indicators. Mozambique is Africa's fourth largest importer of PTDPs when accounting for the size of GDP. Similarly, Rwanda is the third largest importer of digital technologies relative to GDP.

In addition to Namibia, we identify a mix of countries that have improved on all three indicators measuring digital capabilities. These countries, such as Mali, Angola, Togo, and Zimbabwe, are low- or lower-middle-income. Unfortunately, measuring digital capabilities for 16 54 African countries is impossible due to a lack of data.

4.1.5.Africa's overall digital readiness

Overall, our analysis indicates that the countries with the strongest levels of readiness for the digitalization of manufacturing are located in Northern and Southern Africa, including the island economies of the Indian Ocean (Table 11). Only one other country, Senegal, has been able to join this group of countries. North African lower-middle income countries outperform peers in their income group in most indicators we analyse. Not surprisingly, low-income countries appear further down in their readiness for digitalization, dominating the bottom half in Table 11. Rwanda demonstrates the highest level of readiness for digitalization among low-income African countries. Two countries, Senegal and Burundi, have made progress in most indicators.

Tunisia displays the highest potential in adopting and adapting digital technologies in manufacturing. It also performs above the average lower-middle-income country in most indicators (12/17). Morocco comes second in terms of readiness for digitalization in the region, slightly behind Tunisia. Still, Morocco's growth dynamics are stronger than Tunisia's, improving on 11 of the 16 indicators for which data are available, compared to 9 of 16 for Tunisia. However, the two countries boast different strengths. Tunisia is the region's top performer in the more advanced capabilities necessary for the digitalization of manufacturing, namely innovation and digital capabilities. At the same time, Morocco is best positioned in enabling infrastructure. It also performs remarkably well in terms of production capabilities.

Table 11 Readiness of African countries for Digitalization of Manufacturing, Summary Table

Overall ranking (CR1)	Economy	Income group	Overall performance			Enabling Infrastructure			Production capabilities			Innovation capabilities			Digital capabilities		
			Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)	CR1	CR2	CR3	CR1	CR2	CR3	CR1	CR2	CR3	CR1	CR2	CR3
			Relative to region	Relative to income group	Trend	Relative to region	Relative to income group	Trend	Relative to region	Relative to income group	Trend	Relative to region	Relative to income group	Trend	Relative to region	Relative to income group	Trend
			Total score	# of indicators above global average/17	# of indicators improving/16	Score	# Indicators above global average/4	# Indicators improving/3	Score	# Indicators above global average/4	# Indicators improving/4	Score	# Indicators above global average/6	# Indicators improving/6	Score	# Indicators above global average/3	# Indicators improving/3
1	Tunisia	Lower-middle income	3.73	12.00	9.00	0.95	3	2	0.78	1	3	1.00	5	3	1.00	3	1
2	Morocco	Lower-middle income	3.61	10.00	11.00	1.00	3	3	0.93	3	3	0.79	3	4	0.88	1	1
3	South Africa	Upper-middle income	3.52	7.00	5.00	0.93	2	1	0.89	2	1	0.92	3	3	0.79	0	0
4	Mauritius	Upper-middle income	3.46	4.00	9.00	0.88	1	2	0.85	1	1	0.92	2	5	0.81	0	1
5	Seychelles	High Income	3.42	2.00	9.00	0.95	1	2	0.68	0	1	0.86	1	4	0.93	0	2
6	Algeria	Lower-middle income	3.03	9.00	4.00	0.69	2	2	1.00	2	0	0.77	4	2	0.58	1	
7	Botswana	Upper-middle income	3.03	2.00	6.00	0.67	0	1	0.98	2	2	0.71	0	3	0.67	0	0
8	Senegal	Lower-middle income	2.77	3.00	13.00	0.58	0	2	0.86	1	4	0.57	2	5	0.76	0	2
9	Egypt, Arab Rep.	Lower-middle income	2.77	8.00	8.00	0.95	3	2	0.71	2	2	0.76	3	4	0.35	0	
10	Namibia	Upper-middle income	2.70	1.00	7.00	0.63	0	0	0.54	0	0	0.71	0	4	0.82	1	3
11	Eswatini	Lower-middle income	2.66	2.00	9.00	0.64	0	2	0.78	2	3	0.52	0	2	0.73	0	2
12	Lesotho	Lower-middle income	2.51	4.00	5.00	0.66	1	1	0.61	1	0	0.46	0	3	0.78	2	1
13	Cabo Verde	Lower-middle income	2.49	4.00	10.00	0.76	2	2	0.56	1	1	0.56	0	5	0.60	1	2
14	Rwanda	Low Income	2.37	11.00	11.00	0.50	2	3	0.51	3	4	0.56	3	4	0.80	3	
15	Kenya	Lower-middle income	2.27	2.00	6.00	0.74	1	2	0.69	0	0	0.57	1	3	0.27	0	1
16	Mozambique	Low Income	2.21	9.00	6.00	0.68	3	1	0.49	2	0	0.24	1	3	0.81	3	2
17	Zambia	Low Income	2.21	8.00	4.00	0.64	2	2	0.75	3	1	0.22	1	1	0.60	2	0
18	Ghana	Lower-middle income	2.19	3.00	8.00	0.65	1	2	0.71	1	2	0.55	1	3	0.27	0	1
19	Angola	Lower-middle income	2.07	1.00	8.00	0.58	0	2	0.74	1	0	0.16	0	3	0.59	0	3
20	Côte d'Ivoire	Lower-middle income	2.05	1.00	8.00	0.73	1	2	0.71	0	3	0.26	0	3	0.34	0	0
21	Zimbabwe	Lower-middle income	2.04	3.00	10.00	0.74	1	2	0.30	1	2	0.60	1	3	0.41	0	3
22	Congo, Rep.	Lower-middle income	2.02	1.00	7.00	0.69	1	2	0.48	0	2	0.42	0	3	0.43	0	0
23	Madagascar	Low Income	2.02	9.00	7.00	0.45	1	1	0.66	3	1	0.43	2	3	0.48	3	2
24	Tanzania	Lower-middle income	1.78	2.00	7.00	0.61	1	2	0.64	1	2	0.29	0	3	0.24	0	0
25	Mauritania	Lower-middle income	1.72	2.00	10.00	0.42	0	2	0.59	1	2	0.38	1	4	0.34	0	2
26	Uganda	Low Income	1.67	6.00	7.00	0.39	1	1	0.51	2	2	0.39	2	3	0.38	1	1
27	Mali	Low Income	1.64	6.00	8.00	0.50	2	2	0.26	1	2	0.26	0	1	0.62	3	3
28	Gabon	Upper-middle income	1.62	0.00	2.00	0.69	0	1	0.49	0	0	0.45	0	1			
29	Burkina Faso	Low Income	1.61	4.00	9.00	0.42	1	2	0.36	1	3	0.42	1	4	0.40	1	0
30	Togo	Low Income	1.60	8.00	8.00	0.35	1	1	0.51	2	1	0.26	2	3	0.48	3	3
31	Cameroon	Lower-middle income	1.51	0.00	5.00	0.53	0	1	0.51	0	2	0.46	0	2			
32	Nigeria	Lower-middle income	1.46	2.00	7.00	0.40	1	1	0.73	1	3	0.33	0	3			
33	Malawi	Low Income	1.39	6.00	5.00	0.27	1	1	0.30	1	1	0.34	2	3	0.48	2	0
34	Libya	Upper-middle income	1.36	1.00	1.00	0.72	1	1	0.30	0	0	0.20	0	0	0.14	0	
35	Ethiopia	Low Income	1.24	4.00	7.00	0.25	0	2	0.44	1	1	0.35	3	4	0.20	0	0
36	Benin	Lower-middle income	1.24	1.00	7.00	0.17	0	0	0.53	1	2	0.41	0	2	0.13	0	3
37	São Tomé & Príncipe	Lower-middle income	1.24	0.00	6.00	0.49	0	2	0.37	0	1	0.37	0	3			
38	Comoros	Lower-middle income	1.21	1.00	6.00	0.36	0	1	0.54	1	1	0.04	0	1	0.27	0	3
39	Burundi	Low Income	1.11	3.00	13.00	0.12	0	2	0.19	0	4	0.39	1	4	0.40	2	3
40	Congo, Dem. Rep.	Low Income	1.10	3.00	9.00	0.23	0	2	0.39	2	3	0.21	1	4	0.27	0	
41	Djibouti	Lower-middle income	1.02	1.00	0.00	0.27	0	0	0.67	1	0	0.08	0	0			
42	Sudan	Low Income	0.99	6.00	6.00	0.25	1	1	0.09	1	0	0.45	3	3	0.20	1	2
43	Liberia	Low Income	0.89	4.00	5.00	0.56	2	2	0.07	1	1	0.26	1	2			
44	Gambia, The	Low Income	0.84	2.00	2.00	0.25	0	1	0.43	1	1	0.17	1	0			
45	Niger	Low Income	0.80	1.00	4.00	0.19	0	1	0.30	1	0	0.21	0	3	0.09	0	0
46	Guinea-Bissau	Low Income	0.66	3.00	5.00	0.12	0	2	0.36	1	1	0.18	2	2			
47	Guinea	Low Income	0.57	1.00	4.00	0.25	1	2	0.16	0	1	0.16	0	1			
48	Sierra Leone	Low Income	0.48	1.00	4.00	0.13	1	1	0.13	0	2	0.22	0	1			
49	Chad	Low Income	0.47	2.00	3.00	0.13	1	1	0.14	0	0	0.19	1	2			
50	Equatorial Guinea	Upper-middle income	0.47	0.00	1.00	0.30	0	0	0.15	0	1	0.01	0	0			
51	Eritrea	Low Income	0.45	1.00	3.00	0.24	0	1		0	0	0.21	1	2			
52	Somalia	Low Income	0.43	1.00	5.00	0.20	1	2	0.17	0	2	0.05	0	1			
53	Central African Rep.	Low Income	0.28	1.00	2.00	0.00	0	0	0.09	0	1	0.19	1	1			
54	South Sudan	Low Income	0.03	0.00	4.00	0.03	0	2	0.00	0	0	0.00	0	2			

Source: Authors' calculations

Next comes South Africa, with a level of readiness for digitalization of manufacturing, which is the third strongest in the region and the best in Sub-Saharan Africa. Despite being a leader in technology and innovation in the region, it lags the average in its income group in more than half of the indicators. Moreover, the country needs help to improve in most dimensions of the dashboard, raising concerns about its readiness to digitalize in a long-term perspective.

Among low-income African countries, Rwanda reports the strongest readiness to engage with digital technologies to foster industrialization. It outperforms the average country in its income group in 11 of the 17 indicators included in the dashboard, with a positive trend of progress over time in an equal number of indicators. While Rwanda's primary strength lies in its engagement with digital technologies, significant improvements have been made in all foundational capabilities.

Senegal is the only non-Southern, Sub-Saharan country among the ten countries with the highest readiness for African digitalization. Moreover, similar to Burundi, Senegal reports progress in most capability indicators (13/17 indicators). Its strength lies mainly in production capabilities, demonstrating its potential to create a conducive environment for manufacturing firms to innovate and digitalize further.

Burundi is a low-income, East African, francophone economy that generally needs more capabilities to acquire and meaningfully deploy ADP technologies in manufacturing. It is vital in three indicators, relative to its income group, two of which correspond to digital capabilities. This suggests that while Burundi has started to engage with ADP technologies, its foundational capabilities still need to be improved. Despite this, it is –along with Senegal– the country that reports the most progress in the continent, improving on 13 of 16 indicators, and emerging as a country to observe in coming years.

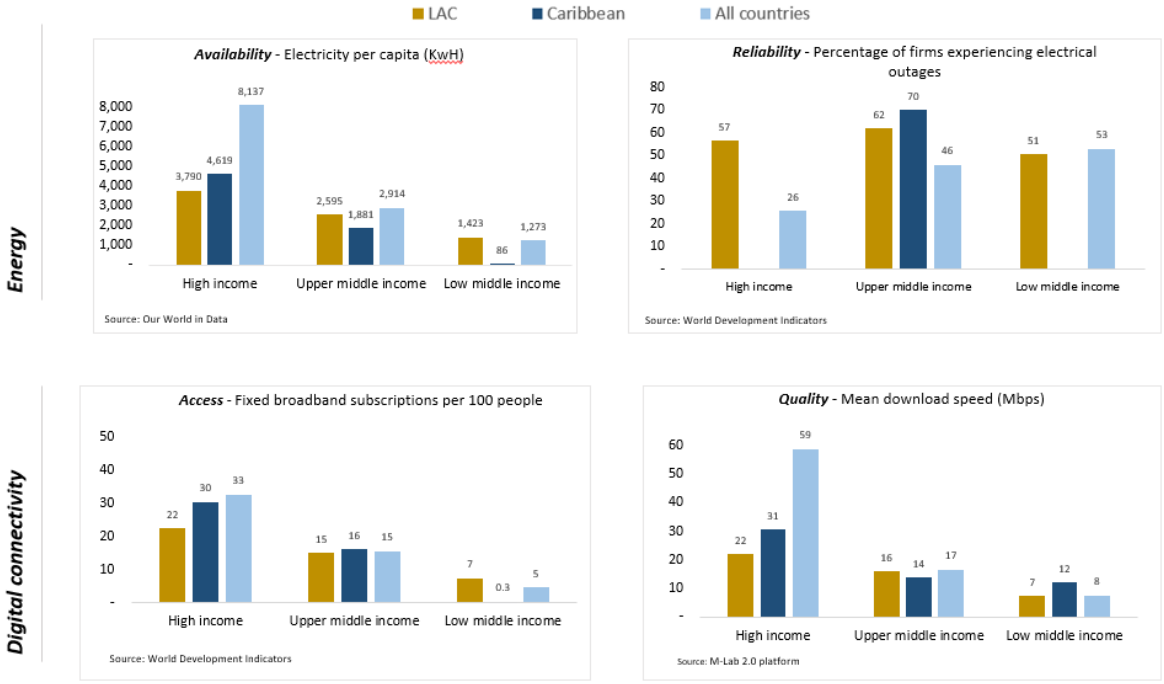
4.2. Latin America

The DRD for Latin America and the Caribbean (calculations Annex 2) compiles each country's performance across the indicators defined in UNIDO and GIZ (2024). This section explores each layer of capabilities to illustrate where countries in the region show different signs of digitalization readiness. We analyze this by looking at performance according to the three criteria described in the methodology, i.e., countries' relative performance across indicators, income groups, and improvement trends. Special attention is paid to countries that perform well in all three criteria.

4.2.1.Enabling infrastructure

Across income groups, the region's performance compares positively to global averages, especially regarding digital connectivity (Figure 1). To some extent, this reflects the priority granted to deploying digital infrastructure and promoting universal access to internet across the region for over a decade (Economic Commission for Latin America and the Caribbean, 2021). In 2021, 76 percent of the population in the region used the internet[13], while significant gaps persist in terms of coverage, especially in rural areas (Economic Commission for Latin America and the Caribbean, 2022a; IICA and Ziegler, 2020), and quality of service for most countries in the region.

Figure 1. Latin America and the Caribbean: enabling infrastructure across income groups



Source: Authors' calculations

Regarding enabling infrastructure, Brazil and Chile feature the strongest capabilities, followed closely by Uruguay (Table 12). While Chile and Uruguay have improved energy availability and access to digital connectivity, Brazil tops in terms of quality of internet connectivity, showing the highest mean download speed in Latin America (33.3 Mbps). El Salvador stands out among lower-middle-income countries, showing a solid performance in all indicators related to enabling infrastructure[14]. Argentina, Bolivia, and Guatemala are other countries with strong growth in enabling infrastructure.

