Potential of the fourth industrial revolution in Africa

STUDY REPORT

unlocking the potential of the fourth industrial revolution in Africa

AFRICAN DEVELOPMENT BANK GROUP

KOAFEC Korea-Africa Economic Cooperation

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STUDY REPORT
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F foreword

We stand on the cusp of a Fourth Industrial Revolution (4IR) and it is crucial that Africa does not miss out. The continent was unable to harness the opportunities of the Industrial Revolution, and has yet to make the most the Digital Revolution. With Africa's population expected to double by 2050 to 2.4 billion people, it is essential that we grasp the leapfrog opportunity offered by the 4IR to make the transition from the agrarian era.

While the 4IR builds on digitalisation, its key characteristic will be the blurring of technological boundaries and the integration of the digital, physical and biological worlds. That means it will be highly disruptive and will affect all industries – and therefore all aspects of our economy, society and governance. This future is not some far-off vision – as this report makes clear, the 4IR is already becoming reality in Africa with the emergence of technologies and applications in Artificial Intelligence, Big Data, Blockchain, the Internet of Things, drones and so on. Not only will these technologies have the potential to seed entirely new industries, but they also have the ability to transform traditional sectors by dramatically improving productivity. Farming is a key example, where the IoT, Big Data, Artificial Intelligence and drones can enable smart, precise and more productive agriculture to help ensure that we can feed Africa's growing population and consign hunger to the past.

The 4IR is also developing at an astonishing pace and, while there are great opportunities, if Africa does not get ready, it will surely widen the gaps between the have and have-nots, the skilled and unskilled, the rich and the poor. For this reason alone, attempting to maintain the status quo is not an option.

Clearly the challenge of the 4IR demands a strategic response from Africa. It requires Africa to unite – policy makers, the private sector and citizens – to build the infrastructure, cultivate our energy and creativity, and mobilise the finance to capitalise on the 4IR opportunity. That will require governments, business, development partners and the African Development Bank to work together to respond to the challenge. This report marks an important first step in identifying the potential opportunities as well as the obstacles to be overcome. The African Development Bank stands ready to play its part in an endeavour that could help bridge Africa's development gap with the rest of the world.

Dr. Akinwumi Ayodeji Adesina
President
African Development Bank

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acronyms

4IR	Fourth Industrial Revolution
AfDB	African Development Bank
AI	Artificial Intelligence
CPI	Corruption Perception Index
FDI	Foreign Direct Investment
FTAs	Free Trade Agreements
LTE	Long Term Evolution
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
HDI	Human Development Index
ICT	Information and Communication Technologies
IIAG	Ibrahim Index of African Governance
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Rights
IT	Information Technology
MSME	Micro, Small and Medium Enterprise
OECD	Organisation for Economic Cooperation and Development
R&D	Research and Development
RDI	Research, Development and Innovation
SME	Small and Medium Sized Enterprise
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
UAVs	Unmanned Aerial Vehicles
US	United States
WEF	World Economic Forum
WGI	World Bank's Worldwide Governance Indicators
WHO	World Health Organization
WIPO	World Intellectual Property Organization

ES executive summary

The coming Fourth Industrial Revolution (4IR) has the potential to transform Africa's economy, increase its productivity and enhance its global trade. In doing so, it would dramatically improve the wellbeing of African citizens. This significant new report – Unlocking the Potential of the Fourth Industrial Revolution in Africa – produced by the African Development Bank, with support from the joint venture composed of the consulting firms: Technopolis Group, Research ICT Africa and Tambourine Innovation Ventures, provides a comprehensive analysis of some major disruptive 4IR technologies for Africa – namely Artificial Intelligence (AI), the Internet of Things (IoT), Big Data, 3D printing, Blockchain and drones.

CONTEXT

The coming Fourth Industrial Revolution (4IR) has the potential to transform Africa's economy, increase its productivity and enhance its global trade. In doing so, it would dramatically improve the wellbeing of African citizens. This significant new report – Unlocking the Potential of the Fourth Industrial Revolution in Africa – produced by the African Development Bank, with support from the joint venture composed of the consulting firms: Technopolis Group, Research ICT Africa and Tambourine Innovation Ventures, provides a comprehensive analysis of some major disruptive 4IR technologies for Africa – namely Artificial Intelligence (AI), the Internet of Things (IoT), Big Data, 3D printing, Blockchain and drones.

The study creates a body of information detailing the emergence of these new technologies on the continent, highlighting their potential use and determining the business case for their development, supply and adoption (see Figure A). In focusing on five African countries – Cameroon, Morocco, Nigeria, South Africa and Uganda – which represent the different combination of strengths and weaknesses that African countries possess, the report critically assesses the business case for 4IR adoption. The study's core objective was to recommend a development strategy for African governments, the private sector and development partners, including the African Development Bank.

POTENTIAL OF THE 4IR TO TRANSFORM AFRICA

The world is experiencing a new Industrial Revolution building on the evolution of the digital revolution (the Third Industrial Revolution). "This Fourth Industrial Revolution with its agile growth is characterized by a fusion of technologies that blurs the lines between the physical, digital and biological spheres and that disrupts the industries of all countries"[1]. It moves at exponential speed, witnessing the emergence of innovative technological trends such as artificial intelligence, the Internet of Things (IoT), robotics, 3D printing, Blockchain, nanotechnology, and others with applications as diverse as the technologies themselves.

The 4IR marks a significant change in the way we work and produce. It is unfolding at an extremely fast pace. It is powered by a wide range of new breakthroughs in the digital (Artificial Intelligence (AI)), in the physical (new materials) and in the biological realms (bioengineering). It is systemic and will deeply affect businesses, governments and society as a whole.

The shift from simple digitalisation (the Third Industrial Revolution) to innovation based on combinations of technologies (the 4IR) is forcing companies of all sectors to re-examine the way they do business. The 4IR offers new possibilities for developing services that can overcome geographical and productivity limitations thanks to dematerialisation (IoT, Blockchain) and improvement of logistics possibilities (drones). It offers citizens new ways to engage with public authorities and even circumvent their supervision. It may bring about possibilities to better address pressing societal and environmental challenges, while alleviating poverty and raising people's wellbeing.

The 4IR also changes the way people interact, work, learn and consume, as it does their sense of privacy and responsibility. It questions the very definition of what it means to be "human", what can and cannot be done by a machine, thus raising serious ethical and moral issues. While much has been said and studied regarding the virtues of new technologies, there is also significant room for negative social disruptions. For instance, the 4IR may cause greater social inequality by disrupting labour markets, leading to job losses and replacements by increased robotisation and automation as well as greater segregation between 'low skill/low pay' and 'high skill/high pay' communities. Furthermore, given the 4IR's emphasis on data accessibility, there are significant concerns around protection of personal data and privacy as well as the need to develop regulatory frameworks to protect the intellectual property of businesses and sensitive personal information.

In the past, Africa was unable to benefit and capitalise on the opportunities brought about by previous industrial revolutions. This weakened its position in relation to international competitors. In light of the benefits and

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figure A

unlocking the potential of the fourth industrial revolution in Africa
one and only path in the next five years — bypass other stages of development

5 main domains of application in Africa

- agriculture
- energy
- industry
- regional integration
- wellbeing

6 key technologies for Africa

internet of things: **$110.8M** capital investments; **market of 12.6Bn$ by 2021**

big data: **$9.5M** capital investments; **40% of all businesses in the planning phase**

additive manufacturing: **$47M** capital investments; **market of 1.63Bn$ by 2022**

artificial intelligence: **$17.5M** capital investments; **market growth of +16% by 2020**

drones: **$7.9M** capital investments; **global market of 100 Bn$ by 2020**

blockchain: **$14.9M** capital investments; **market growth of +16% by 2025**

01 national governments

develop united vision for 4IR

address data circulation challenges at institutional level

develop collaborative and adaptive ICT regulation

seek regional harmonisation of data protection frameworks

prepare the next generation Africa 4.0 workforce

promote widespread innovation

02 intermediary organisations

raise awareness about the potential for and the market for technologies

increase investment in training for 4IR

03 donors

raise awareness for sustained public investment in RDI

finance research projects on the impact of the 4IR

support the creation of regional R&D centres and foster linkages with international R&D centres

support pilot projects for opening up data held in the public and private sector

offer targeted finance

challenges posed by the 4IR, Africa cannot afford to, nor does it have to, miss out on the opportunities brought about by the Fourth Industrial Revolution[2]. This report provides a first blueprint for Africa to capitalise on its strengths and mitigate its weaknesses and grasp the opportunities afforded by the 4IR.

UNLOCKING THE POTENTIAL

With a growing number of business users and end consumers, the 4IR is starting to become a reality in Africa. Studies dating back to 2015 projected high growth in African start-up technological entrepreneurs, identifying 3,500 new technology-related ventures and an anticipated $1 billion in venture capital by 2018[3]. In 2019, this study reveals that reality has surpassed projections, as approximately 6,500 technology start-ups were identified on the continent, among which about 10% develop 4IR applications (712 start-ups). They received $210 million in venture capital investments of the overall $2.27 billion investments in technology start-ups. Not all of these start-ups by any means are focused on the 4IR (many are in the realm of digitisation) but the basis for Africa's growth into 4IR is already there.

On the supply side, Africa cannot as of today be characterised as a producer of 4IR technologies, but rather as an adopter of existing technologies produced and developed elsewhere in the world. These products and services are often developed by foreign corporations or start-ups (e.g. Thales, Airbus, Zipline) but also by African corporations or start-ups to meet African demand.

Africa's large population, which is expected to double by 2050 to 2.4 billion, presents both a source of data to feed innovation in 4IR technologies as well as a dormant valuable market. According to the present analysis, there is margin for growth on the supply side as proposed products and services in Africa stand way below estimated demand levels.

While there is no data available on the turnover of companies proposing 4IR applications, looking at the current level of capital investments is a first step to approximate the current supply levels. For their part, IoT applications are steadily emerging in Africa. More than $100 million of venture capital was invested in African IoT start-ups by 2019, making it by far the most attractive 4IR technology for investors on the continent[4]. The IoT market is projected to reach a value of $12.6 billion by 2021 in Africa and the Middle East, with high potential for growth for producers of IoT applications on the continent. Concerning Big Data, it is estimated that $9.5 million worth of capital investments will have financed Big Data start-ups on the African continent in 2019. In Kenya and Nigeria, IBM estimates that up to 40% of businesses are in the planning stages of Big Data projects.

Additive Manufacturing (AM), including 3D printing, is the second promising 4IR technology on the continent. About $47 million was invested in AM in Africa by 2019, according to Crunchbase. On the demand side, Africa's AM market represented $300 million in 2016 and is estimated to reach $1.3 billion by 2022.

The volume of business for African markets relating to artificial AI, drones and Blockchain is not yet known. However, $17.5 million worth of capital was invested in African AI start-ups by 2019 (Crunchbase) while studies estimate that global economic activity linked to AI will increase by 16% by 2030 compared to 2018[5]. In addition, $7.9 million was injected into African start-ups developing drone applications by 2019 while the global market will be worth $100 billion by 2020. Finally, $14.9 million was injected into African start-ups working with Blockchain in 2019 (Crunchbase) in a global market which is expected to grow by 62.1% between 2015 and 2025[6]. By then, it is estimated that the market would be worth $16.3 billion.

However, countries face key challenges which need to be tackled to unlock the 4IR in Africa, including:

Human capital initial training and retraining.

Entrepreneurs in Africa often lack technical and managerial skills in terms of how to develop successful business models and how to run a business and usually experience shortcomings in the soft skills needed to effectively pitch to investors. There is a need for more targeted capacity-building (e.g. through mentors, Angel investors). Gender imbalance is another issue. Additionally, unlocking the potential of the 4IR will include relying on data that can inform the design of sound policies in the field of human capital development. However, there is an overall scarcity of data for long-term planning and reform.

Governance, policy and regulations.

Overall, lack of awareness and uninformed public opinion, uneven digital inclusion, obsolete governance systems not adapted to spatial and temporal issues posed by the 4IR, as well as competition and digital privacy encroachment represent the biggest challenges standing in the way of the adoption and absorption of emerging 4IR technologies on the African continent.

Information and communication technology (ICT) markets.

On the supply side, the reduced extent and speed of the internet on the continent is hindering the take-up of 4IR technologies. On the demand side, however, a large number of individuals and households do not use, or do not have devices to access, the internet. In fact, potential consumers are mainly the working poor and operate in the informal sector. This may hinder large-scale and widespread adoption of 4IR technologies unless the applications are designed accordingly (i.e. cheap, easy, simple to access) to meet the specific needs of this consumer base. Importantly, if people are not connected then the data they could otherwise produce cannot be captured leading to possibly distorted analyses and conclusions.

Entrepreneurial and innovation support systems.

Africa shows a limited ability to absorb external knowledge while it is at an early stage in terms of closing the technology gap. Universities are still too focused on publication and admit that there is a gap in terms of their capacity to transfer knowledge. Elsewhere, public funding is suboptimal. Technology transfer systems are weak and there is a global lack of R&D investment. Technology hubs, incubators and networks of mentors have not yet reached a professional and critical mass level and thus do not fully play their role as catalysts in the African start-up scene.

Access and diversity of financing.

African businesses, in particular micro, small and medium enterprises (MSMEs), face problems accessing debt or equity financing. On the demand side, there are still significant obstacles facing people working in the informal sector in their efforts to access finance.