[13] World Development Indicators: https://databank.worldbank.org/source/world-development-indicators

[14] Trends can be calculated for indicators of energy access (electricity consumption), energy reliability (electrical outages), and access to connectivity (fixed broadband network). Regarding the quality of digital connectivity, measured by mean download speed, trends cannot be calculated due to changes in methodology from the source, M-Labs.

In the Caribbean, Barbados shows the highest level of capability regarding quality of digital connectivity. The country's mean download speed at 55.9 Mbps, is the highest in Latin America and the Caribbean, and it is closer to the average of high-income economies in the world (58.7 Mbps).

Table 12. Scoring of Latin America and the Caribbean: enabling digital and energy infrastructure

	Ranking CR1	Country	Income group	Criteria 1 (CR1) Relative to region Score	Criteria 2 (CR2) Relative to income group # indicators above global average/4	Criteria 3 (CR3) Trend # indicators improving/3
Latin America	1	Brazil	Upper middle	1.00	3	2
	2	Chile	High	1.00	0	2
	3	Uruguay	High	0.98	0	2
	4	Panama	High	0.93	0	2
	5	Costa Rica	Upper middle	0.91	2	2
	6	Mexico	Upper middle	0.91	2	2
	7	Paraguay	Upper middle	0.67	2	2
	8	Venezuela	Lower middle	0.60	2	1
	9	Argentina	Upper middle	0.58	2	3
	10	Colombia	Upper middle	0.53	1	1
	11	Ecuador	Upper middle	0.44	0	2
	12	El Salvador	Lower middle	0.40	3	3
	13	Peru	Upper middle	0.40	0	2
	14	Bolivia	Lower middle	0.28	2	3
	15	Nicaragua	Lower middle	0.16	2	2
	16	Guatemala	Upper middle	0.09	0	3
	17	Honduras	Lower middle	0.00	0	2
Caribbean	1	Barbados	High	1.00	1	2
	2	Trinidad and Tobago	High	0.94	0	1
	3	Bahamas	High	0.89	0	1
	4	St. Kitts and Nevis	High	0.83	1	2
	5	Grenada	Upper middle	0.64	2	2
	6	Dominica	Upper middle	0.56	1	2
	7	St. Lucia	Upper middle	0.53	1	1
	8	St. Vincent and the Grenadines	Upper middle	0.50	1	2
	9	Belize	Upper middle	0.42	1	2
	10	Jamaica	Upper middle	0.42	1	2
	11	Suriname	Upper middle	0.42	2	1
	12	Antigua and Barbuda	High	0.28	0	1
	13	Dominican Republic	Upper middle	0.25	0	2
	14	Guyana	Upper middle	0.11	0	2
	15	Cuba	Upper middle	0.08	0	2
	16	Haiti	Lower middle	0.00	1	1

Source: Authors' calculations

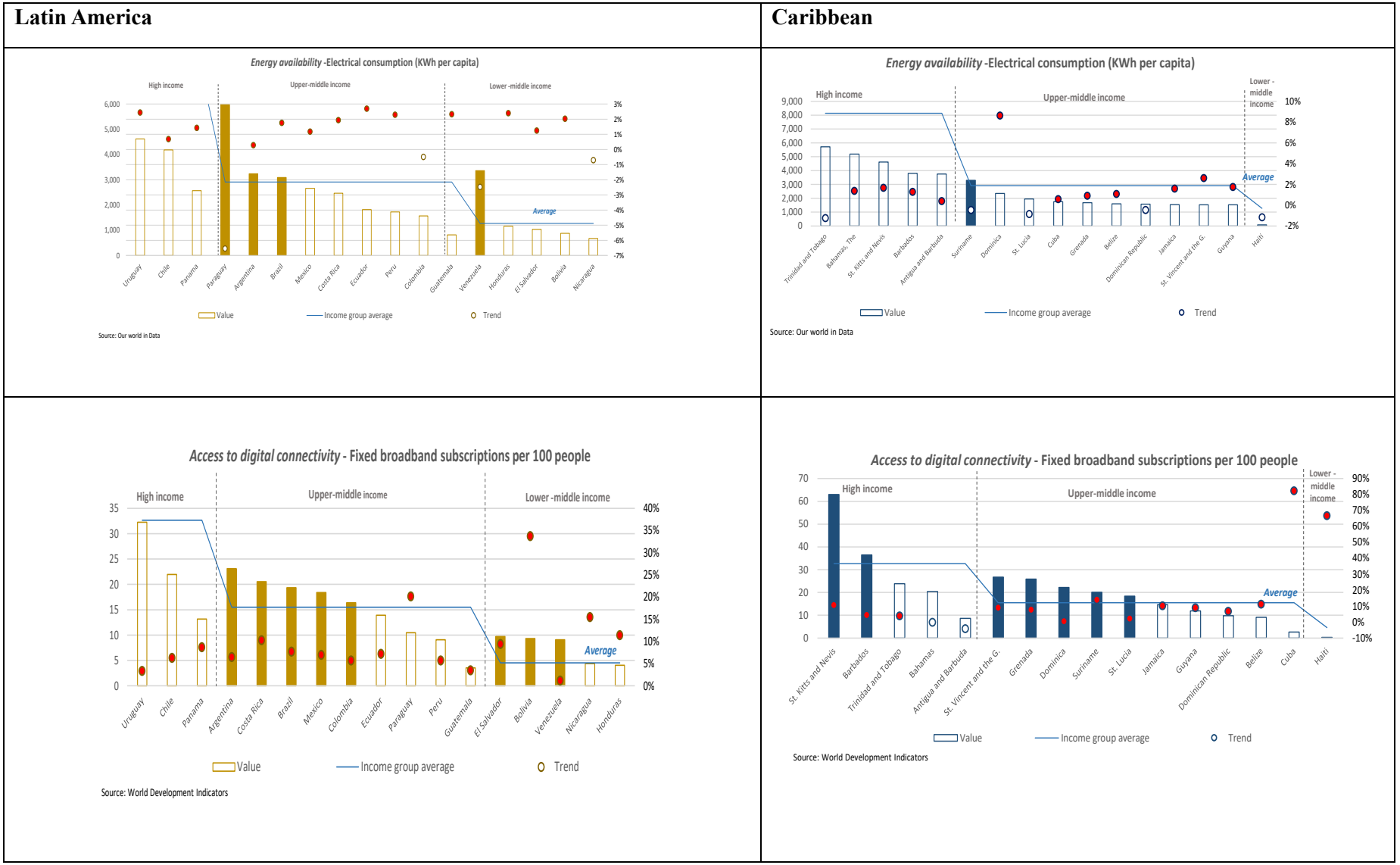
Most Latin America and the Caribbean countries show positive performance in energy availability and access to connectivity. A deep dive into the specific indicators for digital connectivity, access, and quality (Figure 2) finds Uruguay to be the country with the strongest readiness in Latin America; it performs close to the average of high-income countries. Similarly, Brazil and El Salvador outperform the average of their respective income groups in both indicators. Barbados has the highest quality internet connection in the Caribbean and comes second in access to connectivity after St. Kitts and Nevis. Access to fixed broadband networks per 100 people in these two countries exceeds the average of high-income economies.

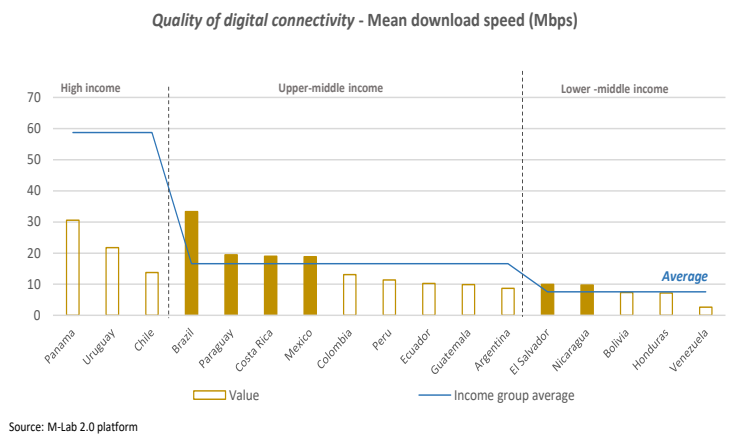
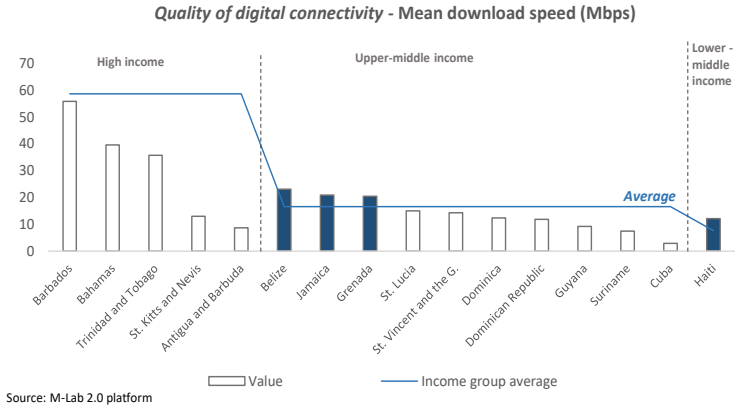
Improving the quality of connectivity is a great challenge for Latin America and the Caribbean. Higher connection speeds are essential to adopt 5G networks, yet most countries in the region need to catch up to other countries worldwide. According to the Global System for Mobile Technology Association (GSMA)[15], adopting 5G networks in Latin America should reach 12 percent in 2025. This situation contrasts with the expectation for North America and Europe, where the adoption of 5G should be five and four times higher, respectively. In terms of mean download speed, data from 2021 show that, Caribbean countries such as Barbados, the Bahamas, and Trinidad and Tobago held position 38th, 58th, and 65th respectively out of 224 countries reported in M-Lab data.[16] Brazil was the best-placed Latin American country, appearing in position 68th, followed by Panama (72), Uruguay (82), Paraguay (94), Costa Rica (97), Mexico (98), Chile (113) and Colombia (115).

[15] https://www.gsma.com/futurenetworks/ip_services/understanding-5g/

[16] M-Lab provides the largest collection of open Internet performance data. https://www.measurementlab.net/; https://www.cable.co.uk/broadband/speed/worldwide-speed-league/

Figure 2. Performance across selected indicators for enabling infrastructure in Latin America and the Caribbean



Latin America	Caribbean
	

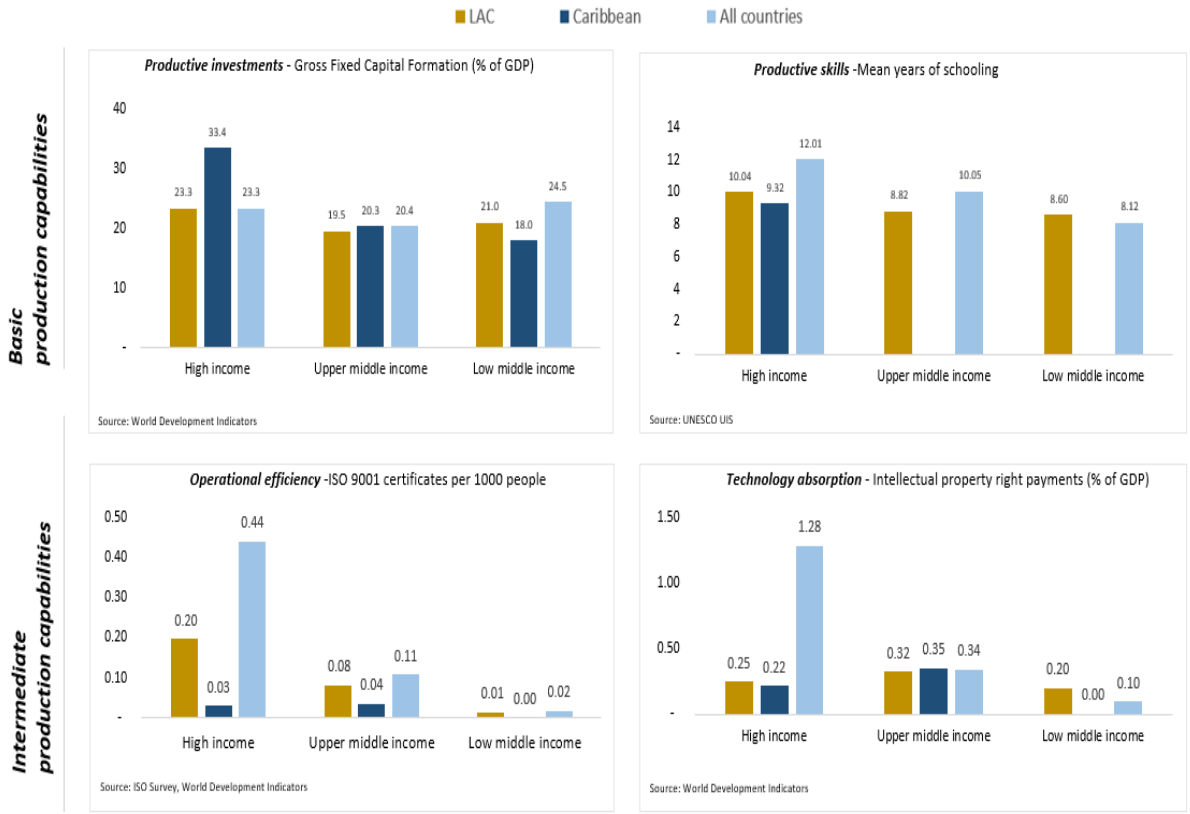
*Note: Columns painted in color represent countries performing above the global income group average, circles in red denote a positive trend from 2015 to 2021. Regarding access to digital connectivity, the last data point available is 2020 for the following countries: Guatemala, Antigua and Barbuda, the Bahamas, Belize, Dominica, Grenada, Guyana, Haiti, St. Kitts and Nevis and St. Lucia. Trends cannot be calculated for the quality of digital connectivity indicators due to changes in the methodology from the source, M-Lab.

Source: Authors' calculations

4.2.2.Production capabilities

Although firms in Latin America underperform in terms of operational efficiency across all income groups, the region is well-placed regarding indicators for productive investment, fundamental skills, and technology absorption. According to the latter, the region's upper-middle-income countries are slightly behind their peers within same income group in the world. In contrast, lower-middle-income countries score twice above the average of this income bracket (Figure 3) These findings suggest that most Latin American countries actively license technologies, measured by the payments for intellectual property rights, which surmises substantial absorptive capacities to introduce ADP technologies.

Figure 3. Latin America and the Caribbean: Performance in terms of production capabilities across income groups



Source: Authors' calculations

Table 13 shows that Chile holds the highest level of productive investment, relative to GDP, in Latin America; it is also above the average of high-income economies. Nevertheless, the country needs to significantly improve indicators for productive capabilities. By contrast, upper-middle-income countries such as Costa Rica, Brazil, Mexico, and Paraguay show the most dynamic performance. These countries report positive trends in three of the four indicators of productive capabilities, joined by El Salvador as the best performer in the lower-middle income group. Costa Rica and El Salvador are

particularly strong in technology absorption, performing above peers in their respective income groups and improving during 2015-2021.

Barbados has the most robust performance in the Caribbean, followed by St. Lucia, Belize, Antigua and Barbuda and the Dominican Republic. The Dominican Republic stands out for its dynamism in productive investment and intermediate production capabilities, captured by the number of ISO 9001 certificates and intellectual property rights payments.

Table 13. Scoring of Latin America and the Caribbean countries in terms of production capabilities

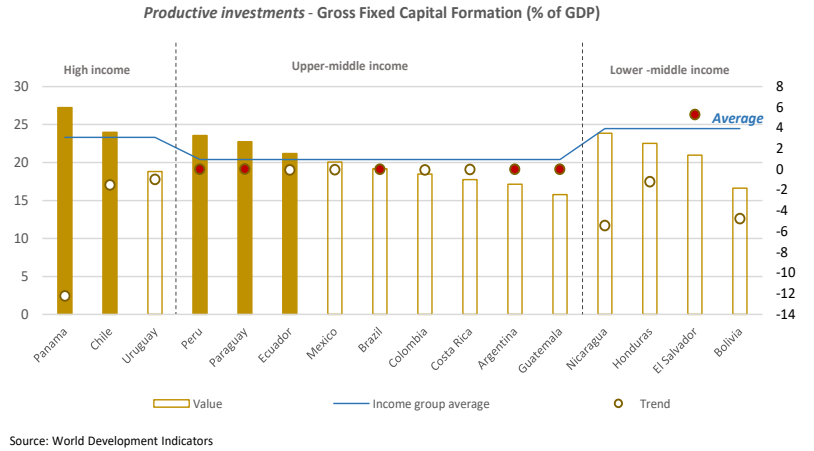
	Ranking CR1	Country	Income group	Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)
				Relative to region	Relative to income group	Trend
				Score	# indicators above global average/4	# indicators improving/4
Latin America	1	Chile	High	1.00	1	0
	2	Argentina	Upper middle	0.61	2	2
	3	Colombia	Upper middle	0.59	2	1
	4	Panama	High	0.57	1	1
	5	Uruguay	High	0.54	0	2
	6	Ecuador	Upper middle	0.52	1	2
	7	Peru	Upper middle	0.50	1	2
	8	Costa Rica	Upper middle	0.48	1	3
	9	Brazil	Upper middle	0.43	0	3
	10	Mexico	Upper middle	0.39	0	3
	11	El Salvador	Lower middle	0.37	2	3
	12	Paraguay	Upper middle	0.37	1	3
	13	Honduras	Lower middle	0.30	1	2
	14	Bolivia	Lower middle	0.22	2	0
	15	Guatemala	Upper middle	0.07	1	2
	16	Nicaragua	Lower middle	0.07	0	0
	17	Venezuela	Lower middle	0.00	1	0
Caribbean	1	Barbados	High	1.00	0	1
	2	St. Lucia	Upper middle	0.91	1	2
	3	Belize	Upper middle	0.87	1	2
	4	Antigua and Barbuda	High	0.78	1	2
	5	Dominican Republic	Upper middle	0.78	1	3
	6	Grenada	Upper middle	0.78	1	1
	7	Jamaica	Upper middle	0.74	1	0
	8	Bahamas	High	0.70	1	2
	9	Suriname	Upper middle	0.70	1	1
	10	Trinidad and Tobago	High	0.70	0	0
	11	St. Kitts and Nevis	High	0.61	0	2
	12	St. Vincent and the Grenadines	Upper middle	0.48	1	0
	13	Guyana	Upper middle	0.43	0	0
	14	Dominica	Upper middle	0.13	0	1
	15	Haiti	Lower middle	0.04	0	2
	16	Cuba	Upper middle	0.00	0	1

Source: Authors' calculations

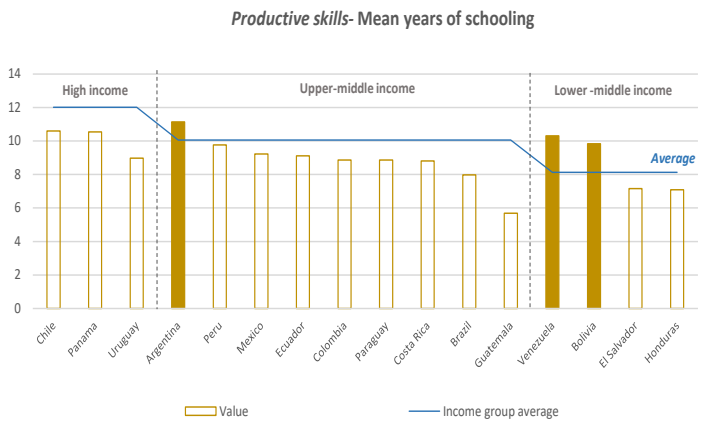
Looking at individual indicators of productive capabilities (Figure 4), several countries stand out due to their positive performance across income groups. Regarding basic production capabilities, most countries with the largest share of productive investment also outperform their respective income group averages. Colombia and El Salvador outperform their peers in the upper-middle and lower-middle income groups, respectively, in terms of intermediate production capabilities. El Salvador shows a positive trend in almost all indicators. A similar conclusion can be drawn for the Dominican Republic in the Caribbean.

Figure 4. Latin America and the Caribbean: Performance in terms of production capabilities income groups

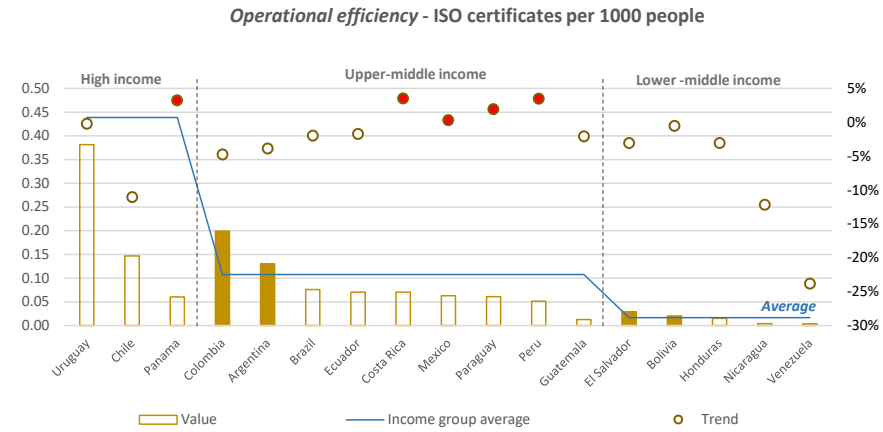
Latin America



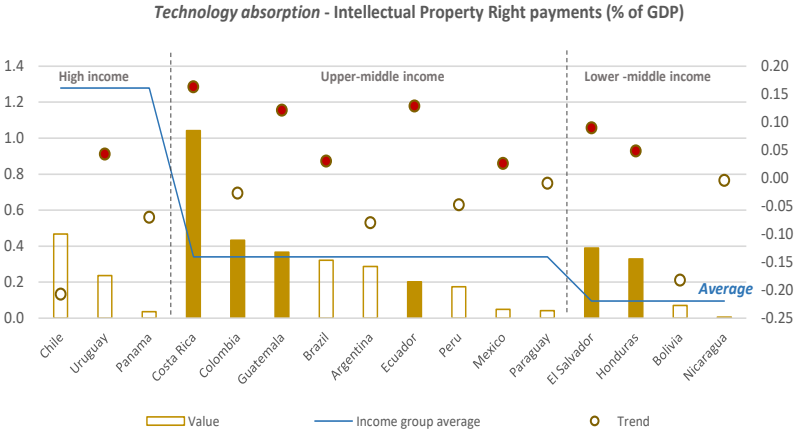
Source: World Development Indicators



Source: UNESCO UIS

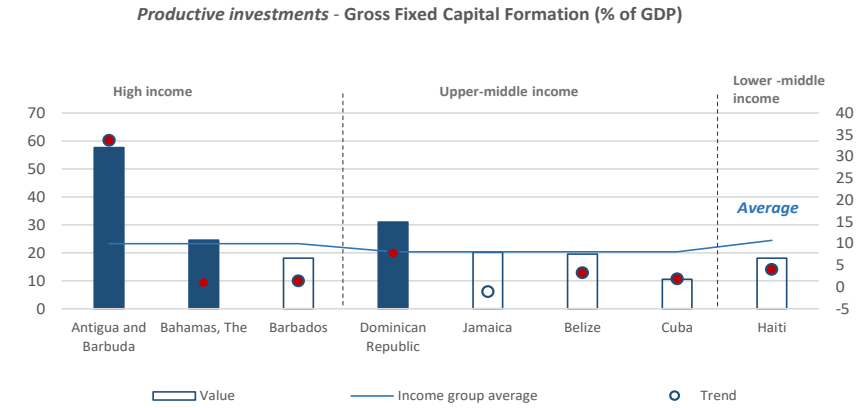


Source: ISO Survey, World Development Indicators

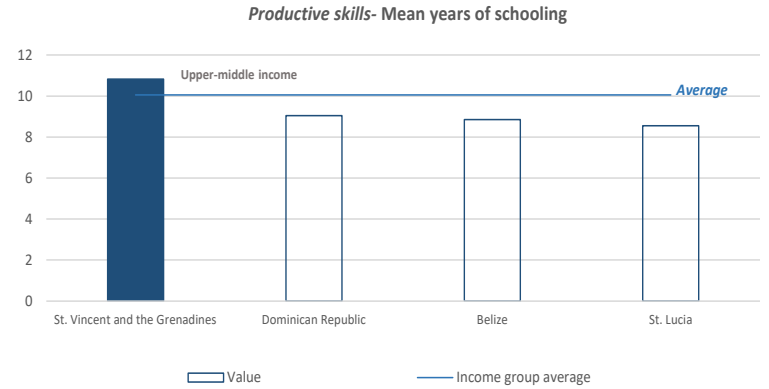


Source: World Development Indicators

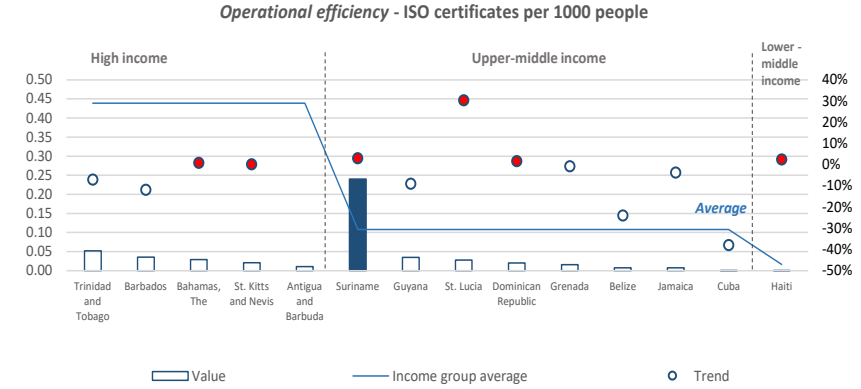
Caribbean



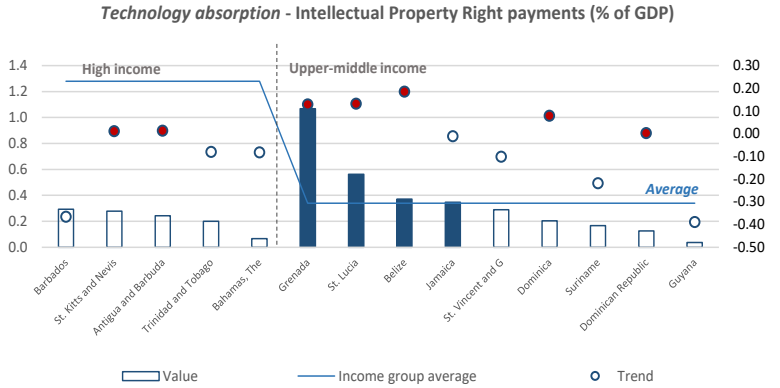
Source: World Development Indicators



Source: UNESCO UIS



Source: ISO Survey, World Development Indicators



Source: World Development Indicators

*Note: Columns in blue denote performance above-average within the respective income group. The red dots represent positive trends during 2015-2021. The latest available year for the indicator on productive investment is 2020 for Antigua and Barbuda. Differences in data availability make benchmarking of basic education skills problematic.
Source: Authors' calculations

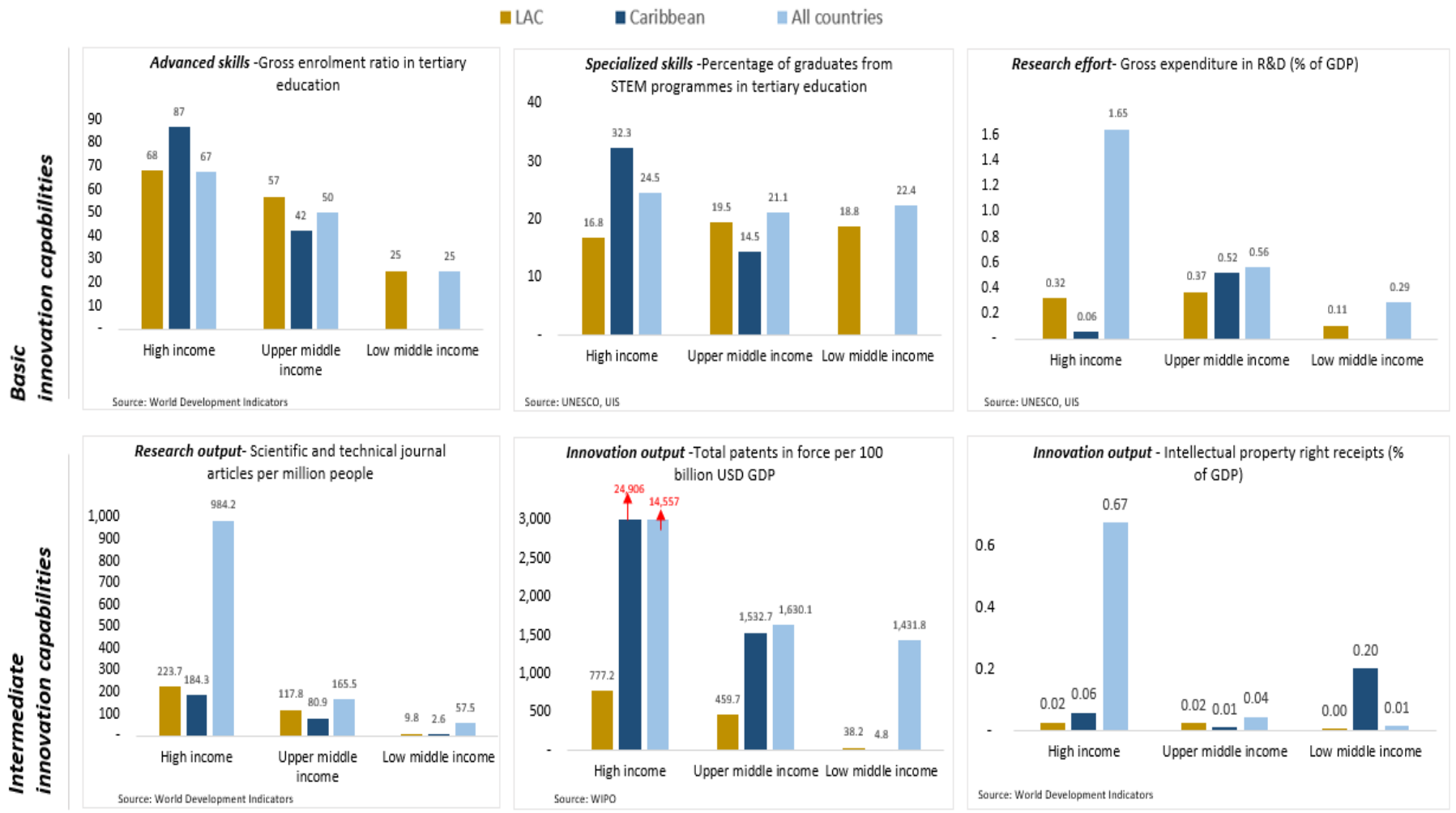
Despite the positive performance in several indicators for production capabilities, it is difficult to indicate their effect on the state of digitalization of manufacturing processes at this point. For instance, one of the crucial elements to assess digital readiness is adopting digital technologies at the firm level. Hence, more research is needed to understand the underlying conditions surrounding the factors that facilitate the use of digital technologies in business in a country-specific context.