RECOMMENDATIONS

Essentially, there are three scenarios that Africa might consider in the 4IR context:

1. the first would be to **maintain the *status quo* and miss out on the revolution**, as Africa did for the three previous industrial revolutions. The study's analysis discards this scenario. To do so would be neither beneficial for Africa's development nor rational given its ability to participate in the 4IR;
2. the second would be to bypass other stages of development and **leapfrog directly to the 4IR**. Even though this path is paved with challenges to be overcome, Africa has more to benefit than to lose from taking the necessary steps to unlock the 4IR. However, it will inevitably have to pass through the third, digital, industrial revolution to ensure it has the digital infrastructure to support the 4IR;
3. the third would be for Africa to **become a producer of 4IR technologies**. This path is, perhaps, too ambitious for Africa as a whole and not foreseeable in the medium term (i.e. within five years). It would require a significant human capital gap to be bridged, which would require longer to achieve. This scenario, however, is not out of the question for some ambitious African countries, but they would need to start to build their human capital now.

In consequence, high-level recommendations were developed to support the range of stakeholders (African policy makers and regulators, business associations, development partners, and the African Development Bank) concerning the African continent's efforts to pursue the 4IR under the second scenario. These recommendations are presented in detail in Chapter 8, and are summarised in Table A.

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table A

summary of recommendations for stakeholders

African policy makers and regulators

1	**Develop a united and coordinated vision to seize the opportunities of the 4IR** coming in the wave of the Continental Free Trade Area in March 2018, the launch of Smart Africa in 2013 and UA Agenda 2063 as an even grander vision;
2	**Bolster or redesign existing governance institutions to better prepare for challenges posed by data circulation.** New institutions may also need to be created to ensure the safety and security of organisations and individuals. This will include developing frameworks and skills to oversee both the technical management of critical facilities and infrastructure that are increasingly exposed to sophisticated and threatening malware, as well as the processing of the substantial amounts of data being generated to fuel the 4IR;
3	**Develop collaborative and adaptive regulation.** Besides public-private interplays and other collaborative governance approaches, greater regulatory agility and insight are needed to manage digital exclusion and tensions between the different policy objectives of competing emerging technologies;
4	**Prepare the next generation Africa 4.0 workforce.** It is evident that digital skills are becoming essential for the jobs of today and tomorrow. In the 21st century, digital literacy is a skill that each citizen must have. From digital literacy to computer science education, these skills can open the door to greater economic opportunities in the workplace of the future. This implies equipping schools with computers and the internet and employing teachers who can deliver digital content courses
5	**Nurture inclusive institutions favouring and promoting widespread innovation to adopt 4IR technologies in productive and service sectors.** Given the cross-cutting nature of 4IR technologies, policy and governance approaches can no longer be designed in a vacuum or in silos by focusing on a particular sector or supply-side issues alone, as has been done in the past. Development of relevant local content and applications in local languages, along with the enhancement of citizens' digital literacy skills, but also a higher level of engineering, coding and economic and creative capacity are all vital to creating an enabling environment necessary to harness the opportunities offered by 4IR;

business associations

1	**Raise awareness and provide information about the potential for and the markets for 4IR technologies. Many entrepreneurs or companies do not yet know the advantages and drawbacks of adopting 4IR technologies.** They would certainly benefit from having access to detailed information on technologies and their market potential;
2	**Increase investment in training.** Business associations should launch measures to favour the integration of foreign competencies in ICT and invest in specific emerging trends training;
3	**Strengthen collaboration with academics** to build evolutive, relevant, adaptable curriculums focused on forging the new competencies required;
4	**Partner with Governments to capture real-time and predictive insights** on the labor market in order to help prepare sound policies and regulation;
5	**Take the lead in supporting existing workforces' upskilling and lifelong learning.**

development partners

1	**Raise awareness among African governments of the need for sustained public investment in scientific R&D.** It is equally important to nurture a strong start-up culture and to ensure the protection of intellectual property. Continent-wide forums on the 4IR would be beneficial, as well as a series of national forums;
2	**Finance research projects on the impact of the 4IR on African economies and societies** which could in turn feed approaches supporting the unlocking of 4IR technologies at regional or national level as well as the rationale for awareness-raising;
3	**Support the creation of regional R&D centres and foster linkages with international R&D centres where countries can learn from more established players.** There should be a focus on demonstration projects of use cases of 4IR technologies in specific sectors and countries with the greatest potential for successful disruption in Africa;
4	**Support pilot projects for opening up data held in the public and private secto**r using public-private partnerships;
5	**Offer finance using blended finance and innovative financial instruments such as guarantees to encourage international investors.** It is important that finance be channelled to 4IR-ready and 'future-proof' infrastructure such as renewable technologies or ICT-ready road infrastructure to avoid locked-in capital and expensive retrofitting for obsolete infrastructure;
6	**Support capacity building activities towards government officials and regulators on 4IR technologies.**

African Development Bank

1	**Strengthen 4IR/digitalisation training and Building Innovative Capacity for Africa through the African Development Institute (ADI);**
2	**The ADI should develop knowledge products on cross-cutting, country- and sector-specific issues with a focus on** universal issues such as principles of data privacy/security laws as well as country-specific regulatory issues;
3	**Experiment with novel financing products, e.g. policy loans** on topics such as data privacy and protection triggering disbursement upon the client country achieving certain benchmarks - typically regulatory or legislative);
4	**Consider digitalisation as a standalone priority** in the High Five domains or increase the salience of digitalisation within the industrialisation priority;
5	**Establish a community of practice (COP) within the AfDB with support from the president's office to improve understanding of the 4IR.** The COP would serve not only to share experience within the AfDB but also to develop linkages with the existing stock of international knowledge. Given the rapid advances in 4IR technologies, such a mechanism to keep abreast of the latest thinking would be ideal without having to commit substantial resources;
6	**Strengthen internal programmes such InnoPitch to incentivise innovation** within the AfDB and foster experimentation with 4IR technologies.

PART 01
introduction

1 understanding the fourth industrial revolution

The world is on the brink of a new and all-encompassing industrial revolution moving at exponential speed. We are witnessing the emergence of innovative technological trends such as artificial intelligence, the Internet of Things (IoT), robotics, 3D printing, nanotechnology and other technologies with applications as diverse as the technologies themselves. The combination of these technological breakthroughs is referred to as the so-called Fourth Industrial Revolution (4IR henceforth). But what does it entail and how will it affect societies and the environment? What are its characteristics and differences compared to previous industrial revolutions? Why talk about the 4IR in Africa and why now?

The following sections will (i) introduce the 4IR, its characteristics and expected effects as well as the emerging technologies driving it and; (ii) discuss the rationale for a study on the 4IR in Africa.

1.1 DEFINITION OF CONCEPTS

1.1.1 Introducing the Fourth Industrial Revolution

The world is experiencing a new Industrial Revolution building on the evolution of the digital revolution (the Third Industrial Revolution). "This Fourth Industrial Revolution with its agile growth is characterized by a fusion of technologies that blurs the lines between the physical, digital and biological spheres and that disrupts the industries of all countries"(Schwab, 2016).

The 4IR builds on foundations laid by previous industrial revolutions. The advent of the steam engine in the 18th century led to the First Industrial Revolution, allowing production to become mechanised for the first time and driving social change as people became increasingly urbanised. In the Second Industrial Revolution, electricity led to mass production. A Third Industrial Revolution (the Digital Revolution), beginning in the 1950s, saw the emergence of electronics, computers and digital technology to automate production. The 4IR follows in the footsteps of the Digital Revolution but is distinct from it (Schwab, 2016).

Like the three revolutions that preceded it, the 4IR will mark a significant change in the way we work and produce. However, as opposed to its predecessors, the 4IR is different with regard to at least three dimensions (Schwab, 2016):

- the first of these key differences is velocity. While, previous industrial revolutions took place over a period of several decades, the 4IR is unfolding at an extremely fast pace;
- the second key difference is scope. The 4IR is powered by a wide range of new breakthroughs in the digital (Artificial Intelligence (AI)), in the physical (new materials) and in the biological realms (bioengineering). Novel technologies and the interaction between them, which offer fresh ways to create and consume, will have an impact on all disciplines, economies, industries and the way we work, will transform how public services are delivered and accessed, and will enable new ways to communicate and govern to emerge;
- The third difference lies in the nature of the impacts generated by the 4IR, which can be characterised as 'systemic'. As mentioned earlier, the 4IR will deeply affect (positively and negatively as will be explored further on) businesses, governments and society as a whole. Figure 1 summarises the expected effects of the 4IR.

The impacts of the 4IR are (and are expected to continue to be) broad and far-reaching. For instance, many industries are witnessing the introduction of new technologies that create entirely new ways of catering to existing needs/demand and significantly disrupt existing value chains. New patterns of consumer behaviour, built on access to mobile networks and data, are forcing companies to adapt the way in which they design, market and deliver products and services. Overall, the inexorable shift from simple digitalisation (the Third Industrial Revolution) to innovation based on combinations of technologies (the Fourth Industrial Revolution) is forcing companies to re-examine the way in which they do business (Schawb, 2016).

The 4IR offers citizens and public authorities new ways to interact with each other. In light of these changes, governments will need to develop a culture of "agile governance" in order to adapt and adequately regulate the potential benefits and challenges brought about by the 4IR, from an economic, social and environmental perspective.

Unlike previous industrial revolutions, decision makers often lack the time to study and understand a specific issue and to develop the necessary response or appropriate regulatory framework given the fast pace at which changes are taking place. Governments and regulatory agencies will need to collaborate closely with businesses, which have shown themselves capable of adapting to disruptive shifts (Schawb, 2016).

The 4IR also changes the way in which people interact, work, learn and consume as it does their sense of privacy and responsibility. It questions the very definition of "human", what can and cannot be done by a machine, thus raising serious ethical and moral issues. While much has been said and studied regarding the virtues of new technologies, there is also significant room for negative social disruptions. For instance, the 4IR can cause greater social inequality by disrupting labour markets, leading to job losses and replacements by increased robotisation and automation as well as exacerbated segregation between 'low skill/low pay' and 'high skill/high pay'. Furthermore, given the 4IR's emphasis on data accessibility, there are serious concerns around privacy as well as the need to develop regulatory frameworks to protect the intellectual property of businesses and sensitive personal information. In conclusion, the technological changes and disruptions brought about by the Fourth Industrial Revolution can be particularly beneficial for the economy and society while posing serious threats if they are not well directed. Policy makers, businesses and people are responsible for guiding its evolution in order to unlock its positive impacts and mitigate the related risks.

1.1.2 Emerging technologies driving the Fourth Industrial Revolution

The 4IR is being driven by new technologies that we will refer to as 'emerging technologies' or enabling technologies. These technologies include, among others, Artificial Intelligence (AI), Big Data analytics, Blockchain, cloud computing, the 5G network, the Internet of Things (IoT), autonomous vehicles, unmanned aerial vehicles (drones), Additive Manufacturing (AM), quantum computing technologies, virtual and augmented reality and robotics. Table 1 presents a brief description of the key emerging technologies associated with the 4IR. The report studies the following technologies in detail: Additive Manufacturing, drones, Artificial Intelligence, Blockchain, IoT and big data.

The emerging technologies have various market applications and potential uses. Table 2 presents some of them.

1.2 RATIONALE FOR A STUDY ON THE FOURTH INDUSTRIAL REVOLUTION IN AFRICA

Despite the existence of considerable differences among its countries, Africa faces a number of considerable structural economic challenges. In the past, the continent has not been able to benefit and capitalise on the opportunities brought about by previous industrial revolutions, weakening its position in relation to international competitors. This is illustrated by a number of existing economic and industrial indicators, including:

- The continent is home to 16% of humanity but produces only 4% of global GDP;
- Less than 1% of the world's billion-dollar companies are African;
- Productivity in Africa is still low, preventing the private sector and the economy from being competitive;
- Most African labour markets are characterised by high unemployment levels, underemployment or vulnerable employment;
- African economies are characterised by large agricultural and informal sectors that generally have low wages and revenues;
- Poverty is still a very widespread phenomenon in Africa and human development indicators are the lowest on the planet.

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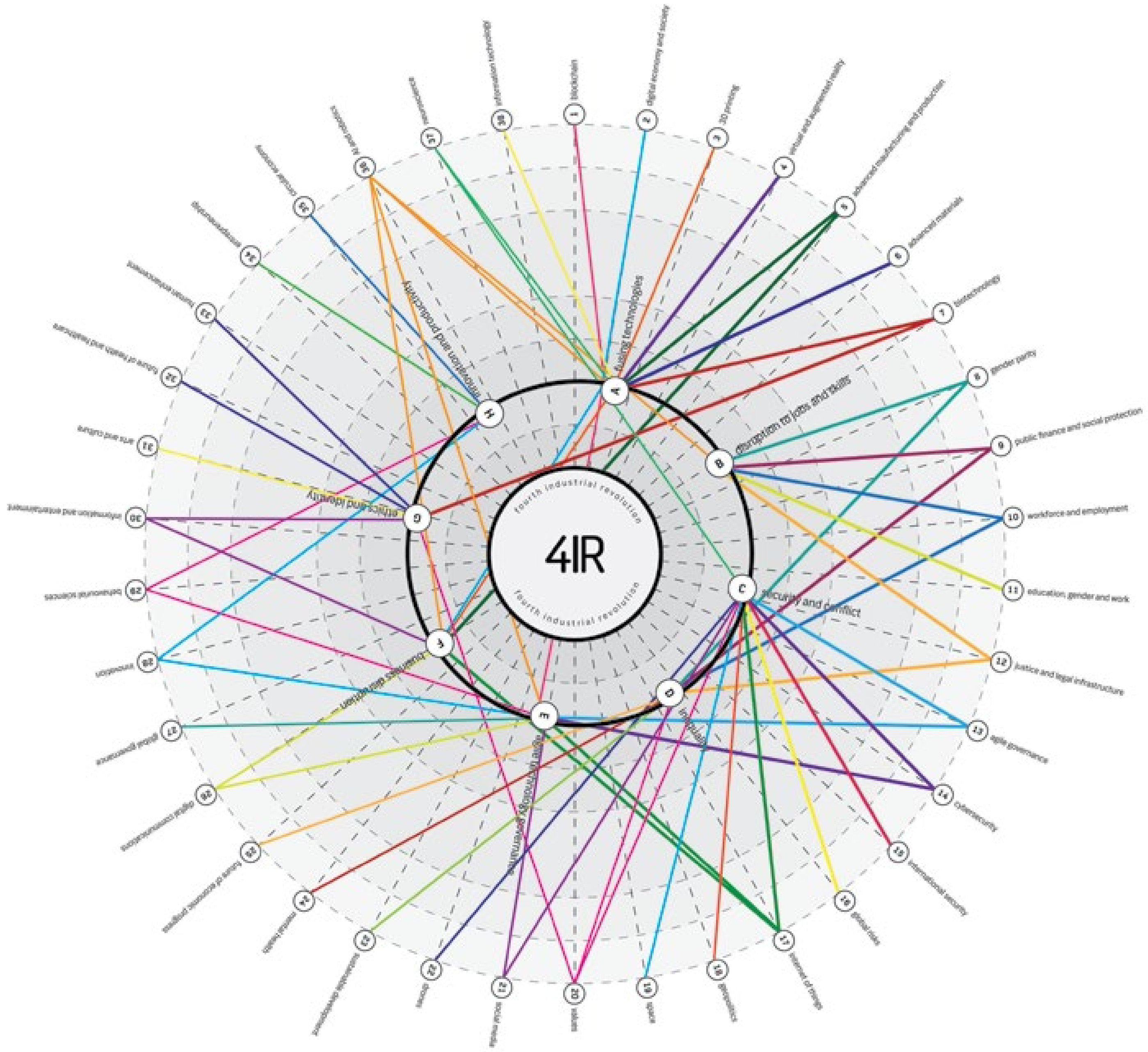
figure 01

the effects of the fourth industrial revolution



ADAPTED FROM
World Economic Forum (2018)