4.2.3. Innovation capabilities

There is a wealth of literature that documents how structural low levels of private sector investment in R&D and the absence of business-university collaboration to encourage knowledge transfer and sharing affects the ability of Latin America and the Caribbean countries to improve the ability of national innovation systems to foster adoption of ADP technologies (OECD and IDB 2022; Santiago, Freire, and Lavopa 2023; Economic Commission for Latin America and the Caribbean 2022b). Our findings largely corroborate this gap in innovation capabilities in the region. Figure 5 shows that Latin America and the Caribbean countries lag behind other economies in essential innovation capabilities. For example, while performance in advanced skills (gross enrolment ratio in tertiary education) is above the average across income groups, performance in specialized skills (percentage of graduates in STEM programs) in upper-middle and lower-middle countries falls below the average of their respective income levels.

Similarly, the region underperforms in terms of research efforts and outputs. For instance, R&D spending as a share of GDP in the region's high-income countries is far behind the average of high-income economies in the world and even below that of upper-middle-income economies in both the region and globally. Low levels of R&D investment can explain the region's lagging position regarding research outputs. For instance, the number of publications of scientific and technical articles per million people is below average across all income groups.

Figure 5. Latin America and the Caribbean: Performance in terms of Innovation capabilities across income groups



Source: Authors' calculations

Chile and Brazil show the most robust innovation capabilities in the region (Table 14), performing particularly well in research and innovation outputs. Unlike R&D expenditure, both countries report improvements in the other five indicators in this layer. Brazil, in particular, is the only country in the region that outperforms its income group in most indicators, except for specialized skills and patents. El Salvador stands out among lower-middle-income countries in the area, outperforming the average for its income group in advanced skills and showing a positive trend in R&D investment and publications.

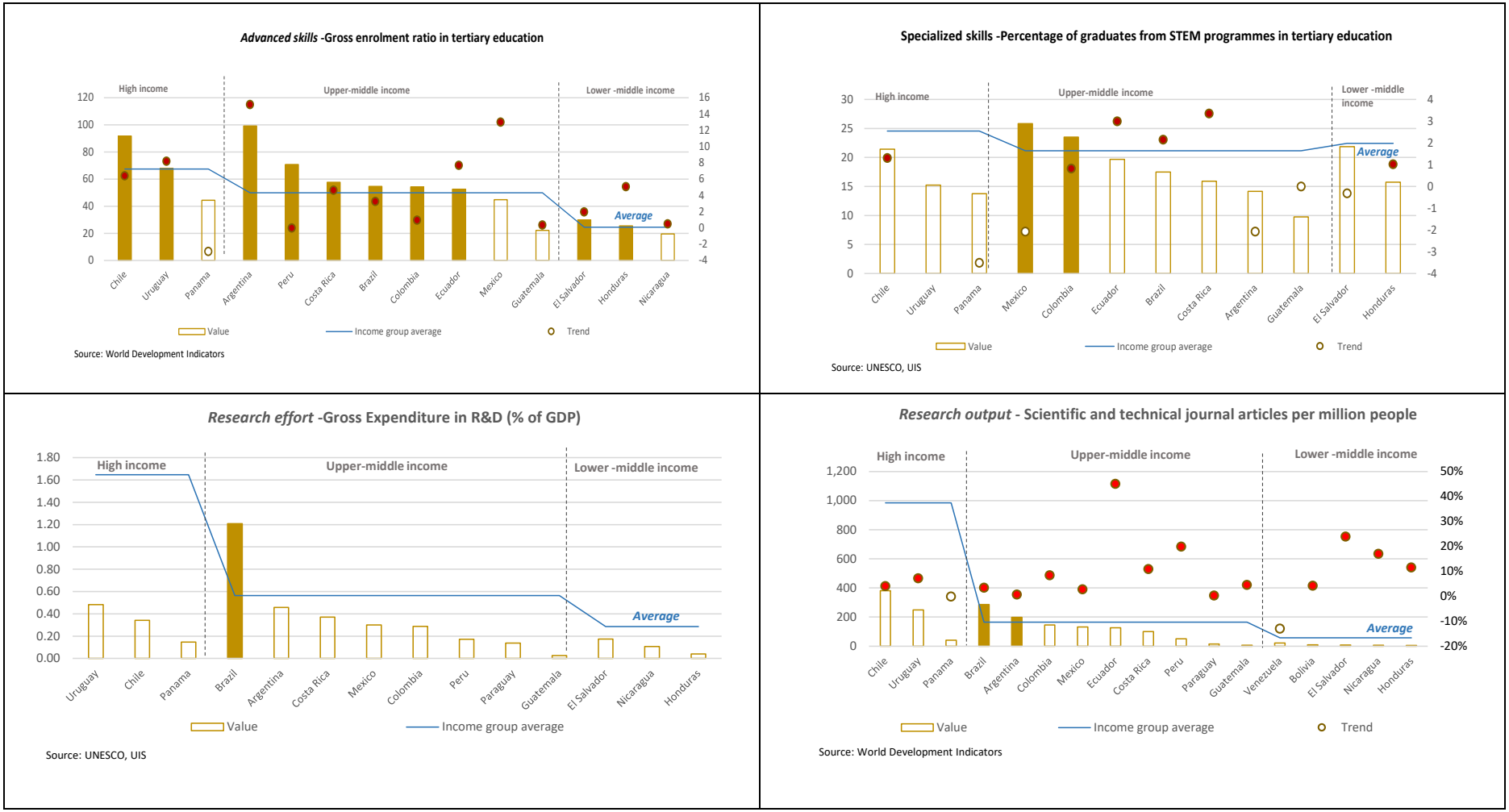
Table 14. Scoring of Latin America and the Caribbean countries in terms of innovation capabilities

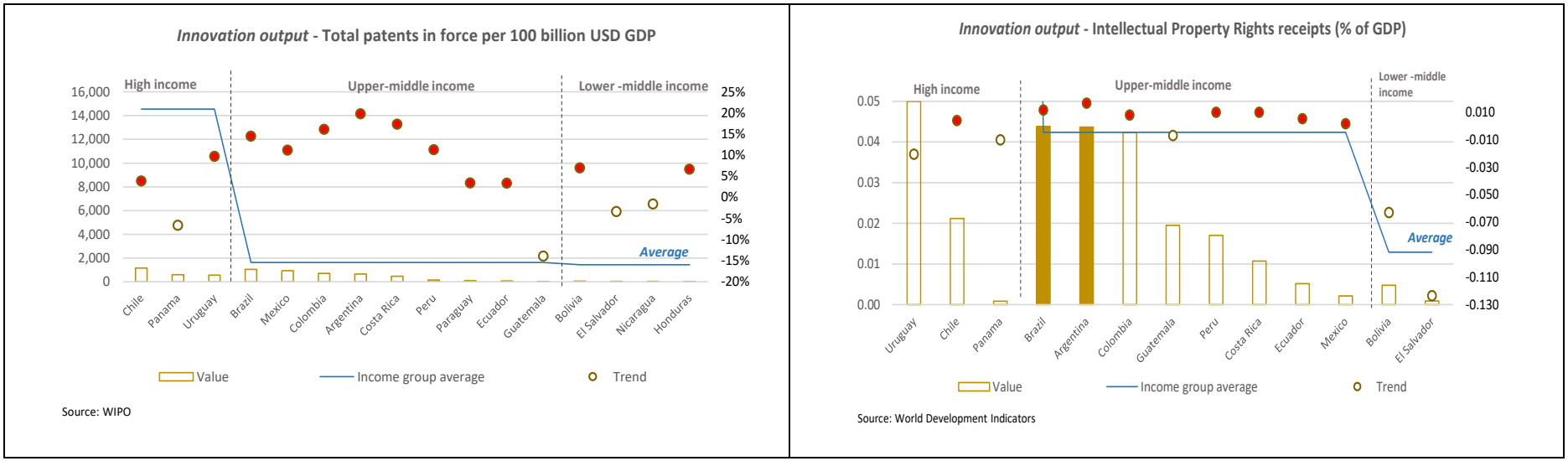
	Ranking CR1	Country	Income group	Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)
				Relative to region	Relative to income group	Trend
				Score	# indicators above global average/6	# indicators improving/6
Latin America	1	Chile	High	1.00	1	5
	2	Brazil	Upper middle	0.99	4	5
	3	Argentina	Upper middle	0.88	3	4
	4	Uruguay	High	0.88	1	4
	5	Colombia	Upper middle	0.84	2	5
	6	Mexico	Upper middle	0.74	1	4
	7	Peru	Upper middle	0.72	2	4
	8	Costa Rica	Upper middle	0.68	1	5
	9	Ecuador	Upper middle	0.46	1	4
	10	Panama	High	0.39	0	0
	11	El Salvador	Lower middle	0.38	1	3
	12	Guatemala	Upper middle	0.14	0	2
	13	Paraguay	Upper middle	0.14	0	3
	14	Bolivia	Lower middle	0.13	0	2
	15	Honduras	Lower middle	0.10	1	4
	16	Nicaragua	Lower middle	0.07	0	2
	17	Venezuela	Lower middle	0.00	0	0
Caribbean	1	Grenada	Upper middle	1.00	2	3
	2	Barbados	High	0.93	1	1
	3	St. Kitts and Nevis	High	0.83	1	2
	4	Trinidad and Tobago	High	0.69	1	2
	5	Jamaica	Upper middle	0.59	0	2
	6	Cuba	Upper middle	0.48	1	4
	7	Dominica	Upper middle	0.45	1	2
	8	Belize	Upper middle	0.38	1	4
	9	Antigua and Barbuda	High	0.34	1	2
	10	Bahamas	High	0.28	0	1
	11	St. Lucia	Upper middle	0.28	0	3
	12	St. Vincent and the Grenadines	Upper middle	0.24	1	1
	13	Haiti	Lower middle	0.03	1	0
	14	Suriname	Upper middle	0.03	0	1
	15	Dominican Republic	Upper middle	0.00	1	3
	16	Guyana	Upper middle	0.00	0	2

Source: Authors' calculations

In the Caribbean, Grenada reports the highest score among the countries where data is available in the subregion. Grenada has highest number of scientific and technical articles per million people, performing above the average for its income group and improving during 2015-2021. Regarding temporal dynamism, Cuba and Belize have improved in four of six indicators, progressing especially in advanced and specialized skills, as well as in patents in force. Due to data limitations, individual indicators for innovation capabilities are presented only for Latin American countries (Figure 6).

Figure 6. Performance across indicators for innovation capabilities – Latin American countries





*Note: Columns in color denote performance above income group averages; red dots represent positive trends during 2015-2021. The indicators for advanced and specialized skills cover the period 2015-2020. Regarding advanced skills, the last available data for Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua corresponds to 2019. Regarding specialized skills, the latest available data for El Salvador and Honduras correspond to 2019. Data for R&D expenditure covers different years between 2015 and 2020, making calculating trends for benchmarking purposes problematic. The indicator for scientific and technical publications covers the period from 2015 to 2018.

Source: Authors' calculations

Argentina and Chile report the strongest levels of advanced skills for innovation –gross enrollment ratios in tertiary education– while Honduras, Guatemala, and Nicaragua[17] record the lowest ratios in the region. Ten countries in the region outperform the average for their respective income group in this indicator, with positive trends during the analysis period, except for Panama. Regarding specialized skills, graduates in STEM programs averaged 19 percent of the total graduates in the region in 2020.

Specific skills towards digital transformation cannot be disaggregated from the indicators used in our analysis. Such diverse skills can be acquired through higher education and vocational training (Economic Commission for Latin America and the Caribbean, 2018). While skills to assimilate and adapt mature technologies include areas of management informatics, those required to incorporate ADP technologies into production processes require training in artificial intelligence and robotics (OECD et al., 2020). It is estimated that over 7,000 undergraduate and training programs in digital technologies are offered in countries such as Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Uruguay; however, only Brazil and Mexico account for 71 percent of the courses linked explicitly to advanced technologies (Economic Commission for Latin America and the Caribbean 2022a).

Overall, the supply of postgraduate programs linked explicitly to the region's digital technologies is scarce, affecting research capabilities (Economic Commission for Latin America and the Caribbean, 2018). Research in the area is primarily made possible through public funding, which mainly targets basic research. Conversely, in more advanced industrial economies, the business sector is the primary source of R&D funding, with emphasis on experimental research (UNESCO, 2021; Economic Commission for Latin America and the Caribbean, 2022b). The structural low level of private sector investment in R&D and the absence of business-university collaboration to underpin innovation are significant obstacles hindering the region’s ability to improve innovation performance, as necessary for a faster adoption of ADP technologies (Economic Commission for Latin America and the Caribbean 2022b; OECD and IDB 2022; Santiago, Freire, and Lavopa 2023).

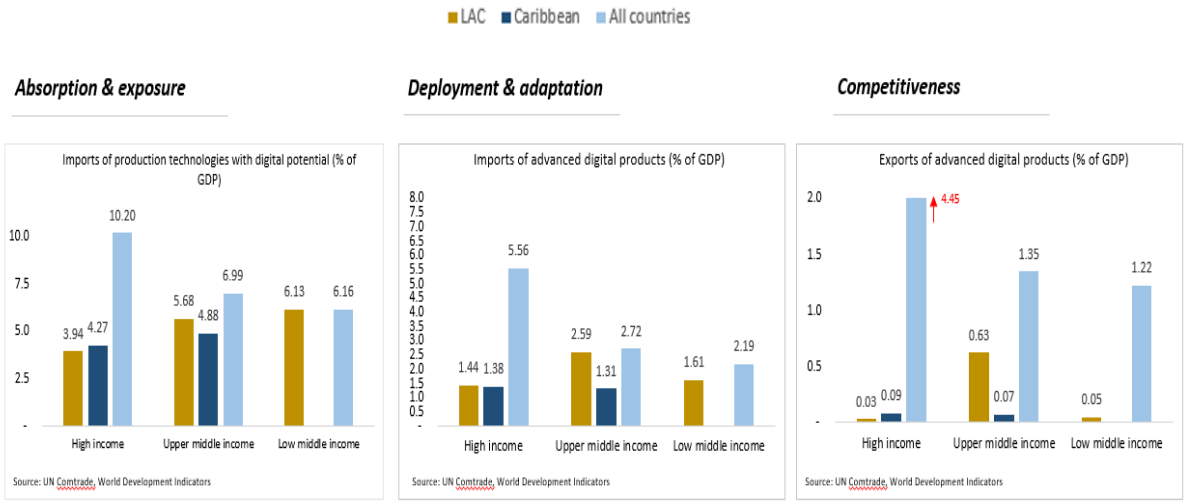
Brazil is the only country in the region that invests more than 1 percent of its GDP in R&D; its strong performance in R&D and patenting activity places it in a prominent position in the region. Brazil's manufacturing ecosystem's technological attainment and innovation capacity have brought the country closer to more advanced economies in the world.

[17] Enrollment ratios in tertiary education for Honduras, Guatemala, and Nicaragua correspond to 2019.

4.2.4. Digital capabilities

Figure 7 depicts the performance of Latin America and the Caribbean in digital capabilities across income groups. Imports of PTDPs, as a share of GDP, by upper-middle-income countries in Latin America fall below the average of their income group, while lower-middle income countries are slightly behind their peers worldwide. Regarding ADP technologies, imports by the region's upper-middle-income countries are close to the average income group. In contrast, lower-middle-income countries lag behind countries in the same income bracket. Finally, exports of ADP technologies lag far behind the world average across all income groups. In the case of the Caribbean, data are available only for six countries in the region, thereby limiting the scope of the analysis.

Figure 7. Latin America and the Caribbean: Digital capabilities across income groups



Source: Authors' calculations

Regarding readiness in digital capabilities, Mexico records the strongest performance in the region (Table 15), followed by Chile, Costa Rica, and El Salvador. These countries show a strong dynamism in all three indicators used in the analysis. In the case of Caribbean countries for which data is available, Barbados comes as the top performer, followed by Belize and the Dominican Republic.

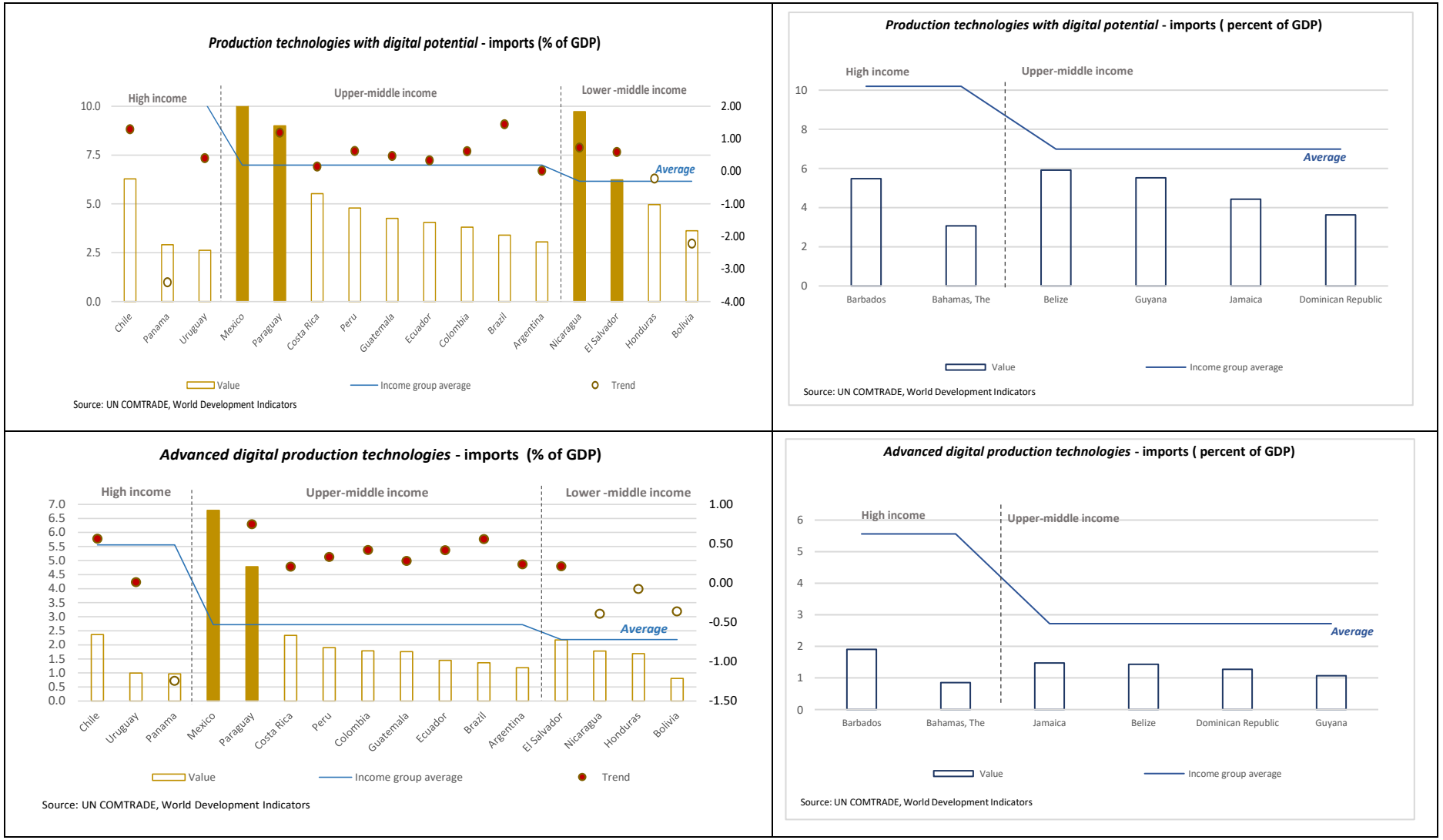
Table 15. Scoring of Latin America and the Caribbean countries in terms of digital capabilities.

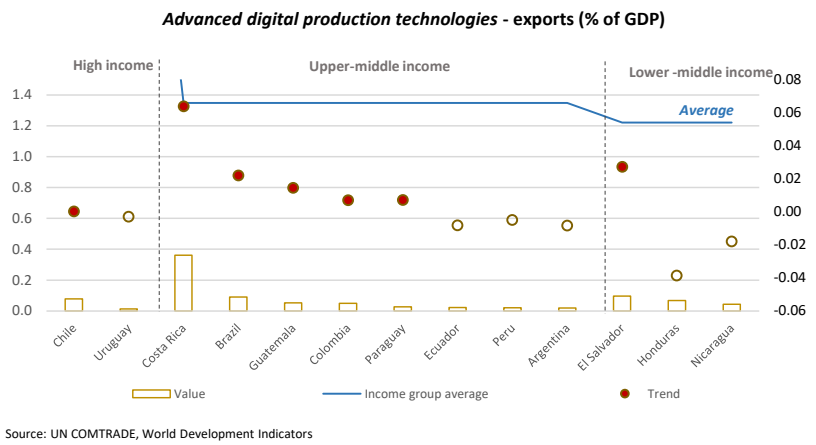
	Ranking CR1	Country	Income group	Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)
				Relative to region	Relative to income group	Trend
				Score	# indicators above global average/3	# indicators improving/3
Latin America	1	Mexico	Upper middle	1.00	3	0
	2	Chile	High	0.81	0	3
	3	Costa Rica	Upper middle	0.81	0	3
	4	El Salvador	Lower middle	0.79	1	3
	5	Paraguay	Upper middle	0.75	2	3
	6	Nicaragua	Lower middle	0.67	1	1
	7	Honduras	Lower middle	0.58	0	0
	8	Guatemala	Upper middle	0.54	0	3
	9	Colombia	Upper middle	0.52	0	3
	10	Peru	Upper middle	0.52	0	2
	11	Brazil	Upper middle	0.46	0	3
	12	Ecuador	Upper middle	0.40	0	2
	13	Argentina	Upper middle	0.23	0	2
	14	Bolivia	Lower middle	0.15	0	0
	15	Uruguay	High	0.15	0	2
	16	Panama	High	0.13	0	0
	17	Venezuela	Lower middle	0.00	0	0
Caribbean	1	Barbados	High	1.00	0	0
	2	Belize	Upper middle	0.73	0	0
	3	Dominican Republic	Upper middle	0.73	0	0
	4	Guyana	Upper middle	0.67	0	0
	5	Jamaica	Upper middle	0.67	0	0
	6	Bahamas	High	0.40	0	0
	7	Antigua and Barbuda	High	0.00	0	0
	8	Cuba	Upper middle	0.00	0	0
	9	Dominica	Upper middle	0.00	0	0
	10	Grenada	Upper middle	0.00	0	0
	11	Haiti	Lower middle	0.00	0	0
	12	St. Kitts and Nevis	High	0.00	0	0
	13	St. Lucia	Upper middle	0.00	0	0
	14	St. Vincent and the Grenadines	Upper middle	0.00	0	0
	15	Suriname	Upper middle	0.00	0	0
	16	Trinidad and Tobago	High	0.00	0	0

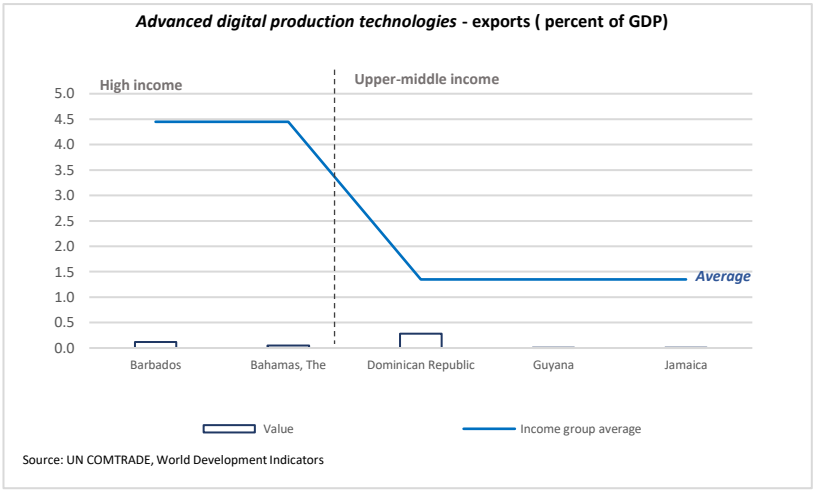
Source: Authors' calculations

Regarding performance across individual indicators (Figure 8), Mexico stands out in the region in terms of imports of PTDP, and imports and exports of ADP technologies. This situation reflects that advanced technologies represent 40 percent of manufacturing value-added in Mexico (Grosman et al. 2021). The country outperforms the average of upper-middle-income countries in the world in both indicators for imports, suggesting a significant level of implementation of sophisticated imported technologies. El Salvador features the most substantial level of digital capabilities among lower-middle-income countries in the region. It outperforms its income group regarding imports of PTDP, while it is close to the average of its peers in terms of imports of ADP technologies. In the Caribbean, Belize leads the imports of PTDP, while in ADP technologies, Barbados leads imports, and the Dominican Republic leads exports.

Figure 8. Performance across indicators for digital capabilities – Latin America and Caribbean







*Note: Columns in color denote countries performing above the global income group average, and red dots represent positive trends during 2017-2021. In the case of Argentina, the trend covers the period 2018-2021. Data for individual Caribbean countries varies significantly from 2017 to 2021 making computation of trends problematic.

Source: Authors' calculations

Overall, the region lags in terms of the adoption of ADP technologies. According to UNIDO (2019), none of the countries in the region fall into the category of *frontrunners*, while only four –Brazil, Argentina, Colombia, and Mexico– are considered *followers*. Among the latter there is a differentiation in the application level of ADP technologies. Argentina, Colombia, and Mexico are identified as users, whereas Brazil is a follower in terms of production (UNIDO 2019). Although identified as a latecomer, the Dominican Republic is the only Caribbean country that appears among the 50 economies engaging with ADP technologies activities as a producer (UNIDO 2019).

4.2.5. Latin America and the Caribbean's overall digital readiness

Table 16 summarizes the performance of Latin America and the Caribbean countries across the different dimensions of the DRD and according to the three criteria introduced for the analysis. The table's first three columns from the left-hand side show the overall performance. The remaining columns on the table's right-hand side show the performance breakdown by capability. Countries rank according to the scores given by the first criteria, which shows the performance relative to Latin America and the Caribbean, respectively. For visualization purposes, the higher scores of the first criteria and the highest number of indicators of the second and third criteria are reflected with the darkest shade of *green*.

Chile, Mexico, Costa Rica, Brazil, and Uruguay report the highest levels of readiness for digitalization of manufacturing in Latin America according to the first criteria, which captures a country's performance across the four layers of capabilities taking the region as a reference. Chile seems well-positioned for the digital transformation journey. Of 16 indicators, ten have improved from 2015 to 2021, and half of them relate to innovation and digital capabilities. However, relative to income level, only two indicators, namely productive investment and advanced skills, place Chile above the average for high-income countries worldwide.

Brazil tops the region in overall performance across the three criteria. When looking at individual capabilities, Brazil's strengths lie in enabling infrastructure and innovation, outperforming its income group in most indicators in both layers of capabilities. Nevertheless, the country's best performance stems from the trend across the four layers of capabilities, where it shows improvement in most indicators for enabling infrastructure, production, and innovation capabilities and in all indicators for digital capabilities. With 13 indicators showing a dynamic performance, Brazil positions itself among the Latin American countries with the highest number of indicators experiencing improvement.

El Salvador emerges as the front-runner of the lower-middle income countries in the region, showing dynamic performance in 12 indicators. The country improved in most indicators of foundational capabilities and presents a positive trend in all indicators for digital capabilities.

In the Caribbean, Barbados leads across the four layers of capabilities, yet Belize and the Dominican Republic stand out as the countries with the most dynamic performance, showing improvement in 8 indicators. Both countries improved in enabling infrastructure, and while Belize presents the highest number of indicators of progress in innovation capabilities, the Dominican Republic shows a positive trend in productive capabilities.

Table 16 Latin America and the Caribbean countries' performance across the Digital Readiness Dashboard.

				Overall performance			Performance by capability											
				Criteria 1 (CR1)	Criteria 2 (CR2)	Criteria 3 (CR3)	*Enabling infrastructure*			*Production Capabilities*			*Innovation Capabilities*			*Digital Capabilities*		
	Ranking CR1	Country	Income group	Relative to region	Relative to income group	Trend	Relative to region	Relative to income group	Trend	Relative to region	Relative to income group	Trend	Relative to region	Relative to income group	Trend	Relative to region	Relative to income group	Trend
				Total score	# indicators above global average/17	# indicators with positive growth rate/16	Score	# indicators above global average/4	# indicators with positive growth rate/3	Score	# indicators above global average/4	# indicators with positive growth rate/4	Score	# indicators above global average/6	# indicators with positive growth rate/6	Score	# indicators above global average/3	# indicators with positive growth rate/3
Latin America	1	Chile	High	3.81	2	10	1.00	0	2	1.00	1	0	1.00	1	5	0.81	0	3
	2	Mexico	Upper middle	3.04	6	9	0.91	2	2	0.39	0	3	0.74	1	4	1.00	3	0
	3	Costa Rica	Upper middle	2.88	4	13	0.91	2	2	0.48	1	3	0.68	1	5	0.81	0	3
	4	Brazil	Upper middle	2.88	7	13	1.00	3	2	0.43	0	3	0.99	4	5	0.46	0	3
	5	Uruguay	High	2.55	1	10	0.98	0	2	0.54	0	2	0.88	1	4	0.15	0	2
	6	Colombia	Upper middle	2.48	5	10	0.53	1	1	0.59	2	1	0.84	2	5	0.52	0	3
	7	Argentina	Upper middle	2.30	7	11	0.58	2	3	0.61	2	2	0.88	3	4	0.23	0	2
	8	Peru	Upper middle	2.14	3	10	0.40	0	2	0.50	1	2	0.72	2	4	0.52	0	2
	9	Panama	High	2.01	1	3	0.93	0	2	0.57	1	1	0.39	0	0	0.13	0	0
	10	Paraguay	Upper middle	1.94	5	11	0.67	2	2	0.37	1	3	0.14	0	3	0.75	2	3
	11	El Salvador	Lower middle	1.93	7	12	0.40	3	3	0.37	2	3	0.38	1	3	0.79	1	3
	12	Ecuador	Upper middle	1.82	2	10	0.44	0	2	0.52	1	2	0.46	1	4	0.40	0	2
	13	Honduras	Lower middle	0.99	2	8	0.00	0	2	0.30	1	2	0.10	1	4	0.58	0	0
	14	Nicaragua	Lower middle	0.97	3	5	0.16	2	2	0.07	0	0	0.07	0	2	0.67	1	1
	15	Guatemala	Upper middle	0.84	1	10	0.09	0	3	0.07	1	2	0.14	0	2	0.54	0	3
	16	Bolivia	Lower middle	0.77	4	5	0.28	2	3	0.22	2	0	0.13	0	2	0.15	0	0
	17	Venezuela	Lower middle	0.60	3	1	0.60	2	1	0.00	1	0	0.00	0	0	0.00	0	0
Caribbean	1	Barbados	High	3.93	2	4	1.00	1	2	1.00	0	1	0.93	1	1	1.00	0	0
	2	Grenada	Upper middle	2.42	5	6	0.64	2	2	0.78	1	1	1.00	2	3	0.00	0	0
	3	Jamaica	Upper middle	2.41	2	4	0.42	1	2	0.74	1	0	0.59	0	2	0.67	0	0
	4	Belize	Upper middle	2.40	3	8	0.42	1	2	0.87	1	2	0.38	1	4	0.73	0	0
	5	Trinidad and Tobago	High	2.33	1	3	0.94	0	1	0.70	0	0	0.69	1	2	0.00	0	0
	6	St. Kitts and Nevis	High	2.27	2	6	0.83	1	2	0.61	0	2	0.83	1	2	0.00	0	0
	7	Bahamas	High	2.26	1	4	0.89	0	1	0.70	1	2	0.28	0	1	0.40	0	0
	8	Dominican Republic	Upper middle	1.77	2	8	0.25	0	2	0.78	1	3	0.00	1	3	0.73	0	0
	9	St. Lucia	Upper middle	1.72	2	6	0.53	1	1	0.91	1	2	0.28	0	3	0.00	0	0
	10	Antigua and Barbuda	High	1.41	2	5	0.28	0	1	0.78	1	2	0.34	1	2	0.00	0	0
	11	St. Vincent and the Grenadines	Upper middle	1.22	3	3	0.50	1	2	0.48	1	0	0.24	1	1	0.00	0	0
	12	Guyana	Upper middle	1.21	0	4	0.11	0	2	0.43	0	0	0.00	0	2	0.67	0	0
	13	Suriname	Upper middle	1.15	3	3	0.42	2	1	0.70	1	1	0.03	0	1	0.00	0	0
	14	Dominica	Upper middle	1.13	2	5	0.56	1	2	0.13	0	1	0.45	1	2	0.00	0	0
	15	Cuba	Upper middle	0.57	1	7	0.08	0	2	0.00	0	1	0.48	1	4	0.00	0	0
	16	Haiti	Lower middle	0.08	2	3	0.00	1	1	0.04	0	2	0.03	1	0	0.00	0	0