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table 01

brief description of key emerging technologies

emerging technology	description
Artificial intelligence	System recognising complex patterns, processing information, drawing conclusions and making decisions. System which may evolve in the future and which would be truly autonomous in its reasoning and thinking and be able to improve itself entirely independently from humans.
Big Data analytics	Complex process of examining large and varied data sets (Big Data) to uncover information including hidden patterns, unknown correlations, market trends, customer preferences and other relevant insights that can help organisations make informed decisions.
Blockchain	Delivery of computing services (servers, storage, databases, networking, software, analytics, and intelligence) over the internet ('the cloud').
Fifth-generation wireless (5G)	Latest iteration of cellular technology engineered to greatly increase the speed and responsiveness of wireless networks.
The Internet of Things (IoT)	System of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.
Autonomous vehicle	Driverless vehicle that can move and guide itself without human input.
Drone	Unmanned flying vehicle that is controlled remotely.
Additive Manufacturing	Process of producing products by computer-aided, layer-by-layer addition of material(s), application of this 3D printing technology on an industrial scale.
Quantum computing technologies	Quantum computers leverage quantum mechanical phenomena to manipulate information, relying on quantum bits, or qubits.
Virtual reality (VR)/Augmented reality (AR)	VR: artificial, computer-generated simulation or recreation of a real-life environment or situation. AR: technology that layers computer-generated enhancements on top of an existing reality in order to make it more meaningful through the ability to interact with it.
Robotics	Industry related to the engineering, construction and operation of robots (machine designed to execute one or more tasks automatically with speed and precision).

SOURCE
Technopolis (2019)

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table 02

market applications and potential uses of some emerging technologies

agriculture

AI-Machine learning	Application in plant breeding to speed varietal selection ; automatic plant management: intelligent robots are reducing applications of inputs by over 90%; identification of biological anomalies; spatial planning and analysis of soil and weather conditions for precision-farming
Drones	Use of drones to monitor crops and soil conditions; cadastral management
Big Data/data science – Internet of Things	Telephone farming; e-extension; inputs-as-service; use of Big Data for credit scoring farmers; internet-enabled irrigation systems; remote telephone farming
3D Printing	Locally fabricated agricultural machines and repair items/parts
Blockchain technologies	Food traceability system for international trade; digital land registers of land titles of farmers; digital records of crop storage in warehouses, reducing need for middlemen
Net positive impact on competitiveness	**Very high: agriculture has many potential entry points and little downside in terms of job losses**

energy

AI-Machine learning	–
Drones	Maintenance of transmission networks
Big Data/data science – Internet of Things	'Smart grids'; sale of solar power as utility/service through internet-enabled cookers and solar panels (e.g. M-Kopa)
3D Printing	Locally fabricated agricultural machines and repair items/parts
Blockchain technologies	Food traceability system for international trade; digital land registers of land titles of farmers; digital records of crop storage in warehouses, reducing need for middlemen
Net positive impact on competitiveness	**High to moderate: much potential here to electrify African households and companies, especially in remote areas**

industry

AI-Machine learning	Potential for development of sophisticated machine-learning algorithms to interpret and/or explore data; fleet management; advanced robots will eliminate the advantage of cheap labour
Drones	Drone-based services (e.g. facilities inspection, mapping); cadastral management in mining sites
Big Data/data science – Internet of Things	Geological data mining may create new opportunities; process optimisation; will enable very specific market segmentation and eliminate mass markets
3D Printing	Locally manufactured parts; will eliminate the factory manufacturing model
Blockchain technologies	Information sharing in transport and logistics; traceability ; management of IP rights
Net positive impact on competitiveness	**High to moderate: Much potential here, but will require much support to build new capability, in AI, data science and 3D printing** It remains to be seen how export-led manufacturing will be affected by technologies such as AI, 3D printing, virtual and augmented reality. Some experts claim that the importance of export-led manufacturing will be diminished by these technologies, as manufacturing facilities will be relocated to developed countries

modernised services and financial inclusion

AI-Machine learning	Potentially many applications (e.g. credit scoring using non-standard data); driverless cars; recruitment, talent matching, HR management
Drones	'Last mile' delivery
Big Data/data science – Internet of Things	Shared economy (e.g. AirBnB); financial inclusion (e.g. micro-insurance); e-commerce (e.g. Jumia, iRoko); FinTech; trend analysis and decision support, customer analytics
3D Printing	Toll/contract manufacturing; community workshops
Blockchain technologies	Numerous trust-based applications ('smart contracting'); cryptocurrency-based transactions; blockchain-enabled financial transaction platforms and systems
Net positive impact on competitiveness	**Very high. This sector is already very dynamic. An e-commerce company valued at $1 billion, M-Pesa, is already the biggest money transfer service in the world.** Driverless cars also have positive expected climate change related outcomes in terms of reducing traffic congestion

health

AI-Machine learning	Chatbots substituting the function of primary healthcare providers and improving diagnostics; health trend analysis; epidemic outbreak predictions
Drones	Delivery of drugs to remote areas
Big Data/data science – Internet of Things	Monitoring vaccines; monitoring of medical deliveries
3D Printing	Printing prostheses for amputees and other health products
Blockchain technologies	Blockchain-enabled platforms to share public health records for further analysis
Net positive impact on competitiveness	**Rather an issue of access to health than competitiveness**

education

AI-Machine learning	Educational programmes
Drones	–
Big Data/data science – Internet of Things	–
3D Printing	–
Blockchain technologies	Certification of diplomas
Net positive impact on competitiveness	**High to moderate: For access to education and improvement of educational programmes which will indirectly improve competitiveness**

smart cities

AI-Machine learning	Optimising public transport systems
Drones	–
Big Data/data science – Internet of Things	Optimising public transport systems (analysis of mobile phone data)
3D Printing	–
Blockchain technologies	–
Net positive impact on competitiveness	**High: Potential gains in time with reduction of traffic jams, but also reduction of pollution.**

regional integration

AI-Machine learning	Intelligent vehicles (i.e. trucks) (with sensors, etc.) at the borders
Drones	Alternative infrastructure (e.g. drones)
Big Data/data science – Internet of Things	–
3D Printing	–
Blockchain technologies	Trade transactions between African countries, used by customs services to collect tax on imports/exports
Net positive impact on competitiveness	**Moderate**

overall impact of 4IR technologies

AI-Machine learning	Will eliminate traditional paths of industrialisation. Relies on ICT and Big Data
Drones	Potential to increase productivity in many sectors. Faces many constraints (regulatory)
Big Data/data science – Internet of Things	Perceived as the most dynamic 4IR technology for Africa. Potential to create many jobs
3D Printing	Presents a big opportunity for African countries directly moving into manufacturing but also a threat insofar as it allows the 'reshoring' of manufacturing work to high-wage countries. Little take-up to date
Blockchain technologies	Potential to formalise the huge informal sector. Regulatory constraints and overall weakness of political will
Net positive impact on competitiveness	**High**

SOURCE
Brooking Institute (2017) and survey of African stakeholders by Technopolis Group (2019)

In light of these challenges, Africa cannot afford to, and it does not have to miss out on, the opportunities generated by the Fourth Industrial Revolution. The 4IR may offer Africa a unique opportunity to structurally transform its economy, increasing its productivity and enhancing its global trade. In addition, it may deliver possibilities to better address pressing societal and environmental challenges whilst alleviating poverty and raising the well-being of its population. The 4IR offers new possibilities for developing services that can overcome geographical and productivity limitations thanks to dematerialisation (IoT, Blockchain) and improvement of logistics possibilities (drones). This becomes clear when looking at the AfDB's High Five priority areas[7].

As mentioned in the previous section, the potentially disruptive nature of the 4IR can be illustrated in a number of fields and sectors, many of which are key to the African economy and development challenges. These include the following:

Agriculture

In the agriculture sector, AI, drones and remote sensors, for example, offer opportunities to monitor farms, fisheries and forestry activities much more effectively. Irrigation systems can be automated and Blockchain can be used to manage water allocations. Many African countries have large agricultural sectors and the 4IR is likely to have a positive impact on farming. In the short term, connecting farmers to the internet can improve farmer productivity, profitability and sustainability. By building on previous technologies such as connected smartphones, these new technonlogies can give farmers better access to market prices, weather information and knowledge about soil, seeds and fertiliser. They may also enable a 'sharing economy' to take root, whereby farmers who cannot afford to buy mechanical equipment can rent it.

Energy

With regard to energy production and distribution, 'smart grids' utilising the IoT and renewable energy sources, that are generated locally close to their consumers rather than in centralised power plants, can effectively provide electricity to people and companies. Blockchain technologies allow for cost-effective and transparent carbon emissions tracking and the establishment of carbon markets.

Manufacturing

In the manufacturing sector, Additive Manufacturing enables people to manufacture products in the vicinity of where they will be consumed and used.

Financial

In the financial sector, building on the development of online/mobile banking and mobile money, AI and Blockchain can develop new 'smart payment' and 'smart banking' initiatives and therefore accelerate financial inclusion and e-commerce.

Health

The 4IR also brings with it new business models for delivering health services (such as telemedicine) using AI and Blockchain. It also enables doctors to collect and understand genetic, environmental and behavioural data on their patients. This enables identification of preventive actions, treatments or cures that are increasingly tailored to a specific individual or community (precision medicine) and potentially lowers the costs of providing health services by reducing money spent on inappropriate medicines. Emerging technologies can provide new ways of preparing for disasters and delivering aid to the worst-affected regions.

Smart cities

Emerging technologies can also help to build Smart Cities in Africa by using the power of Big Data and the IoT in urban transport for example. 'Smart' urban transport systems, which combine multiple technologies and integrate them into a connected system, provide more efficient options for getting around cities and for reducing road deaths, congestion and pollution.

Education

The 4IR certainly does offer opportunities for African citizens and businesses to gain access to new sources of information and new forms of education (online courses utilising AI and virtual classrooms).

Supporting the deployment of the 4IR in Africa make sense in light of these potential sectoral, market and developmental benefits. On top of this, it would appear that doing so would also be relevant from a policy and political perspective given that the existence of various development strategies at the regional and national levels have emphasised the need for structural transformation to increase productivity whilst also absorbing the expanding working age population. Common 4IR-related themes in these agendas include promoting high-productivity agricultural sectors and agro-processing, with jobs along agricultural value chains (in manufacturing, logistics and retail); modernising the services sector using information and communication technologies (ICTs); boosting local content and local participation in extractive industries; developing competitive, export-oriented manufacturing sectors; and investing in the infrastructure necessary for businesses to start and grow (Copley, 2018). Additional recent economic and policy advancements which provide favourable framework conditions for the advancement of the 4IR include the African Union's Agenda 2063, the creation of the African Continental Free Trade Area and the Smart Africa Initiative.

The convergence of all these factors underpins the need for a deeper exploration of the Fourth Industrial Revolution in the African context now. It is important to seize this opportunity in a timely manner and to take advantage of the fact that Africa is still in a position to do so and has the conditions to reap the rewards from this revolution. There is currently a window of opportunity for the continent to bypass traditional phases of industrial development and move directly into an age of more modern industrial practices. This study on 'Unlocking the Potential of the Fourth Industrial Revolution in Africa' should therefore come at the right time. As will be seen in the following chapters, the study aims to provide insights for policy makers, development partners, the private sector and civil society inside and outside Africa to nourish the debate on the potential benefits that Africa can accrue from the 4IR, and the best strategies to pursue to unleash this potential.

2
research and methodology framework

Before presenting the results and the conclusions drawn from the study, this chapter sets out to explain its rationale and objectives, as well as the methodology used in the collection and analysis of data used to support the conclusions.

2.1 STUDY OBJECTIVES AND SCOPE

This study was designed to identify and assess technologies for which a business case can be established in the African context. The overarching objective of this assignment was therefore to create a body of information detailing some of the main new technologies; highlighting their potential use in Africa; determining the business case for their development, supply and adoption; and recommending a development strategy for African governments, the private sector and development partners, including the African Development Bank. The specific objectives of the study are as presented in Figure 2.

The scope of the study has been defined at four levels: technologies (i.e. technological), countries (i.e. geographical), market application (i.e. sectoral) and regulation (regulatory).

2.1.1 Technological scope

The technologies identified for the purpose of this study were selected mostly on the basis of their potential to generate impact and applicability in a range of important sectors and to contribute to Africa reaching the Sustainable Development Goals (SDGs). Technologies were considered relevant to the study when the innovation that they can generate has the potential to spawn further innovation and growth across all sectors where application might be possible.

The selected technologies for this study are: Artificial Intelligence (AI), Additive Manufacturing (AM), Blockchain, Big Data and the Internet of Things (IoT) and drones. A rationale and detailed explanation for their selection is presented in chapters dedicated to these technologies.

Other technologies such as advanced robotics and virtual and augmented reality (VR and AR respectively), on the other hand, were not selected. While advanced robotics

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figure 02

objectives of the 4IR study

4IR studies objectives

from understanding the general context and conditions to adoption of 4IR technologies to applied case studies which in turn allow for drafting a business case and recommendations at the continent level

01
understand the environment

preconditions for adoption of 4IR technologies, challenges and drivers, positive and negative effects

02
describe technologies for knowledge dissemination

including domains of application, potential and condition for adoption

03
benchmark emerging countries

identify preconditions, drivers, positive and negative effects, looking for best practices and replicability

04
demonstrate applications in Africa

draft case studies in African countries of interest to the AfDB on main domains for economic growth and societal improvements

05
conclude on a business case

identify whether there is a business case at the continent level

06
recommend interventions

to African governments and international institutions

07
showcase

propose ICT components to already existing AfDB programmes to showcase examples for international donors' interventions in the Bank's High Five priority areas

has considerable potential for application in areas such as precision agriculture, the costs of capital and cheap labour in Africa still considerably hinder the take-up and purchase of robots and are likely to continue to do so in the near future[8]. Concerning VR, while there is some positive evidence for its use in remote learning[9], notably in engineering or medicine, and while the technology can be implemented cheaply by using existing mobile phones such as screens, current commercial applications are rather focused on entertainment.

2.1.2 Market scope

In addition to selecting a set of technologies, the study also places specific emphasis on selected sectors or market applications tied to the AfDB's High 5s. This includes energy (Light up and Power Africa); agriculture (Feed Africa); industry and services (Industrialise Africa); regional integration (Integrate Africa); and health, education, Smart Cities (Improve the Quality of Life for the People of Africa). These are considered to be sectors and areas where successful introduction and take-up of the technologies can contribute to addressing some of the current challenges standing in the way of Africa's further development. Successful innovation in these sectors therefore has the capacity to generate a broad range of positive knock-on effects and contribute directly to improving social wellbeing.

2.1.3 Geographical scope: African countries selected for in-depth analysis

In addition to developing a continental focus on the potential of the 4IR, the study takes a more detailed look at this issue in five African countries. In order to select these countries for a more in-depth analysis, all African countries were initially assessed according to: i) their level of interest in the emerging technologies on the continent; ii) their ecosystem maturity for the Fourth Industrial Revolution. The data and information gathered through the interviews and web scraping supported this assessment.

In addition to this, African countries were analysed according to the following seven criteria:

- Regional Economic Zone. The countries have been chosen to ensure the representation of each region of Africa (north, south, west, east and central), as each case could look not only at the national level but also at the regional potential;
- Level of public interest in key technologies, which is an indicator of the potential for an end-market take-up (using Google Trends analysis);
- Size of the ecosystem, which is an indicator of the supply-side readiness (using Global Systems for Mobile Communication Association (GSMA) technology hubs mapping);
- Rank by economy size and rank by population size (using data from the World Economic Forum 2018 and from the World Population Review 2019);
- Number/volume of identified projects / initiatives at this stage (through a literature review);
- Spoken and written language of the ecosystem (French, English and other languages).

The project aimed to ensure a balanced mix of selected countries in terms of a) their level of development and b) their geographical situation. Regarding the latter, the study ensured that the five economic zones in Africa are represented in a sample of selected countries while ensuring a balance between frontrunners and less economically advanced countries. On the basis of this information and criteria, the following countries were selected:

South Africa and Nigeria, the two strongest economic leaders. Both countries have large innovation ecosystems and demonstrate considerable interest from civil society with regard to 4IR technologies. During the last South African Innovation Summit (SAIS) in late 2018, the Department of Trade and Industry mentioned its readiness to embrace the 4IR: "as a government and society we should collaborate in creating the enabling environment for entrepreneurs to adapt and adopt the 4IR technologies for the creation of a better life for all[10]". The Nigerian President announced in 2017: "Africa did not take part in the first, second and the third industrial revolutions. We are now enlightened and aware of the coming revolution and must take advantage of the fourth revolution. As a country, we must position ourselves to leverage the benefits provided by the coming era to provide the needed solution to our struggle[11]." The level of buy-in from both governments is thus strong and there are many examples of initiatives that offer potential for scalability to other countries or at a regional level. Both countries, but notably Nigeria, present investment and support opportunities from the AfDB.

Morocco is not leading north Africa but rather the 3rd economy in the region (after Algeria and Egypt) and the 7th ranked in Africa. Morocco's innovation ecosystem is quite dynamic, with 25 active technological hubs, placing the country in 4th position in Africa after South Africa, Nigeria and Kenya. The structure of its economy makes it possible to envisage that 4IR technologies could potentially revolutionise its agriculture, industry, service and energy sectors. The country presents considerable investment and support opportunities for the AfDB.

Cameroon and Uganda are two medium ranked economies (respectively 15th and 17th). Both qualify and offer the advantage of having conducive innovation ecosystems. Cameroon is a new player in west francophone Africa. In mid 2018, the Forum 'Shaping Cameroon 4IR' underlined how Cameroon is lagging behind but also how much the technology ecosystem is booming. Uganda is a medium sized country with no access to the sea. Many private initiatives have been identified so far (e.g. CTA MUIIS, Solar No, Mama-Ope).

2.1.4 Geographical scope: benchmark emerging countries

Two non-African countries have been selected for the purpose of drawing comparisons and gaining inspiration when it comes to support for the deployment of the 4IR. As a result, the countries were mainly selected on the basis of the degree of maturity of their supporting policy efforts (Republic of Korea) and the potential for replicability of the experiences developed (India).

Korea already boasts a highly advanced and competitive economy that has made great strides towards 4IR adoption. For instance, Korea has the highest density of robots worldwide, with 631 robots per 10,000 human workers[12]. Korean multinationals are leading in industries ranging from semiconductors to mobile phones. The Korean example shows that a country can successfully develop a globally competitive manufacturing sector even without a sizeable home market by focusing on exports from the outset. However, many development economists doubt that this export-oriented model for economic development can be replicated in Africa and in the context of the 4IR, which may lead to more decentralised and local production and reduces the significance of the relative cost of labour in different markets. Small markets also have one disadvantage compared to the likes of the US or China when it comes to the use of AI for revolutionising industries, which is the lack of a large data basis, with data being the most important resource in the context of 4IR. This could mean that 'smart specialisation' in niche sectors becomes more important than ever. Additionally, despite Korea's successes, its manufacturing industry has lost some of its competitive edge of late and rising wages combined with stagnating productivity have led to a rise in youth unemployment[13] – a problem shared by many African countries despite starkly different demographics.

India is another economy providing useful benchmarks for Africa's industrial potential. Both have the opportunity to bypass several stages of development by transitioning directly to the Fourth Industrial Revolution. Both Africa and India have already bypassed stages in the area of telecommunications and created innovative mobile device-based business solutions. Both stand to enjoy the biggest benefits in sectors linked to sustainable economic growth such as clean energy, green agriculture and improved farm management with the help of digital tools, the circular economy, e-mobility and urban planning[14]. Both are at an early stage in terms of creating the innovation ecosystem consisting of investors, start-up incubators, government and research institutes that can kickstart economic transformation. Indian government initiatives such as Startup India, Make in India and the Digital India campaign and India Innovation Growth may be instructive as far as developing a strategy for Africa is concerned. Both India and Africa share one key characteristic, which is favourable demographics: the population median age in India is 27 years old and 19 years old in Africa[15]. This provides the potential for innovation to spread in vibrant societies but also the risk that technological innovation and automation pose to a large workforce. However, Africa and India can only capitalise on this 'demographic dividend' if they manage to educate their population. The percentage of formally skilled workers stands at 4.7% in India compared to 96% in Korea[16].

2.1.5 Regulatory scope: SADC regulatory case study

The study additionally examines the required legal and regulatory reforms to undertake at country and regional level with the aim of supporting the take-up of the 4IR. For that purpose, a case study on the SADC harmonised data protection framework has been conducted.

The case study critically reviews the alignment of SADC data protection laws with international and regional frameworks, including data protection aspects of the African Union Malabo Convention. It also assesses the level of harmonisation of SADC protection laws in the SADC. Specifically, the study reviews constitutional provisions on privacy, the level of enactment of data protection legislation and the appointment of a data protection authority in all SADC countries. Finally, the study provides actionable policy options for the SADC Secretariat and for SADC countries that wish to implement new data protection laws or amend existing ones. Last but not least, the study recommends how to strengthen the SADC model law taking into account the increasing digitalisation and the subsequent risks for SADC users.

2.2 STUDY METHODOLOGY AND LIMITATIONS

2.2.1 Conceptual framework for conducting the analysis

The conceptual framework used to conduct the analysis for this study is comprehensive, including the enabling factors for the adoption of technologies, and takes into account the positive and negative interactions between technologies, businesses and their environment. This framework combines a theoretical (potential) and practice-based (concrete cases) approach dovetailing with an hourglass approach (general to country/domain cases) to produce sensible forecast solutions (recommendations).

The methodology focused on studying enabling factors for the adoption of technologies and studying the potential of technologies, then developing concrete case studies for adoption in specific countries and for different domains of application. This was done through the extensive analysis of technologies, initiatives at emerging market and African levels and concentrating on a number of technologies, domains and countries. This is represented in Figure 3.

2.2.2 Work organisation

Data collection work and analysis were conducted on the basis of five main work packages and three work sub-packages, as presented in Figure 4.

Data was collected mainly through the following activities:

- An extensive literature analysis of existing research by international cooperation and research organisations (e.g. AfDB, OECD, UNICO, World Bank, USAID, AFD, WEF, ISS, ODI);
- An analysis of existing information concerning markets and venture capital investments, using Crunchbase database as one of the rare sources of information on investments in start-ups in Africa[17];
- An Africa-wide survey to get a broad view of trends, pre-conditions, measure the perceptions of different private sector specialists (business associations, technology hubs, start-ups and venture capital investors) towards different innovation-related, economic, regulatory, legal, public policy and ethical challenges and opportunities posed by the 4IR technologies and propose sensible policy/investment solutions (see appendix A);
- Interviews with high level stakeholders, with AfDB staff, with regulatory stakeholders (see appendix B);
- Written contribution of Korean stakeholders;
- Five country visits (to Morocco, Nigeria, Cameroon, South Africa, Uganda). One field visit per case study country was organised to allow the team to gain a deeper understanding of the local conditions and characteristics and to be able to identify the most relevant use cases. Field visits took place over five days and included face-to-face meetings with key stakeholders from government, the private sector, researchers and NGOs (about 25 interviews);