Source: Authors' elaboration

5. Discussion and conclusions

In this paper, we applied a framework of macro-level cumulative capabilities to explore readiness for digitalization of manufacturing in two developing regions, namely Africa and Latin America and the Caribbean. The analysis reveals a heterogeneous picture across the two areas. While progress is evident in specific capability dimensions necessary to enable the digitalization of manufacturing, considerable shortcomings across several dimensions of capabilities still need to be addressed; these would require dedicated policy interventions in the two regions. Analysis per capability dimension renders a wealth of information about individual country's performance within each region, allowing us to identify strengths and challenges and recent trajectories in each such dimension over the period 2015-2021. Below, we discuss some insights for Africa, Latin America, and the Caribbean separately, followed by general observations for both regions.

Africa

Africa has benefitted enormously from digitalization and related innovations in various fields, such as e-commerce, where mobile penetration and the development of mobile banking applications such as M-PESA have been reshaping how businesses operate and engage with clients across the continent. Blockchain technology applications are being explored to foster value chain development (UNIDO, 2020), while the introduction of drones to deliver medical supplies to remote areas is a significant achievement in tackling health challenges in the region (AUDA-NEPAD, 2023).

Emerging evidence suggests that manufacturers across the continent are increasingly adopting digital technologies to improve efficiency, reduce costs, and increase the overall productivity of their firms. For instance, a recent UNIDO firm-level survey reveals that 12 percent of African manufacturing firms use ADP technologies (Calza and Lavopa, 2022). This figure is close to the global average, 14.14 percent, or even the share of firms observed in Latin America, 13.13 percent. In practice, these figures mask a more complex situation characterized by different levels of adoption of digital technologies by African –and, more generally, across developing country– firms. A handful of dynamic firms coexist with a larger share of firms that operate based on "analog technologies" (UNIDO, 2019; Andreoni and Anzolin, 2019).

Several structural challenges that have hampered industrialization in Africa are also at play regarding progress towards digitalization. Such challenges deter investments in advanced digital systems, technologies, and practices by manufacturing firms. Unreliable energy supply, poor availability and quality of digital infrastructure, a primarily low-skilled labor force, coupled with low-quality education systems, lack of adequate financial services, weak innovation systems, and weak regulatory frameworks all contribute to the patchy use of ADP technologies within African countries' manufacturing sectors (Banga and Willem te Velde 2018). African countries with an active use of ADP technologies are

identified as “followers in use” (i.e., Algeria and South Africa), far away from the 10 “frontrunner” economies, based on the classification presented in (UNIDO 2019).

Our data confirms these challenges, and we find that, on average, Africa lags behind other regions in all four enabling capabilities considered in our analysis: enabling infrastructure, production capabilities, innovation capabilities and digital capabilities. Even with this, there is much variation in the level of digital readiness across the continent. Overall, we find several North African, Southern African, and island economies that possess more of the foundational and digital capabilities required for digitalization than other countries in the region, with the former generally showing more positive trends during the study period.

Our findings suggest that five countries are best equipped to engage with digital technologies in manufacturing. These are Tunisia, Morocco, South Africa, Mauritius and Seychelles. Each of them has their unique strengths and challenges. Tunisia thrives in its trade with digital technologies, importing and exporting more than any other African country, while Morocco excels in energy reliability. South Africa, although proving to be the readiest for the digital transformation of its manufacturing sector in Sub-Saharan Africa, has seen weak progress across capabilities since 2015.

By contrast, Senegal has experienced improvements in almost all dimensions. It is among Africa’s top 10 countries in digital readiness, particularly its readiness to invest in fixed capital –a proxy for productive capabilities-, being its strength. Among low-income African countries, Rwanda seems the best equipped for digital transformation in manufacturing. It outperforms peers in its income group in most indicators and stands out as the third largest importer of digital technologies in Africa, relative to its GDP.

Observing the region by capabilities, we find that Morocco is the best positioned in Africa in terms of enabling infrastructure, outperforming its income group, and experiencing advancements on three of the four indicators measured. Among low-income countries, Mozambique has the most vital enabling infrastructure. Algeria is the region’s top performer for production capabilities, though the country has been unable to improve on any of the related capabilities. Senegal, which placed among the top five African economies in production capabilities, has seen advancements in all four aspects. Zambia is the only low-income country among the top ten in Africa. Tunisia has the most innovation capabilities in the region, while Mauritius, Senegal, and Cape Verde have seen the most dynamism in innovation-related dimensions. Low-income countries underperformed in this capability, with Rwanda leading the group. Finally, Mozambique and Rwanda – both low-income countries - are among the top ten African countries in terms of trade in digital technologies, while Tunisia is the strongest performer. Namibia is the only country among the top five improving on all indicators.

Our findings suggest that several lower-middle-income and particularly low-income countries in Africa have been engaging with digital technologies more than the global average of their respective income groups. Several of these economies have improved the most on this front as well. At the same time, these countries still face significant challenges in building the foundational capabilities required to ensure the most effective use of ADP technologies and to promote further digitalization in the sector.

Progress observed in several African economies to engage with digital technologies is highly commendable, particularly in their challenging circumstances. It is invaluable for the future of industrial development in the region. However, in countries where a large part of manufacturing firms is small, micro, or informal and where the use of computers altogether is limited (World Bank, 2023), the lack of well-designed policies and initiatives to create an adequate environment for more firms to be in the position to acquire and meaningfully engage with such technologies will result in widening digital divides within countries, as well as with other economies. We find that each country on the continent has its unique challenges. Governments are encouraged to consult multidimensional, quantitative analyses to corroborate and expand on some of the findings presented in this paper to help identify the most urgent intervention area.

Latin America and the Caribbean

In the case of Latin America and the Caribbean, our findings support recent studies that document the region's progress in digital infrastructure, especially in improving access to connectivity through fixed networks and mobile technology (Economic Commission for Latin America and the Caribbean 2021). At the business level, the percentage of firms with internet access exceeds 80 percent in most countries (OECD et al., 2020), yet the greater coverage has not translated into a wider adoption of digital technologies to transform productive activities since other factors such as the development of digital skills and other competencies to use those technologies are needed (OECD et al., 2020; Economic Commission for Latin America and the Caribbean, 2021).

The quality of digital connectivity is still a challenge for the region. Only countries such as Chile and Brazil are moving in the direction of more advanced economies, accelerating the adoption of 5G in their radio spectrum bands, which is particularly important to support the effective application of ADP technologies in 'smart production' processes (UNCTAD, 2021a; Economic Commission for Latin America and the Caribbean, 2021; 2022a). The limitations in the deployment of 5G networks, in general, could also explain why the levels of digitalization at the firm level remain low in the region, especially regarding the adoption of more sophisticated technologies in manufacturing.

A challenge for Latin America and the Caribbean towards digitalization of manufacturing is to move from policies that mainly encourage the adoption of digital technologies towards the support for digital transformation of production processes, enhanced innovation performance, and the creation of new

digitally-enabled business models (OECD et al., 2020). This assertion is in line with the findings from a recent study by Paus and Robinson (2022) on the innovation behavior of firms in five Latin American countries.[18] The authors demonstrate that capital investment, using the internet for business purposes, and having an internationally recognized quality certificate are as essential drivers of innovation as increasing the expenditure in R&D.

Since micro, small, and medium enterprises (MSME) dominate the business structure in the region, most countries have directed their policy efforts to promote MSMEs' engagement with digitalization through initiatives focusing more on raising awareness and providing training and technical assistance to develop digital skills, rather than targeting the digital transformation of production processes (Heredia, 2020). In this context, Chile and Brazil stand out among the few countries in the region that have moved forward in establishing specific programs to promote digital transformation in line with advanced manufacturing; for example, Brazil launched the Science and Technology and Innovation Plan for Advanced Manufacturing in 2017, and Chile developed the Strategic Program for Smart Industries (PEII) 2015-2025 (Grosman et al., 2021; Santiago, 2018; OECD et al., 2020).

Throughout our capabilities analysis, Brazil and Chile are the most prepared for a digital transformation of manufacturing in the region. Besides improving in enabling infrastructure, both countries show a positive trend in innovation and digital capabilities. While Chile leads the region in foundational capabilities, Brazil performs best in the three criteria. It shows favorable conditions in the highest indicators relative to the average of its global income level. Moreover, Brazil appears among the most dynamic countries across the four capabilities. In general, most countries in Latin America show progress in their trade interactions with ADP technologies. However, Brazil stands out as one of the four countries in the region that fall into the category of followers among the 50 economies actively engaging with these technologies (UNIDO, 2019).

Significant progress in the application of technology and innovation in the local manufacturing ecosystem has allowed Brazil to become the only Latin American country to join the Global Network of Advanced Manufacturing Hubs[19] (AMHUBs). This initiative, launched by the World Economic Forum in 2018, is a knowledge-sharing platform that aims to highlight regional learning experiences and best practices in advanced manufacturing at the global level. The network intends to become an incubator for stakeholders to build partnerships and cross-hub collaborations to address common challenges in global manufacturing systems.

[18] The study explores firms' innovation behavior in five Latin American countries: Argentina, Colombia, Ecuador, Peru, and Uruguay during from 2006 to2017.

[19] Currently, the network includes 13 hubs – Spain (Basque Country), Denmark, Brazil, India (Tamil Nadu), Turkey, Italy (Lombardy), United States (Michigan, New England, Ohio), Qatar, Australia (Queensland), Saudi Arabia, South Korea (Ulsan). [https://www.weforum.org/projects/global-network-of-advanced-manufacturing-hubs]

El Salvador emerges in the Digital Readiness Dashboard as one exciting case in the region. The country appears as the best-placed lower-middle-income countries, showing a dynamic solid performance in most indicators across the foundational capabilities, and improving in all the indicators for digital capabilities.

By contrast, in the Caribbean, Barbados leads the subregion across the four layers of capabilities. Nevertheless, the Dominican Republic, Belize, and Cuba stand out as countries with the most dynamic performance. While the Dominican Republic shows the highest number of indicators of improvement in production capabilities, Belize and Cuba show a positive trend in innovation capabilities.

An integrated view

From an integrated perspective, our findings hint more of pockets of interesting cases of capability building for digitalization in each region under study rather than a general trend. To some extent, this may reflect the need for a more generalized adoption of strategic approaches to foster digitalization of manufacturing in each continent. Despite the heterogeneity in-country experiences and the different stages of industrialization and digitalization in both continents, a broad cross-regional examination of the data allows us to make five general observations.

First, countries at lower income levels need help developing the capabilities necessary for digitalization in manufacturing, especially regarding foundational capabilities. We find that lower-middle-income countries appear only in the bottom half of the overall Latin American ranking and low-income countries dominate the lower rankings in Africa. This finding may be interpreted as a correlation between our findings and the overall level of development achieved by individual countries in each region. However, we cannot find further distinctions, such as between high-income and upper-middle-income countries in LAC or between upper-middle-income and lower-middle-income countries in Africa. Therefore, while the lower-income countries per region struggle more so in developing the required capabilities, for the remaining countries additional research on a case-by-case basis should shed additional light on the readiness of individual economies for the digitalization of manufacturing.

Second, and related to the above, most countries in both regions cannot match the levels of digital readiness expected for their income bracket. Regarding countries' overall readiness across all 17 indicators, we find that six countries in Africa (11 percent of all countries), namely Tunisia, Morocco, Algeria, Rwanda, Mozambique, and Madagascar, were able to obtain higher than global average values of their respective income groups in more than half of all indicators. In the case of Latin America and the Caribbean, the countries performing most strongly compared to their income groups were Brazil, Argentina, and El Salvador. These countries performed above the global average values of their respective income groups in seven of the 17 indicators used in the analysis. Hence, while several

countries feature promising developments in certain aspects of digital readiness, very few countries can perform better than the global average of their respective income group overall.

Third, progress made over the 2015-2021 period was more evident in Latin America and the Caribbean than in Africa. Our analytical framework assumes that countries need to perform well on all four capabilities to progress in the establishment of a conducive environment to adopt, adapt, and engage with digital technologies in manufacturing. Accordingly, seeing positive trends across the range of relevant dimensions, rather than in only a few, is essential to determining readiness for the digitalization of manufacturing. During the study period, 12 countries in Latin America, the Caribbean, and 13 countries in Africa have improved in more than half of the digital readiness indicators. This equates to 36 percent of Latin American and Caribbean countries and 24 percent of African countries. In the former region, most countries showing progress are in Latin America and less in the Caribbean, while in Africa, this was only the case for certain individual countries spread across the continent - interestingly, many of them being French-speaking countries. The slow pace of progress in Africa could be a concern regarding their future competitiveness in manufacturing and a possibly increasing digital divide.

Fourth, in both regions under study, the most progress was made in enabling infrastructure and the least in production capabilities. Both regions have experienced more progress in enabling infrastructure than any other capability dimension considered in the analysis. In effect, Latin America has had the most widespread improvements in enabling infrastructure; 88 percent of countries showed dynamic performance in more than half the indicators, while the share is 63 percent for the Caribbean and 56 percent in Africa. These shares are significantly above those we find in other capabilities. The evident link between digital and energy infrastructure for digitalization may be a determining factor for countries to have focused much on improving these in particular.

Fewer countries have seen progress in production capabilities than in any other capability dimension. In both regions, just under 20 percent of the countries have improved on most aspects measured for production capabilities. The share becomes higher for Latin America when separated from the Caribbean (29 percent). However, this progress is lower for both continents than in any of the other three capability dimensions. While adequate infrastructure is an indispensable prerequisite for digitalization, possibly less tangible capabilities, including production and innovation capabilities, must likewise experience such boosts in order to absorb new and ever-changing technologies.