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figure 03

conceptual approach

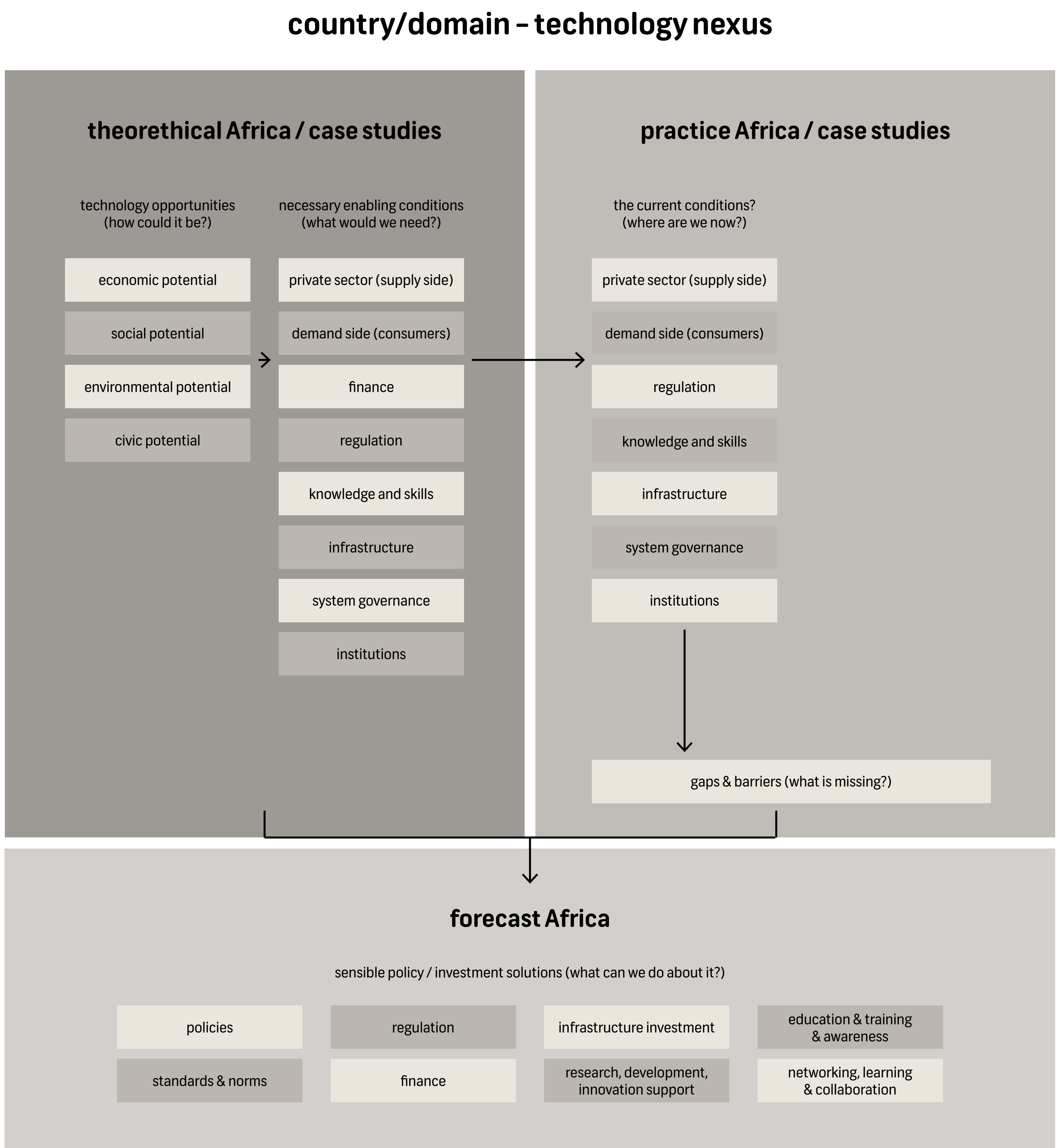

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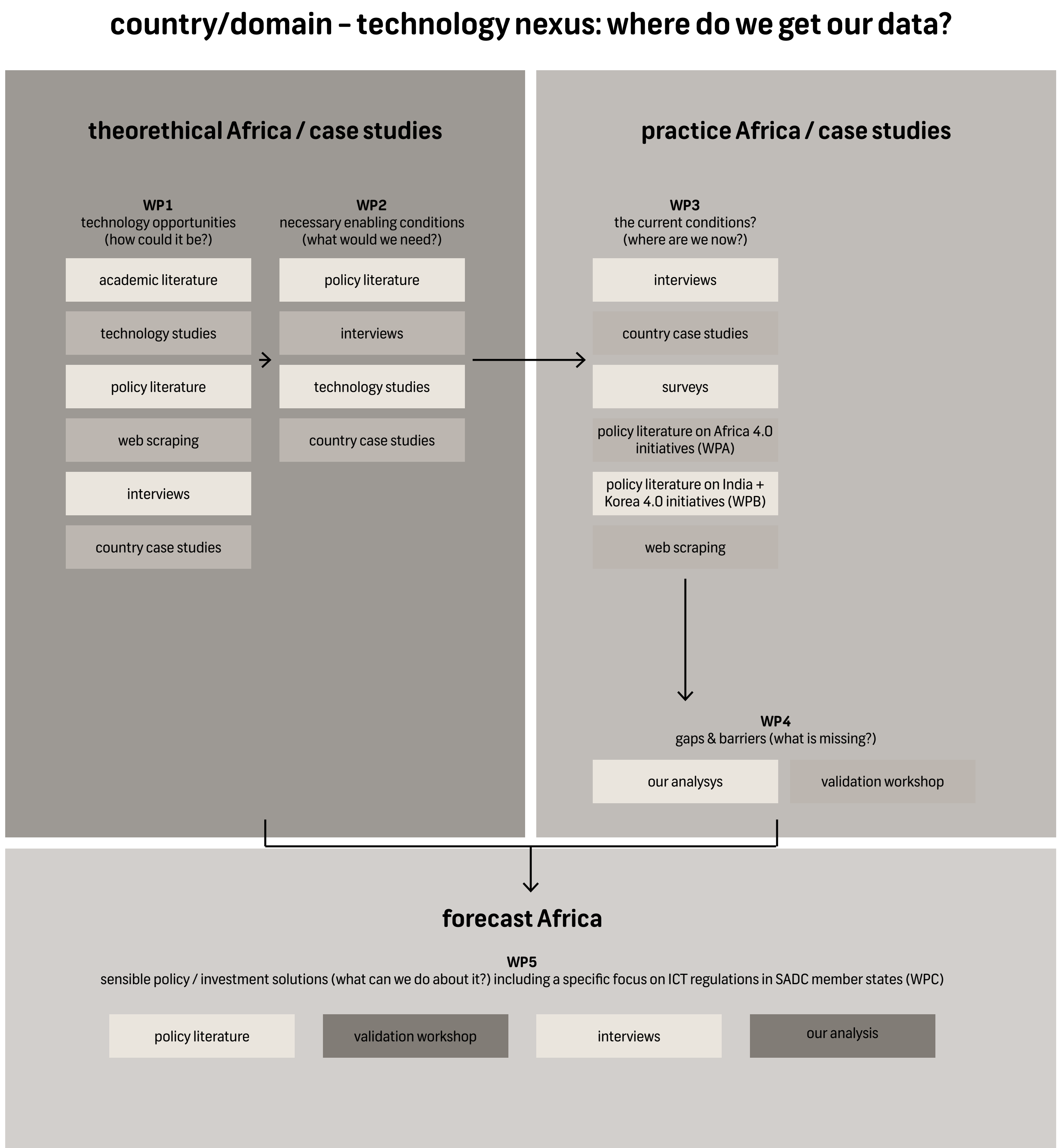
figure 04

work organisation



- Triangulation of data analysed in five technology chapters (on Artificial Intelligence, Additive Manufacturing, Big Data/the Internet of Things, Blockchain, drones), five country case studies (on Morocco, South Africa, Nigeria, Cameroon and Uganda), two benchmark cases (on India and Korea) and a regulatory analysis (of SADC data regulation framework harmonisation).

2.2.3 Study limitations

Data concerning markets for 4IR technologies are still quite scarce and scattered in Africa. While it was originally foreseen that a detailed market analysis was to be conducted as part of the study, the possibility of doing so was limited given the absence of standardised data at sectoral level in African countries (GDP, jobs, productivity).

PART 02
state of the fourth industrial revolution in africa

3
Africa's state of readiness for the fourth industrial revolution

The Fourth Industrial Revolution (4IR) adds a layer of complexity to the already challenging task of developing and implementing industrial strategies that promote productivity and inclusive growth. Countries need to adjust their national strategies to the changes induced by the 4IR. This requires countries to start by understanding the factors and conditions that have the greatest impact on the transformation of their production systems (enabling factors) and then assess their readiness to leverage production in the 4IR era in relation to those factors/conditions.

The analysis of the literature, interviews and surveys conducted for the purpose of this study converges to identify key enabling factors which are instrumental in ensuring that benefits can be gained from the 4IR. These enabling factors not only improve the ability of a country to consume emerging technologies but, more importantly, equip them to develop market applications of these technologies.

The key enabling factors lie in human capital, governance, policy and regulation, entrepreneurial and innovation support systems, and access to finance and infrastructure.

The following sections will (i) assess Africa's current level of readiness for the 4IR and (ii) provide a detailed assessment of each of the above-mentioned enabling factors.

3.1 OVERALL ASSESSMENT OF AFRICA'S STATE OF READINESS FOR THE FOURTH INDUSTRIAL REVOLUTION

In this study, a state of readiness for the 4IR is regarded as the ability to capitalise on future production opportunities, mitigate risks and challenges, and be resilient and agile in responding to unknown future shocks. Readiness can be measured by assessing a country's current baseline of production and the key enablers that position it to capitalise on the 4IR to transform production systems.

One objective is to leverage existing work/methodology to measure country readiness while ensuring the largest geographical coverage possible. As such, readiness has been assessed using the World Economic Forum approach (WEF, Readiness for the Future of Production Report 2018, 2018), which is more comprehensive and allows international comparison on readiness for the 4IR.

3.1.1 Readiness assessment methodology and global readiness assessment results

The readiness assessment is data-driven and analyses how well positioned countries currently are to shape and benefit from the changing nature of production in the future. It covers two main components: Structure of Production, or a country's current baseline of production; and Drivers of Production, which represent the key enablers that position a country to capitalise on the 4IR to transform production systems (Figure 5).

The assessment includes 59 indicators across the Drivers of Production and Structure of Production components. The assessment is forward-looking given that it measures readiness for the future rather than performance at present. In addition, it measures average national readiness, not just the highest-performing areas within a country.

The countries included in the assessment are assigned to one of four archetypes based on their performance in the Drivers of Production/Future Production (i.e. vertical axis) and Structure of Production/current production (i.e. horizontal: axis). (see figure 6).

As shown in Figure 7, of the 100 countries and economies included in the assessment, only 25 countries from Europe, North America and East Asia are Leading countries, or in the best position to benefit from the changing nature of production. These 25 countries already account for over 75% of global Manufacturing Value Added (MVA) and are well positioned to increase their share in the future. Furthermore, approximately 70% of robot sales take place in China, Germany, Japan, Korea and the United States. Germany, Japan and the United States dominate the landscape of high-value industrial robots while China serves as the most rapidly growing market.

Approximately 90% of the countries from Latin America, Middle East, Africa and Eurasia included in the assessment are classified as nascent countries, or the group least ready for the future of production.

3.1.2 Africa's state of readiness for the Fourth Industrial Revolution

African countries all have a low level of readiness for the future of production, as illustrated by weaker performance across the Drivers of Production as well as a limited Structure of Production (see Table 3).

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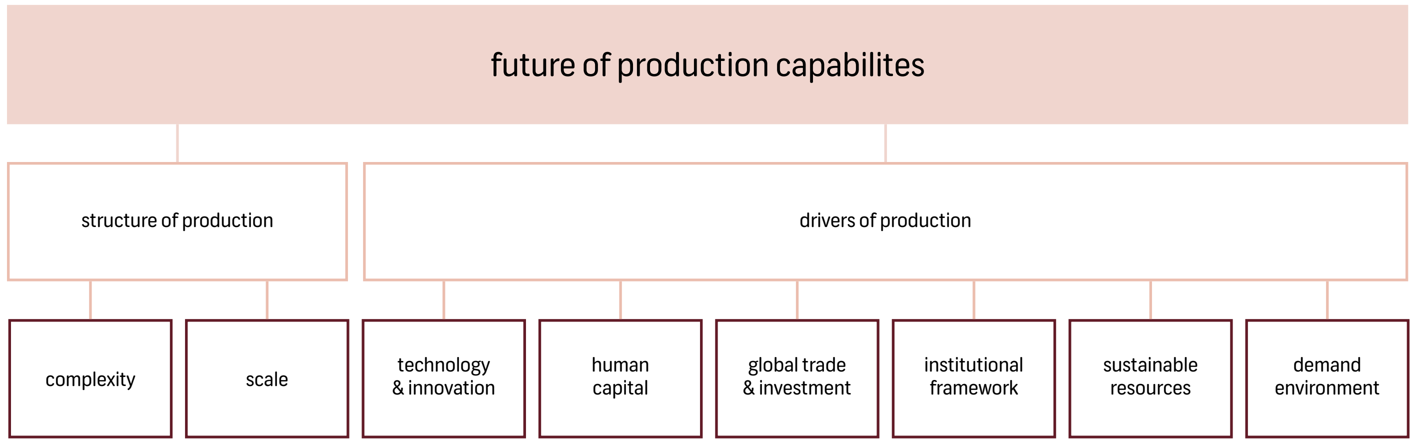
figure 05

readiness diagnostic model framework



ADAPTED FROM
World Economic Forum (2018)

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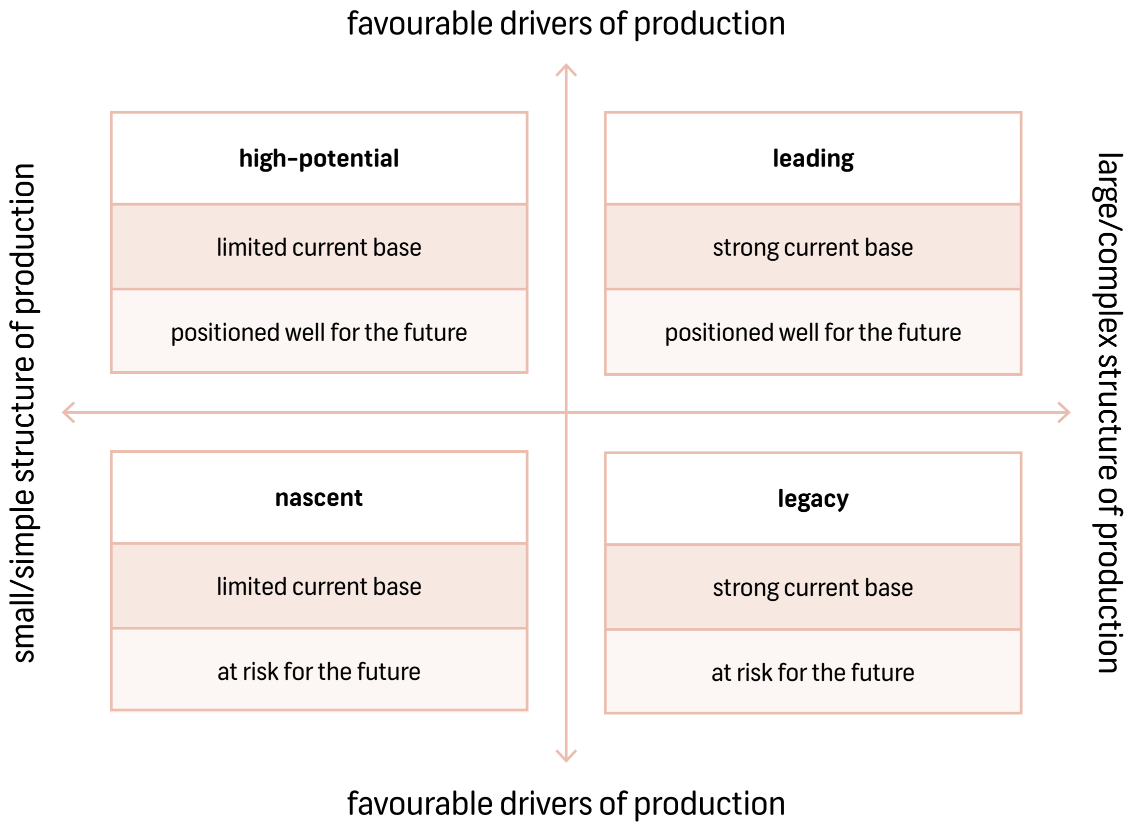
figure 06

country archetypes



ADAPTED FROM
World Economic Forum (2018)

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figure 07

global map of readiness assessment results 2018

ADAPTED FROM
World Economic Forum (2018)

table 03

Africa readiness for future production score

	Structure of production		**Drivers of production**	
Countries	Scores (0-100)	Rank (out of 100)	Scores (0-100)	Rank (out of 100)
Algeria	2.83	90	3.70	87
Botswana	3.17	86	4.43	69
Cameroon	1.84	98	3.24	100
Egypt	4.99	46	4.46	68
Ethiopia	2.01	96	3.29	98
Ghana	1.96	97	4.14	77
Kenya	2.97	88	3.83	83
Mauritius	3.84	73	5.37	39
Morocco	3.67	77	4.35	73
Nigeria	1.66	100	3.68	88
Senegal	3.11	87	3.74	85
South Africa	5.03	45	5.02	49
Tanzania	2.39	93	3.28	99
Tunisia	4.83	51	4.41	72
Uganda	2.25	94	3.31	97
Zambia	2.39	92	3.54	95

SOURCE
World Economic Forum (2018)

It is important to highlight that none of the African countries made it to the top third of the global ranking: Mauritius and South Africa rank among the middle third and particularly stand out among their African counterparts, while the other countries fall in the bottom third.