Lastly, more advanced countries progressed more in innovation capabilities, while lower-income countries did so in production capabilities. Our tables show that all countries that have improved on production capability indicators are those at relatively lower levels of economic development. No high-income country was experiencing such progress in LAC and Africa; there was neither a high nor upper-

middle-income country among these. Meanwhile, countries with improved innovation capabilities tend to be upper-middle income, already performing better in both regions. This is more pronounced in Latin America. Here, the nine countries with the strongest innovation capabilities also improved in at least four of the six indicators. It was less likely for countries further down the ranking to progress in the same number of indicators. For Africa, a similar –though weaker– trend can also be found in digital capabilities, where it is more likely for those countries trading more with digital technologies to progress more. No clear pattern was found in enabling infrastructure. While these trends show efforts of lower-income countries to address some basic capabilities, they also hint towards a possible divergence in levels of more specialized capabilities, particularly those related to innovation.

The multidimensional approach proposed in this paper acknowledges that the digital transformation of manufacturing implies a broad frame of policy realms. It is about industrial policies, as much as digitalization agendas and their interaction with a diverse range of policies securing enabling infrastructure are in place, the promotion of science, technology and innovation, the encouragement for business and entrepreneurship development, the progress in education systems generally and in those areas explicitly targeting labor skilling and upskilling, among others.

Our study points out several directions for further research. For example, considering the structural heterogeneity of the regions under study, further country-specific analysis should explore how macro-level performance translates into the actual uptake of ADP technologies in productive processes. Such research should shed light on the interaction of different factors in a country-specific and even sector-specific context. In this paper we identified several countries that could offer enriching case studies for other countries in the respective region. There are ample possibilities to explore further the data presented in the dashboard and tables for individual capability dimensions.

While it would be interesting to analyse readiness for digitalization looking into indicators at the industry level, there are two main reasons why this is problematic. Firstly, there needs to be more internationally harmonized data to measure such aspects at the sector level, enabling a benchmarking exercise such as the one carried out in this paper. Secondly, the sector is integrated within a national economic ecosystem, leveraging the country's available resources (e.g., skills, infrastructure, and innovation systems). Using macro-level indicators allows us to measure better the sector's potential, rather than its current performance, taking into account the context of digitalization at the national level. A crucial element remains to assess how digital readiness at the macro- or even meso-level influences the adoption of ADP technologies at the firm level in the regions under study. We invite analysts and policymakers use this information by analysing the country of interest more in-depth and identifying the most compelling countries to learn from, based on the specific needs or objectives.

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Annex 1: Readiness for the digitalization of manufacturing, Africa's Digital Readiness Dashboard

				Foundational Capabilities													Digital Capabilities		
			Capability	Enabling Infrastructure				Production capabilities				Innovation capabilities						Import of PTDP & ADPT	Export of ADPT
			Dimension	Energy		Digital		Basic		Intermediate		Basic (effort)			Intermediate (output)			Absorption & exposure to PTDP	Deployment & adaptation of ADPT	Industrial competitiveness in ADPT
			Indicator name	1 Energy availability	2 Energy reliability	3 Access to digital connectivity	4 Quality of connectivity	5 Productive investments	6 Productive skills	7 Operational efficiency	8 Technology absorption	9 Advanced skills	10 Specialised skills	11 Research effort	12 Research output	13 Innovation output (patents)	14 Innovation output (royalties)	15 Absorption and exposure to PTDP	16 Deployment and adaptation of ADPT	17 Industrial competitiveness in ADPT
			Measure	Electricity consumption per capita	Percentage of firms experiencing electrical outages	Fixed broadband subscriptions per 100 people	Mean download speed (Mbps)*	GFCF (% of GDP)	Mean years of schooling	ISO 9001 certificates	Intellectual Property Right payments (royalties) (% of GDP)	Gross enrolment ratio in tertiary education	Percentage of graduates from STEM programmes in tertiary education	Gross Expenditure in R&D (% of GDP)	Scientific and technical journal articles per million people	Total patents in force per 100 bi USD GDP	Intellectual Property Right receipts (royalties) (% of GDP)	Imports of production technologies (% of GDP)	Imports of digital products (% of GDP)	Exports of digital products (% of GDP)
			Source	OWID	WDI	WDI	M-Lab	WDI	UNESCO UIS	ISO	WDI	WDI	UNESCO UIS	UNESCO UIS	WDI	WIPO	WDI	UNCOMTRADE, WDI	UNCOMTRADE, WDI	UNCOMTRADE, WDI
			Years	2015-2021	2015-2021	2015-2021	2021	2015-2021	2016-2021	2015-2021	2015-2021	2015-2021	2015-2021	2015-2020	2018	2015-2021	2015-2021	2017-2021	2017-2021	2017-2021
Economy	Country code	Region	Income group																	
Algeria	DZA	North Afric	Lower mid	1,755.17		9.46	3.08	37.25		0.0122	0.115	53.74	30.13	0.53	124.77	25.15	0.00010	6.581	1.502	0.003
Angola	AGO	Sub-Sahara	Lower mid	476.18		0.79	5.88	20.23		0.0030	0.181	10.63	12.01	0.03	0.96	4.45	-	3.906	1.045	0.038
Benin	BEN	Sub-Sahara	Lower mid	18.47	95.60	0.16	2.59	25.54		0.0024	0.003	11.09	19.66		19.07	5.83	0.00011	1.685	0.516	0.006
Botswana	BWA	Sub-Sahara	Upper mid	846.07		7.84	3.65	27.91		0.0070	0.605	24.73	18.51		114.45	141.93	0.00274	4.954	1.335	0.032
Burkina Fa	BFA	Sub-Sahara	Low incom	79.18		0.07	10.73	21.40	1.92	0.0010	0.003	9.54	20.68	0.25	12.36	0.00	0.00450	3.493	0.841	0.014
Burundi	BDI	Sub-Sahara	Low incom	28.68		0.03	2.82	13.11	2.80	0.0010	0.000	5.95	19.67	0.21	1.84	143.89	0.00013	4.209	1.100	0.002
Cabo Verd	CPV	Sub-Sahara	Lower mid	765.39		5.19	7.94			0.0544	0.070	23.62	16.13		15.21	51.65	0.00191	6.161	1.748	0.005
Cameroon	CMR	Sub-Sahara	Lower mid	295.97	92.50	2.73	3.04	18.84		0.0027	0.028	14.27			34.92	11.03	0.00398			
Central Afr	CAF	Sub-Sahara	Low incom	27.49		0.01		16.36		0.0002					4.02	79.48				
Chad	TCD	Sub-Sahara	Low incom	18.04	70.20	0.00	2.39	18.97		0.0002		3.25		0.30	0.99	25.47				
Comoros	COM	Sub-Sahara	Lower mid	170.39		0.15	3.99	13.29		0.0024	0.159				4.23		-	2.513	0.909	0.004
Congo, De	COD	Sub-Sahara	Low incom	115.13		0.03	3.63	27.16	6.76	0.0003	-	7.00	15.46	0.41	1.71	5.42	-	3.401	0.612	0.004
Congo, Re	COG	Sub-Sahara	Lower mid	688.85		0.26	12.07	13.83		0.0026	0.069	12.67	15.13		12.25	22.44	0.00033	2.401	0.554	0.113
Côte d'Ivoi	CIV	Sub-Sahara	Lower mid	399.59	78.80	1.22	9.54	24.07		0.0087	0.019	9.91		0.07	9.73	8.57	-	2.605	0.541	0.018
Djibouti	DJI	North Afric	Lower mid	54.27		1.32	1.46	29.72		0.0045					5.83	0.00				
Egypt, Arat	EGY	North Afric	Lower mid	1,851.05	28.20	9.94	6.94	11.99	9.05	0.0212	0.085	38.90	11.24	0.96	128.46	458.01	-			
Equatorial	GNQ	Sub-Sahara	Upper mid	868.78		0.06	1.30	4.84		0.0018					1.73	0.00				
Eritrea	ERI	Sub-Sahara	Low incom	124.30		0.14	2.41			0.0000		3.36	29.05		6.20					
Eswatini	SWZ	Sub-Sahara	Lower mid	620.66	77.30	1.02	3.73	14.07		0.0235	0.398			0.27	29.34	948.70	0.00161	5.536	1.343	0.034
Ethiopia	ETH	Sub-Sahara	Low incom	122.13	80.00	0.18	1.20	28.02		0.0007	0.007	10.43		0.27	17.95	1.80	0.00004	2.244	0.481	0.013
Gabon	GAB	Sub-Sahara	Upper mid	978.14		2.69	4.99	16.79		0.0111		21.07			29.10	19.79				
Gambia, Th	GMB	Sub-Sahara	Low incom	113.64	93.20	0.19	2.04	36.56		0.0008				0.07	13.84	0.00		1.753	0.336	
Ghana	GHA	Sub-Sahara	Lower mid	637.77		0.35	9.23	16.85		0.0041	0.306	18.69	15.22		41.33	9.02	0.01423	2.880	0.538	0.012
Guinea	GIN	Sub-Sahara	Low incom	205.44	84.20	0.01	2.39	16.75	2.13	0.0004	-	6.72			2.22	18.64	-			
Guinea-Bis	GNB	Sub-Sahara	Low incom	38.82		0.16	1.24	24.33		0.0010	-				7.80		0.01387			
Kenya	KEN	Sub-Sahara	Lower mid	223.18	82.80	1.49	11.27	19.60		0.0095	0.038	10.04			24.96	111.47	0.05028	2.484	0.727	0.011
Lesotho	LSO	Sub-Sahara	Lower mid	219.16	71.80	0.65	8.46	22.42		0.0013	0.116	10.20	15.36	0.05	8.43	40.06	0.00781	7.891	2.228	0.018
Liberia	LBR	Sub-Sahara	Low incom	177.15	44.30	0.26	5.23			0.0012					5.19	199.49				
Libya	LBY	North Afric	Upper mid	4,754.07		4.99	3.73	11.69		0.0042					24.99	4.67		3.270	0.428	0.001
Madagasca	MDG	Sub-Sahara	Low incom	72.28		0.11	16.28	19.12	5.07	0.0022	0.087	5.53	29.09	0.01	4.75	138.19	0.00109	3.836	0.961	0.016

Annex 1: Readiness for the digitalization of manufacturing, Africa's Digital Readiness Dashboard….. Cont.

				Foundational Capabilities													Digital Capabilities		
			Capability	Enabling Infrastructure				Production capabilities				Innovation capabilities						Import of PTDP & ADPT		Export of ADPT
			Dimension	Energy		Digital		Basic		Intermediate		Basic (effort)			Intermediate (output)			Absorption & exposure to PTDP	Deployment & adaptation of ADPT	Industrial competitiveness in ADPT
			Indicator name	1 Energy availability	2 Energy reliability	3 Access to digital connectivity	4 Quality of connectivity	5 Productive investments	6 Productive skills	7 Operational efficiency	8 Technology absorption	9 Advanced skills	10 Specialised skills	11 Research effort	12 Research output	13 Innovation output (patents)	14 Innovation output (royalties)	15 Absorption and exposure to PTDP	16 Deployment and adaptation of ADPT	17 Industrial competitiveness in ADPT
			Measure	Electricity consumption per capita	Percentage of firms experiencing electrical outages	Fixed broadband subscriptions per 100 people	Mean download speed (Mbps)*	GFCF (% of GDP)	Mean years of schooling	ISO 9001 certificates	Intellectual Property Right payments (royalties) (% of GDP)	Gross enrolment ratio in tertiary education	Percentage of graduates from STEM programmes in tertiary education	Gross Expenditure in R&D (% of GDP)	Scientific and technical journal articles per million people	Total patents in force per 100 bi USD GDP	Intellectual Property Right receipts (royalties) (% of GDP)	Imports of production technologies (% of GDP)	Imports of digital products (% of GDP)	Exports of digital products (% of GDP)
			Source	OWID	WDI	WDI	M-Lab	WDI	UNESCO UIS	ISO	WDI	WDI	UNESCO UIS	UNESCO UIS	WDI	WIPO	WDI	UNCOMTRADE, WDI	UNCOMTRADE, WDI	UNCOMTRADE, WDI
			Years	2015-2021	2015-2021	2015-2021	2021	2015-2021	2016-2021	2015-2021	2015-2021	2015-2021	2015-2021	2015-2020	2018	2015-2021	2015-2021	2017-2021	2017-2021	2017-2021
Economy	Country code	Region	Income group																	
Malawi	MWI	Sub-Sahara	Low incom	71.39		0.07	4.96			0.0007	0.547	1.72			12.59	15.84	0.02634	3.745	1.089	0.015
Mali	MLI	Sub-Sahara	Low incom	154.76	86.60	0.66	4.72	20.17	1.63	0.0009	-	4.90		0.16	4.53	73.14	-	4.140	1.415	0.024
Mauritania	MRT	Sub-Sahara	Lower mid	407.37		0.42	2.54	48.72		0.0017	0.000	5.87	34.55	0.01	4.76	70.03	-	4.802	0.581	0.003
Mauritius	MUS	Sub-Sahara	Upper mid	2,217.22		25.32	8.53	19.52		0.1603	0.094	44.26	21.61	0.42	100.32	6696.13	0.01542	5.438	2.239	0.045
Morocco	MAR	North Afric	Lower mid	1,113.91	20.90	5.70	10.33	27.01		0.0321	0.105	43.45	28.90		140.75	718.85	0.00080	6.449	2.186	0.819
Mozambiq	MOZ	Sub-Sahara	Low incom	620.69	52.80	0.20	7.17	23.11	3.06	0.0020	-	7.31	9.56	0.31	4.73	6.34	-	8.404	1.862	0.027
Namibia	NAM	Sub-Sahara	Upper mid	620.52		3.05	4.42	14.26		0.0190	0.008	27.26	8.92		64.98	430.52	0.01703	8.739	2.266	0.020
Niger	NER	Sub-Sahara	Low incom	17.82	78.00	0.05	3.23	28.54		0.0001	-	4.37	12.34		2.44	40.23	-	1.941	0.408	0.004
Nigeria	NGA	Sub-Sahara	Lower mid	147.47		0.03	8.68	33.11		0.0019	0.057	12.10			28.24	5.67	-			
Rwanda	RWA	Sub-Sahara	Low incom	63.14	39.00	0.24	6.29	26.63	4.33	0.0013	0.002	7.27	32.10	0.76	13.53	9.03	0.00483	5.894	2.288	0.023
São Tomé	STP	Sub-Sahara	Lower mid	448.19		1.53	2.43			0.0047	0.009	18.10			3.45	189.9	0.00000			
Senegal	SEN	Sub-Sahara	Lower mid	332.41		1.23	7.02	30.41	2.83	0.0044	0.038	15.63		0.58	24.93	10.86	0.02354	5.223	1.436	0.084
Seychelles	SYC	Sub-Sahara	High incom	6,104.09		38.77	12.04			0.1007	0.167	17.30	19.81	0.22	98.49	22895.12	0.09692	8.940	2.908	0.058
Sierra Leor	SLE	Sub-Sahara	Low incom	24.94	71.80		2.19	11.14		0.0004	0.031				5.18	74.22	-			
Somalia	SOM	Sub-Sahara	Low incom	24.02		0.70	1.59	16.31		0.0009					0.63	13.11				
South Afric	ZAF	Sub-Sahara	Upper mid	3,758.07	92.00	2.85	19.94	13.09	11.37	0.0639	0.347	24.24	17.41	0.62	226.87	3749.51	0.03229	4.730	1.902	0.276
South Sud	SSD	Sub-Sahara	Low incom	53.03		0.00	1.40	5.75			0.004	0.75			0.87	0.00				
Sudan	SDN	Sub-Sahara	Low incom	363.36		0.07	1.80	3.46		0.0012	-	16.92	28.62		9.47	29.13	-	4.555	0.422	0.000
Tanzania	TZA	Sub-Sahara	Lower mid	128.48		1.95	8.60	43.22		0.0018	0.005	7.83	9.50		10.38	17.69	0.00001	2.545	0.540	0.010
Togo	TGO	Sub-Sahara	Low incom	72.88	93.80	0.62	3.54	23.65		0.0035	-	15.40			10.70	0.00	0.00001	4.074	0.976	0.014
Tunisia	TUN	North Afric	Lower mid	1,706.77	40.20	12.20	7.46	15.97	7.20	0.0905	0.057	32.76	38.29	0.75	466.34	317.01	0.04706	9.997	3.853	2.495
Uganda	UGA	Sub-Sahara	Low incom	95.96		0.08	8.52	23.34		0.0037	-	5.06			16.21	14.80	0.03647	2.750	0.748	0.015
Zambia	ZMB	Sub-Sahara	Low incom	909.46	87.10	0.41	5.48	28.91		0.0017	0.158				11.95	22.58	-	5.360	0.910	0.020
Zimbabwe	ZWE	Sub-Sahara	Lower mid	502.70	76.50	1.28	7.92	12.40	8.46	0.0009	0.017	8.88	30.22		23.87	70.49	0.01154	4.557	0.730	0.008

Green cells represent positive change during 2015-2022. Grey cells indicate that due to lack of data, no growth could be calculated. Differences in data availability ‘per indicator, per country: *Percentage of firms experiencing electrical outages:* Benin, 2009-2014, Cameroon, 2009-2016, Côte d’Ivoire, 2009-2016, Egypt, Arab Rep., 2013-2020, Eswatini, 2006-2016, Ethiopia, 2011-2015, Gambia, The, 2006-2018, Guinea, 2006-2016, Kenya, 2013-2018, Lesotho, 2009-2016, Liberia, 2009-2017, Mali, 2010-2016, Morocco, 2013-2019, Mozambique, 2007-2018, Niger, 2009-2017, Rwanda, 2011-2019, Sierra Leone, 2009-2017, South Africa, 2009-2020, Tunisia, 2013-2020, Zambia, 2013-2019, Zimbabwe, 2011-2016; *Fixed broadband subscriptions per 100 people:* Central African Republic, 2015-2019, Cameroon, 2015-2020, Congo, Dem. Rep., 2015-2020, Congo, Rep., 2014-2021, Eritrea, 2015-2020, Ethiopia, 2015-2020, Guinea, 2015-2020, Gambia, The, 2015-2020, Equatorial Guinea, 2015-2020, Liberia, 2015-2020, Libya, 2015-2020, Morocco, 2015-2020, Niger, 2015-2020, South Sudan, 2015-2019, Eswatini, 2015-2020, Chad, 2015-2020, Togo, 2015-2020; *GFCF (percent of GDP):* Burkina Faso, 2015-2019, Djibouti, 2015-2020, Guinea-Bissau, 2015-2020, Lesotho, 2015-2020, Mozambique, 2015-2020; *Mean years of schooling:* Burkina Faso, 2014-2018, Burundi, 2014-2017, Democratic Republic of the Congo, 2013-2016, Egypt, 2006-2017, Guinea, 2014-2018, Mali, 2015-2020, Mozambique, 2015-2017, Rwanda, 2014-2018, Senegal, 2013-2017, South Africa, 2015-2019, Tunisia, 2012-2016, Zimbabwe, 2014-2017; *ISO 9001 certificates:* Guinea-Bissau, 2017-2021, São Tomé and Príncipe, 2015-2019; *Intellectual Property Right payments (royalties) (percent of GDP):* Benin, 2015-2020, Burkina Faso, 2015-2020, Burundi, 2015-2018, Congo, Rep., 2016-2020, Côte d’Ivoire, 2015-2020, Ghana, 2018-2021, Guinea-Bissau, 2015-2018, Senegal, 2015-2018, Sierra Leone, 2015-2020, Sudan, 2018-2021, Tanzania, 2015-2020, Togo, 2015-2020, Zimbabwe, 2015-2020; *Gross enrolment ratio in tertiary education:* Angola, 2015-2019, Benin, 2015-2020, Cabo Verde, 2015-2018, Cameroon, 2015-2018, Chad, 2010-2015, Congo, Dem. Rep., 2016-2020, Congo, Rep., 2015-2017, Cote d'Ivoire, 2015-2020, Egypt, Arab Rep., 2015-2018, Eritrea, 2010-2016, Ethiopia, 2015-2018, Ghana, 2015-2020, Kenya, 2015-2019, Lesotho, 2015-2018, Madagascar, 2015-2020, Malawi, 2015-2018, Mali, 2015-2019, Mauritania, 2015-2020, Mauritius, 2015-2020, Mozambique, 2015-2018, Namibia, 2015-2020, Niger, 2015-2020, Nigeria, 2011-2018, Sao Tome and Principe, 2010-2016; *Percentage of graduates from STEM programmes in tertiary education:* Benin, 2015-2020, Botswana, 2017-2020, Burundi, 2016-2018, Cabo Verde, 2016-2018, Ghana, 2015-2020, Lesotho, 2015-2018, Madagascar, 2015-2020, Mauritania, 2016-2020, Mauritius, 2017-2020, Mozambique, 2015-2018, Namibia, 2015-2020, Niger, 2015-2019, Rwanda, 2016-2020, South Africa, 2015-2020, Sudan, 2012-2015, Tunisia, 2015-2020, Zimbabwe, 2010-2015; *Gross Expenditure in R&D (percent of GDP):* Burkina Faso, 2014-2020, Burundi, 2012-2018, Democratic Republic of the Congo, 2009-2015, Ethiopia, 2013-2017, Gambia, 2011-2018, Lesotho, 2011-2015, Madagascar, 2014-2017, Mali, 2015-2019, Mauritius, 2017-2020, Mozambique, 2010-2015, Rwanda, 2016-2019, Senegal, 2010-2015, South Africa, 2015-2019, Tunisia, 2015-2019; *Total patents in force per 100 bi USD GDP:* Congo, Dem. Rep., 2014-2021, Liberia , 2017-2021, Sao Tome and Principe, 2019-2021; *Intellectual Property Right receipts (royalties) (percent of*

GDP): Benin, 2015-2020, Burkina Faso, 2015-2020, Burundi, 2015-2018, Congo, Rep., 2016-2020, Cote d'Ivoire, 2015-2020, Egypt, Arab Rep., 2018-2021, Ghana, 2018-2021, Guinea-Bissau, 2016-2020, Malawi, 2019-2021, Mali, 2017-2020, Mauritania, 2018-2021, Niger, 2015-2020, Senegal, 2015-2018, Sierra Leone, 2015-2020, Tanzania, 2015-2020, Togo, 2016-2020, Zimbabwe, 2015-2016; *Imports of production technologies (percent of GDP):* Angola, 2018-2021, Benin, 2019-2021, Botswana, 2018-2021, Burundi, 2019-2021, Cabo Verde, 2019-2020, Comoros, 2018-2021, Congo, Rep., 2018-2021, Côte d'Ivoire, 2018-2020, Ethiopia, 2019-2021, Ghana, 2018-2019, Kenya, 2019-2021, Malawi, 2019-2021, Mali, 2018-2019, Mauritania, 2020-2021, Mozambique, 2018-2021, Niger, 2018-2021, Senegal, 2019-2021, Seychelles, 2018-2021, Sudan, 2017-2018, Togo, 2018-2021, Tunisia, 2018-2021, Uganda, 2018-2020, Zimbabwe, 2018-2021; *Imports of digital products (percent of GDP):* Angola, 2018-2021, Benin, 2019-2021, Botswana, 2018-2021, Burundi, 2019-2021, Cabo Verde, 2019-2020, Comoros, 2018-2021, Congo, Rep., 2018-2021, Côte d'Ivoire, 2018-2020, Ethiopia, 2019-2021, Ghana, 2018-2019, Kenya, 2019-2021, Malawi, 2019-2021, Mali, 2018-2019, Mauritania, 2020-2021, Mozambique, 2018-2021, Niger, 2018-2021, Senegal, 2019-2021, Seychelles, 2018-2021, Sudan, 2017-2018, Togo, 2018-2021, Tunisia, 2018-2021, Uganda, 2018-2020, Zimbabwe, 2018-2021; *Exports of digital products (percent of GDP):* Angola, 2018-2021, Benin, 2019-2021, Botswana, 2018-2021, Burundi, 2019-2021, Comoros, 2018-2021, Congo, Rep., 2018-2021, Côte d'Ivoire, 2018-2020, Ethiopia, 2019-2021, Ghana, 2018-2019, Kenya, 2019-2021, Malawi, 2019-2021, Mali, 2018-2019, Mauritania, 2020-2021, Mozambique, 2018-2021, Niger, 2018-2021, Senegal, 2019-2021, Seychelles, 2018-2021, Togo, 2018-2021, Tunisia, 2018-2021, Uganda, 2018-2020, Zimbabwe, 2018-2021.

Source: Authors' calculations

Annex 2: Readiness for the digitalization of manufacturing, Digital Readiness Dashboard for Latin America and the Caribbean

Layers		Foundational Capabilities														Digital Capabilities		
		Enabling Infrastructure				Production capabilities				Innovation capabilities						Digital capabilities		
		Energy		Digital		Basic		Intermediate		Basic (effort)		Intermediate (output)				Absorption & exposure	Deployment & adaptation	Competitiveness in digital technologies
Dimensions		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
		Energy availability	Energy reliability	Access to digital connectivity	Quality of connectivity	Productive investments	Productive skills	Operational efficiency	Technology absorption	Advanced skills	Specialised skills	Research effort	Research output	Patents	Royalties	Imports of PTDP	Imports of ADP	Exports of ADP
LATIN AMERICA																		
1	Argentina	3,239.63	65.10	23.10	8.68	17.13	11.14	0.130	0.287	99.17	14.15	0.46	198.03	644.67	0.044	3.054	1.188	0.019
2	Bolivia	876.69	35.10	9.33	7.36	16.63	9.83	0.020	0.071				8.86	54.44	0.005	3.623	0.802	0.000
3	Brazil	3,091.46		19.37	33.34	19.17	7.98	0.076	0.322	54.57	17.50	1.21	286.19	1,049.48	0.044	3.406	1.362	0.090
4	Chile	4,181.46		21.96	13.76	23.97	10.59	0.147	0.468	91.67	21.41	0.34	380.81	1,164.45	0.021	6.279	2.367	0.079
5	Colombia	1,570.56	53.90	16.37	13.13	18.48	8.86	0.199	0.432	54.24	23.52	0.29	146.01	703.74	0.042	3.807	1.787	0.049
6	Costa Rica	2,466.07		20.54	19.02	17.76	8.80	0.071	1.042	57.67	15.89	0.37	100.66	457.36	0.011	5.528	2.336	0.361
7	Ecuador	1,817.09	62.40	13.94	10.25	21.20	9.11	0.071	0.202	52.59	19.68		125.90	68.76	0.005	4.056	1.448	0.022
8	El Salvador	1,038.93	47.60	9.71	9.95	20.98	7.15	0.029	0.389	29.92	21.85	0.17	7.24	41.76	0.001	6.228	2.176	0.097
9	Guatemala	820.06	54.40	3.52	9.85	15.78	5.68	0.013	0.367	22.14	9.77	0.03	6.11	20.93	0.020	4.258	1.759	0.052
10	Honduras	1,164.58	69.80	4.06	7.17	22.51	7.09	0.015	0.330	25.46	15.73	0.04	4.61	21.06	0	4.966	1.689	0.067
11	Mexico	2,659.32		18.40	18.83	20.05	9.22	0.063	0.048	44.81	25.82	0.30	131.80	939.32	0.002	13.185	6.786	4.997
12	Nicaragua	675.86	49.90	4.38	9.75	23.85		0.004	0.006	19.56		0.11	6.64	35.68	0	9.716	1.782	0.044
13	Panama	2,571.67		13.17	30.58	27.21	10.54	0.060	0.036	44.38	13.74	0.15	41.51	600.58	0.001	2.910	0.965	0.000
14	Paraguay	5,969.75	83.00	10.48	19.41	22.72	8.86	0.061	0.042			0.14	15.21	101.28		8.998	4.779	0.027
15	Peru	1,724.43	52.20	9.09	11.35	23.56	9.76	0.052	0.175	70.74	29.64	0.17	50.61	151.85	0.017	4.792	1.901	0.021
16	Uruguay	4,617.27	56.60	32.26	21.73	18.82	8.98	0.381	0.236	67.88	15.24	0.48	248.68	566.42	0.050	2.626	0.997	0.014
17	Venezuela	3,359.95		9.10	2.62		10.31	0.004					21.43					
CARIBBEAN																		
1	Antigua and Barbuda	3,754.20		8.63	8.69	57.65		0.0107	0.24258				61.45	19,780.77	0.00			
2	Bahamas	5,197.10		20.42	39.71	24.57		0.0294	0.06653				49.19	8,074.16	0.00	3.069	0.8529	0.0516
3	Barbados	3,805.07		36.47	55.92	18.07		0.0356	0.29227				135.76	88,649.41	0.28	5.479	1.9059	0.1199
4	Belize	1,599.85		9.12	23.12	19.51	8.85	0.0075	0.37167	23.23	18.39		23.84	2,568.73	0.00	5.916	1.4349	0.0000
5	Cuba	1,754.56		2.64	2.92	10.50		0.0009		53.76	12.27	0.52	85.52	1,414.04				
6	Dominica	2,346.93		22.22	12.41			0.0000	0.20347				177.91	902.23	0.00			
7	Dominican Republic	1,581.24	54.10	9.76	11.87	30.99	9.04	0.0204	0.12680	61.16	11.55		4.58	103.99	0.00	3.630	1.2739	0.2843
8	Grenada	1,685.07		25.88	20.49			0.0161	1.06846	104.56	15.68		378.95	1,335.94	0.00			
9	Guyana	1,528.77		11.92	9.26			0.0348	0.03711				17.44	298.34	0.00	5.524	1.0711	0.0060
10	Haiti	86.48		0.27	12.12	18.05		0.0004	0.00000				2.65	4.77	0.20			
11	Jamaica	1,538.35		14.62	20.96	20.15		0.0074	0.34628	27.13			58.27	607.19	0.04	4.431	1.4744	0.0018
12	St. Kitts and Nevis	4,618.84		62.97	12.96			0.0210	0.27760	86.68			534.54	7,666.92	0.00			
13	St. Lucia	1,948.09		18.41	15.02		8.55	0.0278	0.56286	16.36			21.42	354.76	0.03			
14	St. Vincent and the Grenadines	1,533.45		26.71	14.32		10.83	0.0000	0.28896	8.47			11.59	7,741.81	0.00			
15	Suriname	3,295.33	86.00	20.07	7.44			0.2398	0.16642				29.27	-	0.00			
16	Trinidad and Tobago	5,722.07		23.86	35.81			0.0518	0.20049		32.34	0.06	140.37	359.77	0.00			

Notes: The latest data point available for digital connectivity is 2020 for the following countries: Guatemala, Antigua and Barbuda, the Bahamas, Belize, Dominica, Grenada, Guyana, Haiti, St. Kitts and Nevis, and St. Lucia. The latest available year for the indicator of productive investment is 2020 for Antigua and Barbuda. The indicators for advanced and specialized skills, respectively, cover the period 2015-2020. Regarding advanced skills, the latest available data for Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua corresponds to 2019. Regarding specialized skills, the latest data for El Salvador and Honduras is from 2019. Data for R&D expenditure covers different years between 2015 and 2020. The indicator for scientific and technical publications covers the period 2015-2018. Trends cannot be calculated for the quality of digital connectivity due to changes in the methodology from the source, M-Lab.

Source: Authors' calculation

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