The great majority of African countries under review face the challenge of improving their readiness with regard to all enablers, even if performance levels vary across countries. The enabling factor where Africa's performance is the weakest compared to global counterparts is Human Capital. Based on the analysis, the top five performers for Human Capital in Africa are Mauritius, South Africa, Botswana, Tunisia and Ghana.

That said, Mauritius does stand out as an exception to the general rule which applies to Africa. The country has developed strengths in building a relatively strong technology and innovation ecosystem, an institutional framework among the best performing worldwide, stronger linkages to global value chains and attractiveness to investors. Still, human capital remains a challenge, even if, on a continental level, the country has the highest readiness score on this dimension.

In spite of a generally low readiness level, some countries in Africa demonstrate more readiness than others. As illustrated by the archetype analysis presented in figure 8, African countries can be clustered as followed:

LEADING COUNTRIES
Mauritius, South Africa, Egypt, Tunisia and Morocco.

NASCENT COUNTRIES
Nigeria, Kenya, Senegal, Zambia, Tanzania, Uganda, Ethiopia and Cameroon.

Botswana appears to be on the border of 'Leading countries', while Ghana is on the border of 'High potential countries'.

Leading countries are African leaders in manufacturing today that are also relatively well positioned for the 4IR due to their performance in the enabling factors, while Nascent countries have a limited current base and are not so well positioned for the 4IR because their performance in the enabling factors is weaker.

3.2 DETAILED ASSESSMENT ON EACH ENABLING FACTOR

The following sections present a more in-depth analysis of the assessment of each enabling factor.

3.2.1 Human capital

As previously stated in our readiness assessment, Africa's performance in human capital is a major concern and may represent one of the major roadblocks for the continent to benefit from the 4IR.

The World Economic Forum (WEF) defines human capital "as the knowledge and skills people possess that enable them to create value in the global economic system" (WEF, Global Human Capital Report, 2017). This definition of human capital was adopted by the African Development Bank (AfDB) in its Human Capital Strategy for Africa (2014-2018).

The following sub-sections focus on the specific needs and challenges that the 4IR in Africa faces with regard to education, skills and competencies where specific needs appear in the context of the 4IR.

EDUCATION IN THE ERA OF THE 4IR
While education systems are highly context-specific, consensus is emerging on key areas where actions need to be taken to have a relevant and responsive education ecosystem that can meet the needs of today's and tomorrow's labour market. Those are: early childhood education, future-ready curricula, digital fluency, robust and respected technical and vocational education, early exposure to the workplace and ongoing career guidance, a professionalised teaching workforce, openness to education innovation and Lifelong learning (WEF, Realizing Human Potential in the Fourth Industrial revolution, An Agenda for Leaders to shape the Future of Education, Gender and Work , 2017).

Africa's education system is far from embodying these characteristics as is explained in the following sections.

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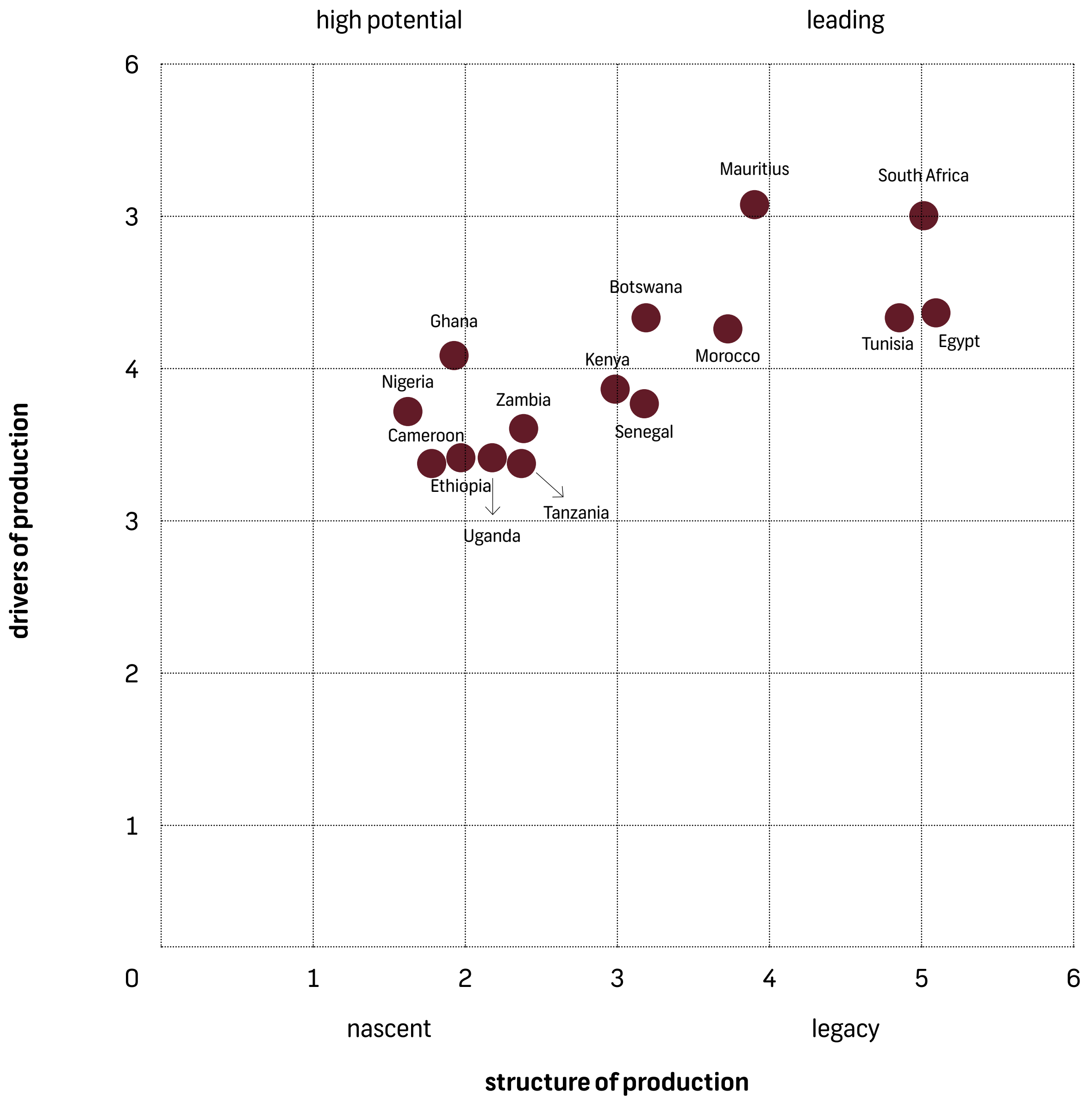
figure 08

Africa state of readiness for the 4IR: assessment results



NOTE Countries were plotted to archetypes based on their weighted Structure of Production and Drivers of Production scores. Given the evolving nature of readiness for the future of production, archetypes will likely resonate more strongly with countries at the extremes of the various archetypes. Similarly, countries that are positioned near the borders of other archetypes may have attributes of more than one archetype. The analysis has been performed for African countries for which data are available.

ADAPTED FROM
World Economic Forum (2018)

The importance of early childhood education and quality preschool in the development of beneficial cognitive and socio-behavioural skills, which are important for future learning abilities in the 4IR, have been well documented (World Bank, 2019). Globally, only half of all 3- to 6-year-olds have access to preschool education. In low-income countries this share is one-fifth (World Bank, 2019). In Malawi, less than 40% of 3- to 6-year-olds attend an early childhood education programme, while the share drops to 6% in Mali. In 2012, North America and Western Europe spent 8.8% of their education budgets on preschool education; in Sub-Saharan Africa the share allocated was only 0.3% (World Bank, 2019).

In primary and secondary education, issues of access and quality loom large in Africa: about 50 million children are not going to school. Africa is also the only region in the world where the number of out of school adolescents has risen in recent years, partly because of rapid population growth among the poorest, who also have the lowest access to education. Learning levels across Sub-Saharan Africa are very low: less than 15% of primary school students pass a minimum proficiency threshold in mathematics, while the proportion in reading is lower than 10% (World Bank, The Human capital Project in Africa, 2018). An international comparison of Education Quality made by Altinok et al. (2018)[18] shows that Asian countries seem to outperform countries from other regions at primary and secondary level, followed by North America and Europe. Latin America and the Caribbean and northern Africa are the next best performers, followed by Sub-Saharan Africa.

In addition, a future-ready education system must ensure that everyone has the basic digital skills to function in society as well as opportunities to gain intermediate skills that improve employment and enable more meaningful uses of technology. It encompasses providing children and young people at primary and secondary education level with early exposure to digital skills, computational thinking, skills needed to develop successful careers in the digital economy and creating multiple pathways for adults to build skills at different stages of life. The situation regarding those factors is not the same across Africa. In fact, while some countries provide children and young people with good access to computers and the internet at school (Egypt, Mauritius, Morocco, Rwanda), others do not perform as well (Angola, Ghana, Liberia, Niger, Sierra Leone, Sudan) (Figure 10 and Figure 11).

A future-oriented Technical and Vocational Education and Training (TVET) education ecosystem requires: access to well-developed and modern TVET qualifications; certification and credentialling systems based on agreed industry standards and the identified needs of both learners and employers and updated on a rolling basis to ensure continued relevance; and employer input into its design (WEF, 2017b).

Although there are significant positive efforts to strengthen them, the TVET systems in many African countries are characterised by under-resourced, obsolete or damaged infrastructure; inadequate inter-sectoral linkages; lack of labour management information systems; limited curricula and inadequate human resources[19]. As a result, on average, executives think that the quality of vocational training in Africa is low (WEF, 2018b).

In tertiary education, access and quality issues are also relevant. Currently, in Sub-Saharan Africa, the gross tertiary enrolment ratio is 9% while the world average is 37%; and this, even if African governments spend 20% of their budget on tertiary education while the world average is 22%[20]. Most of African universities have lower quality. More than half of the countries considered in the 4IR readiness assessment do not have a university ranked in QS World University Ranking 2018 out of 972 universities. Only Egypt and South Africa stand out, with, respectively, five and nine national universities appearing in this ranking (WEF, 2018b).

Moreover, there is an acute lack of STEM-graduate, scientists and engineers in Africa. Currently, African college graduates with a STEM degree represent a mere 2% of the continent's total university age population but are increasingly needed across a wide variety of industries (WEF, The Future of jobs and skills in Africa, 2017c). On average, executives think that scientists and engineers are hardly available in Africa. They also think that it is difficult

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figure 09

proportion of schools with access to computers for pedagogical purposes (%)

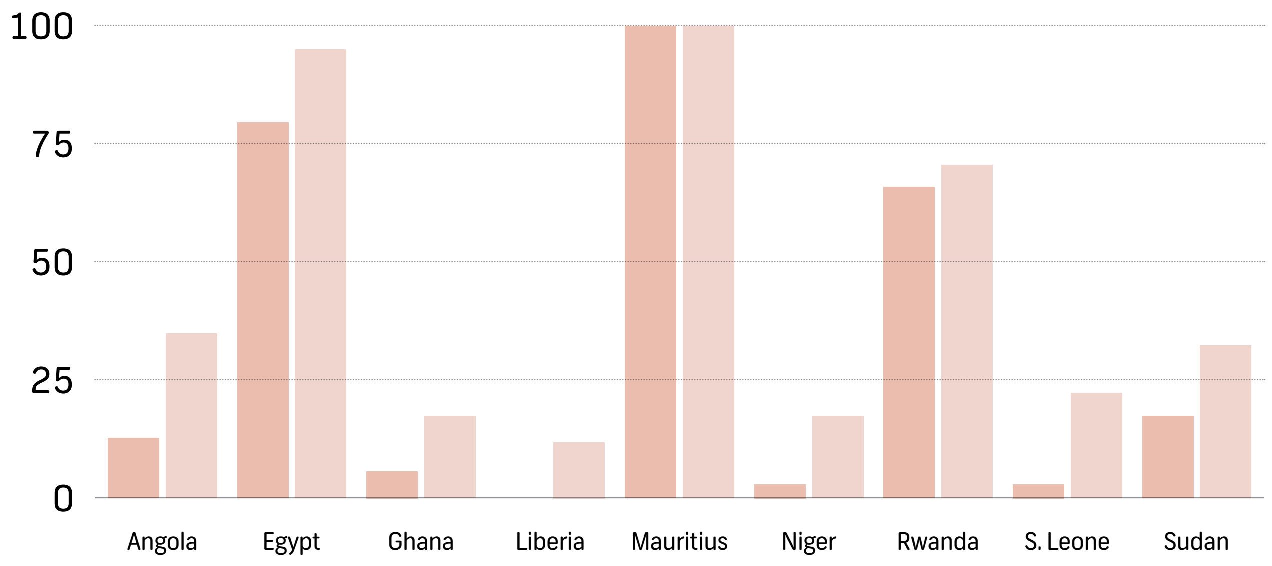

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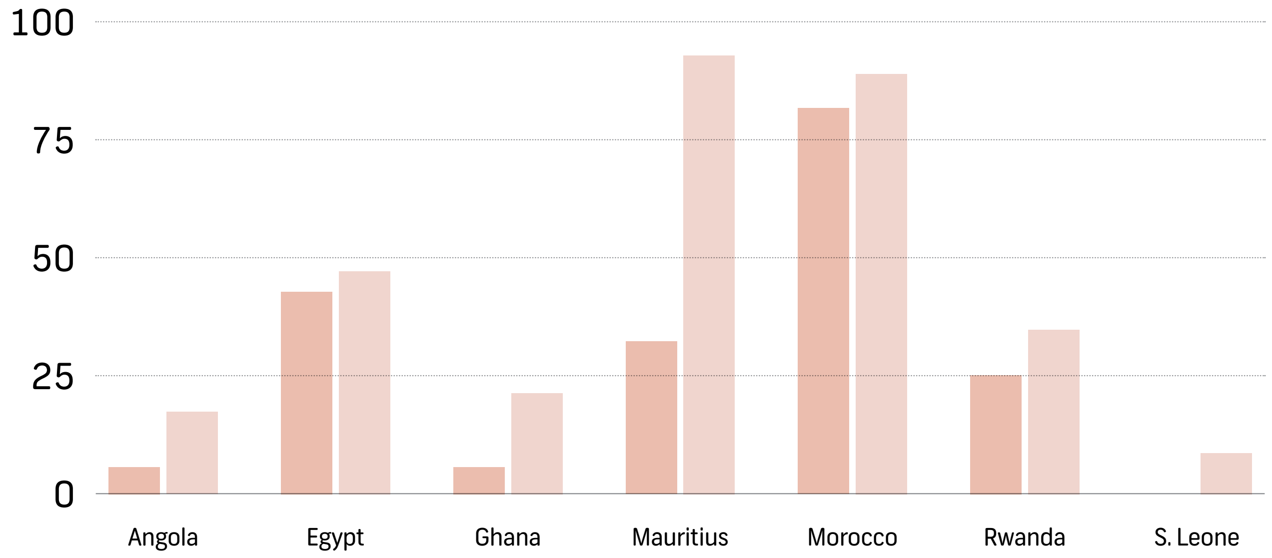
figure 10

proportion of schools with access to the internet for pedagogical purposes (%)



ADAPTED FROM
UNESCO Institute for Statistics (2019)

primary school seconday school

to attract talented people from abroad to Africa and retain talented people. (WEF, Readiness for the Future of Production Report 2018, 2018b).

Finally, the indicators on lifelong learning ecosystems are weaker in Africa compared to others. For example, on average, the unemployed do not benefit from a support system to reskill, it is more difficult to find high quality professional training services and companies invest less in training and employee development in Africa (WEF, 2018b).

SKILLS AND COMPETENCIES IN THE 4IR ERA

The skills and competencies needed to succeed in the 4IR are described by the WEF as "21st-Century Skills" (Soffel, 2016). They are a combination of: foundational literacies (literacy, numeracy, scientific literacy, ICT literacy, financial literacy, cultural and civic literacy), soft competencies (critical thinking/problem solving, creativity, communication, collaboration) and character quality (curiosity, initiative, persistence/grit, adaptability, leadership, social and cultural awareness).

As a result of the overall low quality of the education system, African countries' performance concerning foundational literacy is lower compared to others. For example, according to the United Nations Educational, Scientific and Cultural Organization (UNESCO), on average 61% of adults in Sub-Saharan Africa can read and write with understanding, one of the lowest adult literacy rates in the world. Adult literacy rates range from 19% in Mali to 90% in the Seychelles. Fourteen of the 22 countries in the world with literacy rates below 60% are in Sub-Saharan Africa. On average, the quality of maths and science education is the lowest in Africa (WEF, 2018b). In general, ICT illiteracy is still at a very high rate in Africa. An analysis of the WEF Future for Production data reveals that the active population in Africa possesses on average lower digital skills (WEF, 2018b). For example, in Sudan, less than 5% of the youth and adults can perform basic tasks with a computer, while in Morocco the proportion is generally less than 45% (figure 12).

Concerning soft skills, African countries' scores are lower on critical thinking in teaching (WEF, 2018b).

3.2.2 Access and diversity of financing

A fully-fledged 4IR in Africa will need to build on strong and sufficiently financed African businesses. This requires stable and liquid national and regional capital markets as well as an attractive environment for inward foreign direct investment.

In Africa, as in many parts of the world, the largest part of the business base is made up of micro, small and medium enterprises (MSMEs). Sub-Saharan Africa alone has 44 million MSMEs, with Nigeria accounting for 37 million. Overall, 97% of Sub-Saharan African enterprises are microenterprises, i.e. they have less than 10 employees.

More than half of Sub-Saharan African microenterprises (52%) and SMEs (54%) are to some extent, credit-constrained, which means that they have limited access to external financing or faced issues obtaining it in the past. The World Bank estimates that around 18% of MSME potential financing demand in Sub-Saharan Africa is not currently met[21].

Firms in Sub-Saharan Africa identify by a large margin access to finance as the key constraint in their business (23.6%), followed by electricity (13.6%), competition from the informal sector (11.3%) and political instability (10.3%). Across Africa, in 18 out of 47 surveyed countries, access to finance is the most significant obstacle to business, followed by political instability (eight countries) and electricity (seven countries)[22].

Overall, 85.2% of all firms in Sub-Saharan Africa, surveyed for the World Bank Enterprise Survey, have a bank account. However, when it comes to accessing debt finance for their business, on average only 21% have a line of credit. Consequently, only 20% of firms use banks to finance investments and therefore only 9.4% of investments in Sub-Saharan Africa are financed by debt through banks. A total of 74% of investments were financed internally without any assistance from equity providers or financial intermediaries, which indicates the presence of severe barriers when growing and scaling up businesses.

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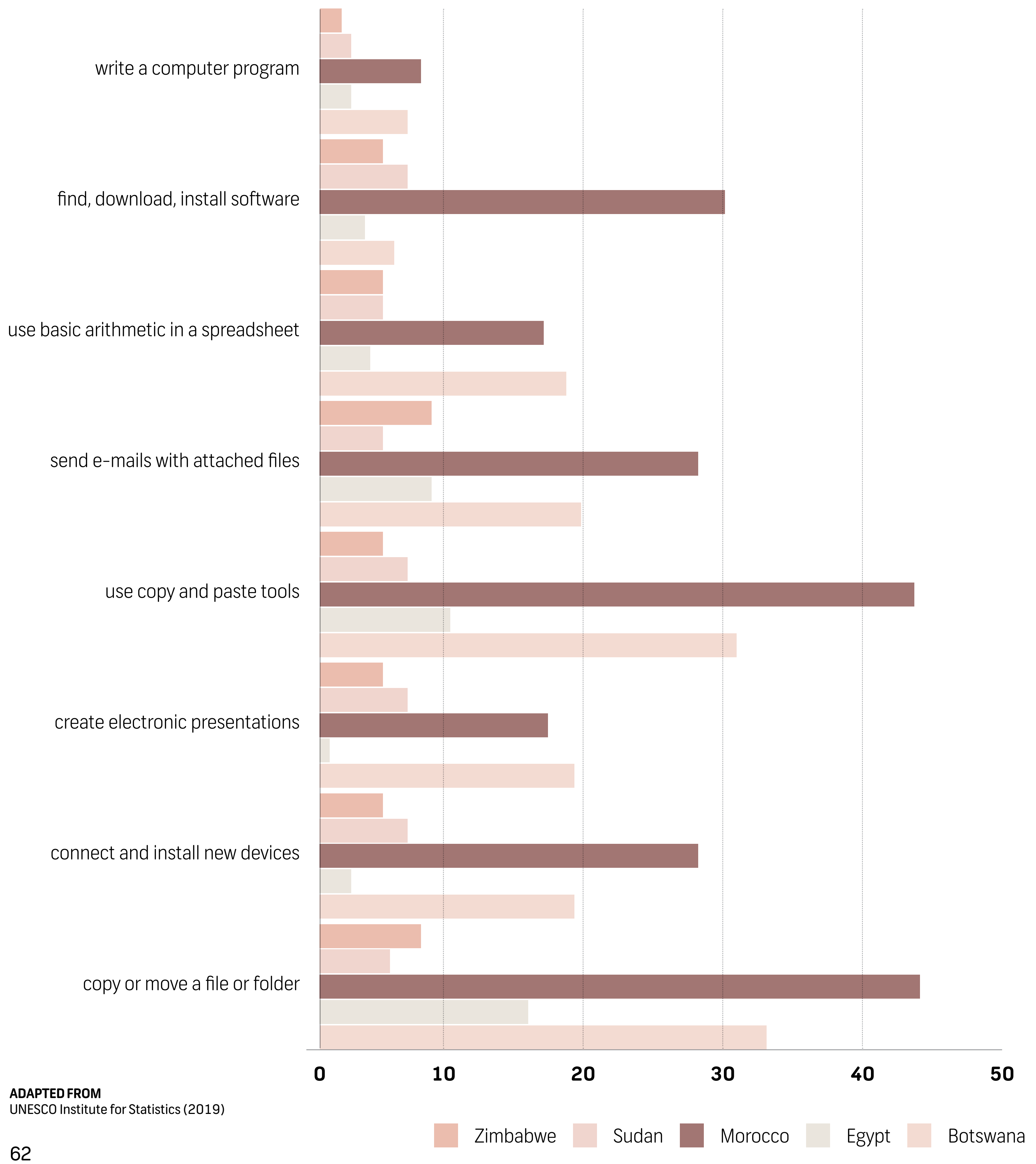
figure 11

proportion of youth/adults with ICT skills, by type of skill (%)



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UNESCO Institute for Statistics (2019)

The currently available financial sector support to MSMEs, but also to individuals, is dominated by banks. Moreover, stock markets and market instruments such as bonds are under-developed in most of Africa, and mostly not relevant to MSMEs[23]. Due to the low competition, as well as the high lending and low deposit rates, some African countries still have double-digit interest margins for loans. This is also partly caused by attractive high-yielding government bonds which crowd out lending to SMEs. These high yielding government bonds are more attractive to banks than high risk SME lending. SME lending often only happens with substantial portfolio guarantees from International Financial Institutions. Nevertheless, some African countries have seen interest rate improvements in the last two decades[24]. In addition to crowding out by government bonds, there are problems with credit risk assessments due to the poorly developed public registries and problems for African citizens to prove ownership of their assets. Information asymmetry is notably leading to high costs of capital.

Business angels, wealthy individuals who support projects with their own savings, are not widespread in Africa, notably in French-speaking Africa, for several reasons (McKenson, 2016). First, there is no regulatory framework for this type of investor. Also, diplomas are favoured over experience, which makes potential investors very cautious in their choices given that many entrepreneurs have a low level of education and/or training in entrepreneurship (BafD, 2011). The number of people with sufficient levels of wealth to become business angels is also limited. On top of this, potential business angels often choose to invest their money in developed countries, where the return on investment is more attractive than in Sub-Saharan Africa. Recently, initiatives such as Ivoire Business Angels and the Cameroon Angels Network have emerged (Kenguéléwa, 2016).

Africa also faces low rates of foreign direct investment, which currently only accounts for 2.9% of the global share of global inward foreign direct investment estimated to represent around $41.8 billion in 2017. UNCTAD data, displayed in Figure 12, shows that top host countries, in terms of US$ value of inflows, are Egypt ($7.4billion), Ethiopia ($3.6 billion), Nigeria ($3.5 billion), Ghana ($3.3 billion), and Morocco ($2.7 billion). Key investors in 2017, based on the total Foreign Direct Investment (FDI) stock, were the United States ($57 billion), the United Kingdom ($55 billion), France ($49 billion), China ($49 billion) and South Africa ($24 billion). The most significant change since 2011 has been significant volumes of investment from China, which more than doubled from $16billion in 2011 to $40 billion in 2017. Italy and Hong Kong have also significantly increased their share of investment in the region.

Moreover, in recent years FDI inflows dropped both in terms of absolute numbers, as well as in terms of global shares. (see Figure 13).

Key 4IR sectors such as motor vehicles and transport equipment; transport, storage and communications; and business services make up a relatively small share of greenfield FDI investment. However, the electricity, gas and water service sector accounts for more than a third of all FDI.

On a more positive note, FDI inflows into 4IR-relevant technologies are taking place, for example in Nigeria, Kenya and Tanzania. In Nigeria, technology start-ups are receiving support from venture capitalists. The country is also witnessing sustained Chinese investments into the manufacturing sector and from US technology companies such as Facebook or Uber. Facebook and Uber are also investing in Tanzania. Furthermore, US firms such as Microsoft and Oracle are also responsible for increasing ICT investments in Kenya[25].

With regard to SMEs and start-up financing, there is also a growing number of private equity funds specialising in SME financing that have emerged, particularly in eastern, western and southern Africa (e.g. Aureos Capital Funds, Business Partners International Kenya SME Fund) (Beck & Cull, 2014). The positive experiences of these funds then help to attract donors and private investors. The availability of private equity can have positive spill-over effects on the managerial skills of the companies that it finances, which fills the gap in their administrative and financial management (BafD, 2011). Private equity funds

f

figure 12

inward FDI Africa 2017

Flows by range

- above $3.0bn
- $2.0 to $2.9b
- $1.0 to $1.9bn
- $0.5 to $0.9bn
- below $0.5bn

2017 inflows

41.8bn

2017 decrease

-21.5%

share in world

2.9%

Top 5 host economies

economy $ value of inflows
2017 % change

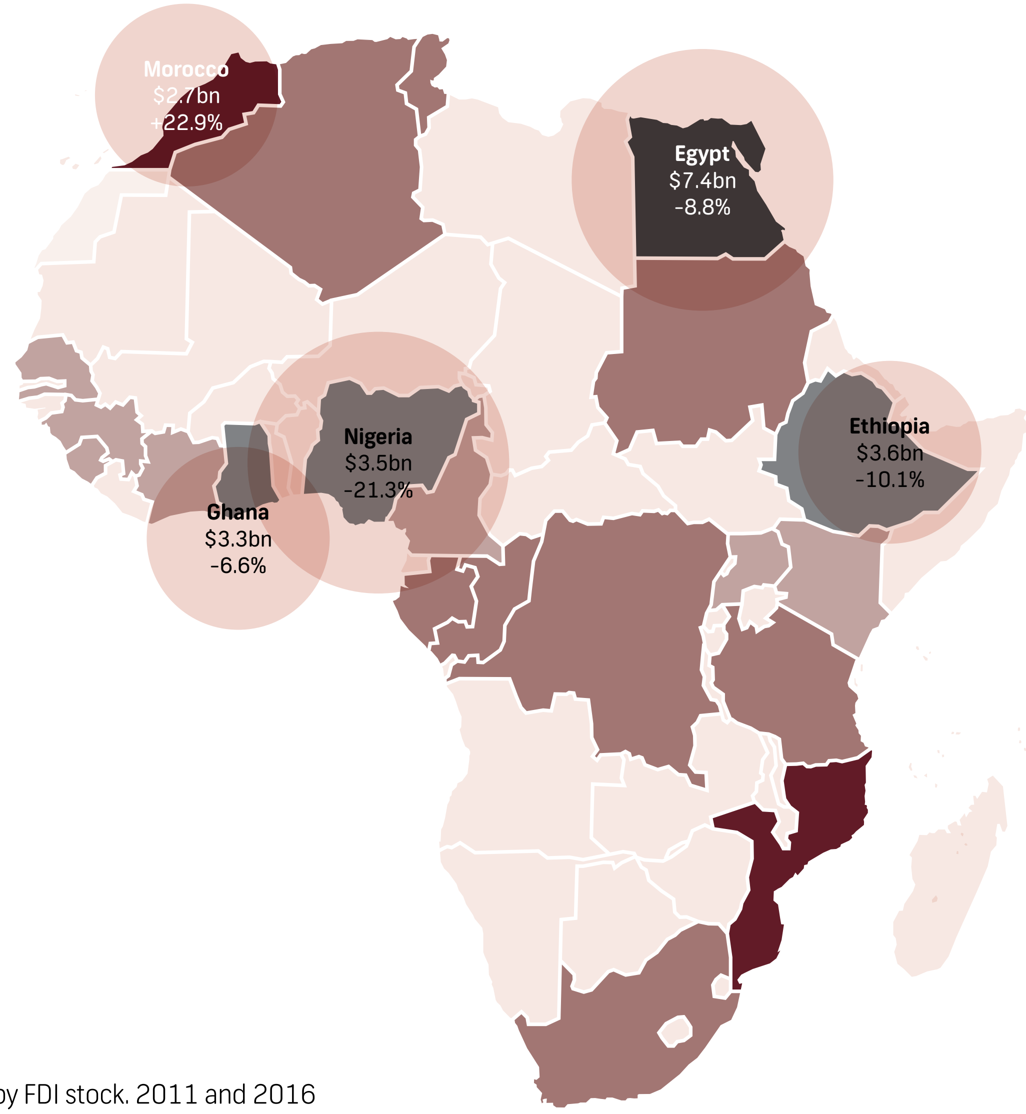
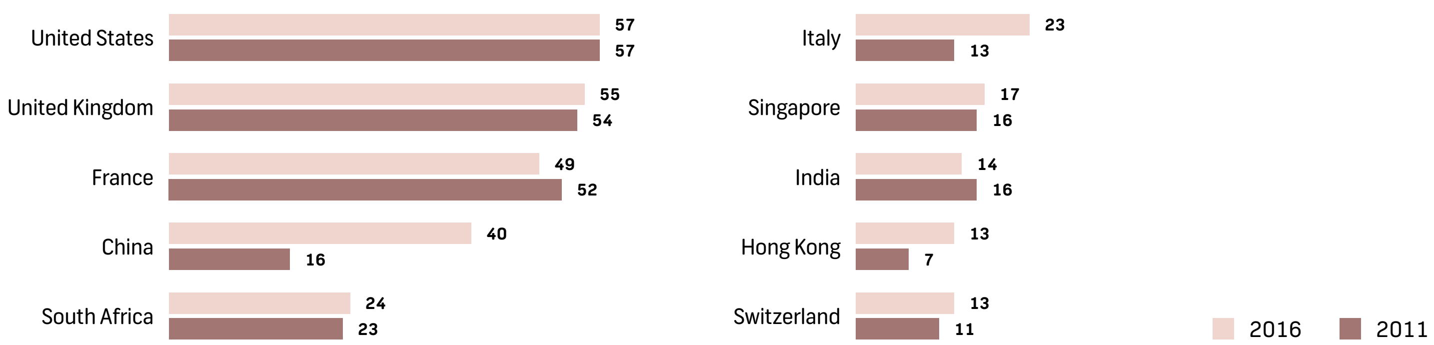


figure 12a

top 10 investor economies by FDI stock. 2011 and 2016 (billions of dollars)



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UNCTAD. (2018). FDI Flows Africa **Note** *The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Final boundary between Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.*

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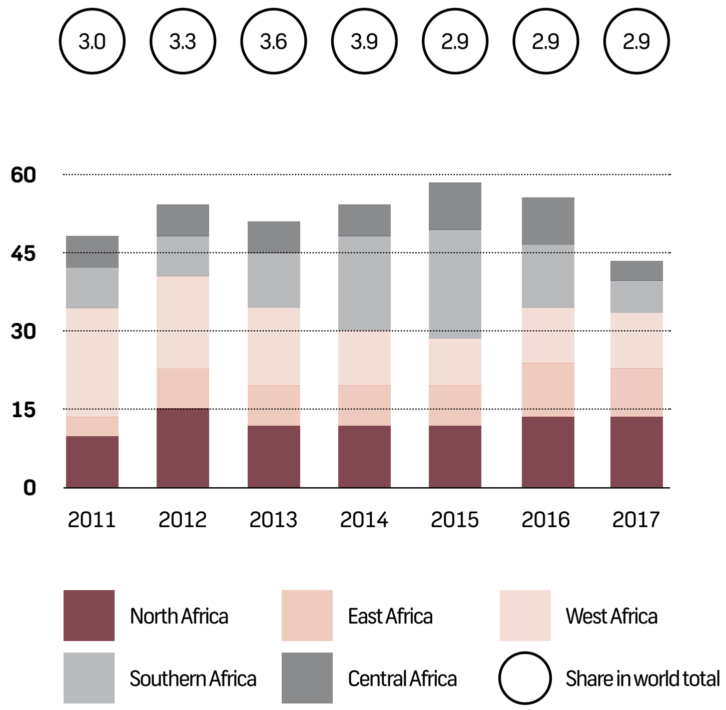
figure 13

FDI inflows Africa & announced greenfield FDI projects 2017

FDI inflows, 2011–2017
(billions of US dollars and per cent)



Announced greenfield FDI projects by industry, 2016–2017
(millions of US dollars and per cent)

Sector/Industry	Africa as destination		Africa as investor	
	2016	2017	2016	2017
Total	**94 039**	**85 305**	**11 772**	**5 796**
Primary	**3 713**	**10 574**	**-**	**-**
Mining, quarrying + petroleum	3 713	10 574	-	-
Manufacturing	**19 357**	**21 060**	**5 991**	**2 907**
Textiles, cloathing and leather	1 077	3 998	46	91
Chemicals + chemicals products	5 107	5 664	4 596	1 194
Non-metallic mineral products	1 144	3 036	576	314
Motor vehicles and other transport equipment	2 754	1 506	28	40
Services	**70 969**	**53 671**	**5 782**	**2 889**
Electricity, gas and water	15 601	37 485	156	156
Construction	16 732	6 488	2 542	204
Transport, storage and com-munications	12 872	3 215	698	452
Business services	22 734	3 063	1 030	829

ADAPTED FROM
UNCTAD. (2018). FDI Flows Africa original map

mainly finance companies with high innovation potential: more than two thirds of the companies they finance have introduced new services and/or products.

Mobile money services now flourish in countries where dominant mobile networks were able to exploit largely unbanked populations[26] while, in countries like South Africa and Nigeria, where populations were significantly banked, the take-up of mobile money services has been much slower.

Recently adopted financial and telecom regulations have been key to financial inclusion enabled by mobile money platforms. For example, the flourishing of mobile money in Uganda is attributed to non-binding regulatory guidelines. For instance, despite the country introducing mobile money guidelines in 2013, the guidelines are not binding. However, in countries such as South Africa and Nigeria, where the regulations are more stringent, the scope of mobile operators has been limited and the development of mobile money is modest. For example, according to RIA After Access survey, Nigeria, despite its rhetorical commitment to mobile money and the wish to emulate Kenya, has the lowest mobile money take-up at only 1%[27].

There is evidence of the merging of traditional banking services with wider FinTech services and applications. A number of banks have invested in, or acquired, FinTech start-ups or businesses. Banks are also collaborating with peer-to-peer lenders and innovative payment systems. For instance, third-party mobile wallets are being used by established banks. South Africa has also seen the advent of the FinTech bank where three entities, relying on their sophisticated technology platforms, have applied for and been granted banking licences.

3.2.3 Governance, policy and regulations

The term governance (which includes government) refers to the expanded process of decision- and rule-making in increasingly complex economies and societies. This includes formal state functions and delegated state authority to specialised regulatory institutions, coupled with more participatory policy formulation processes that draw on expertise and experience outside the bureaucratic state in the private sector and civil society in order to optimise outcomes.

The analysis of good governance practices encompasses themes such as (i) voice and accountability; (ii) political stability and absence of violence; (iii) government effectiveness; (iv) regulatory quality; (v) rule of law; and (vi) control of corruption[28].

In the context of Africa, the level of quality of governance and institutions affects peace, stability, rule of law and prospects for economic development.

According to the Ibrahim Index of African Governance (IIAG)[29] over the past decade, public governance in Africa has achieved a relatively moderate upward course, largely propelled by accomplishments in categories such as gender, health and infrastructure. The 2018 IIAG shows that, in the last decade, roughly three out of four Africans live in countries with improved public governance. In the last ten years, 34 out of 54 African countries have witnessed improvements in overall governance. In particular, Côte d'Ivoire, Morocco, and Kenya have, in the last decade, achieved significant accomplishments in this regard, stepping up from 41st, 25th, and 19th place out of 54 countries to 22nd, 15th and 11th respectively[30].

Developed e-government systems and practices indicate the presence of good governance systems in indices such as IIAG. According to the UN E-Government Survey 2018, Africa lags behind in e-government development compared to the rest of the world. While the share of African countries with an improved E-Government Development Index (EGDI) grew in 2018, this movement has mainly been led from low to middle EGDI-level groups. The number of African countries within the High-EGDI level group remains at the modest count of six: Ghana, Mauritius, Morocco, Seychelles, South Africa and Tunisia[31].

Emerging technologies are difficult to govern and regulate due to their innate disruptiveness and novelty. This process is even more difficult in countries where traditional governance systems are fragile. The following paragraphs identify and explain some of the most significant challenges that Africa will face in this field.

To begin with, there is no unified approach to data protection in Africa, often making it difficult for organisations to adapt and meet disparate requirements across the continent. In 2014, however, the African Union (AU) adopted the *Convention on Cyber Security and Personal Data Protection*[32]. The document provides guidance for African countries on how to address issues from cybercrime to personal data protection and e-commerce, with the intention of promoting awareness of cyber risks and challenges and to coordinate improved policies and regulation for member states. However, only nine out of 55 AU member states have signed the convention. In addition, only 19 African countries have, to date, enacted data protection and privacy laws[33], while six have laws in draft stages[34]. The remaining countries either have no legislation or have no data available[35].

Where African personal data protection laws do exist, they restrict the transfer of personal data to third parties located outside the country concerned unless the data is handled in a manner that complies with relevant legislation. In addition to legislative differences, differences in the level of capacity and efficiency of data protection authorities on the continent pose a compliance challenge for organisations[36] and could expose African users to global risk.

Despite the significant benefits to companies, consumers and national economies that arise from the ability of organisations to share data across borders easily, dozens of countries — across every stage of development — have set up barriers to cross-border data flows. This includes, for instance, data residency requirements that confine data within a country's borders, a concept known as 'data localisation[37]'. Data localisation can be explicitly required by law or can result from other restrictive policies that make it onerous to transfer data legally, such as requiring companies to store a copy of the data locally, requiring companies to process data locally and mandating individual or government consent for data transfers. For example, in 2014, Nigeria passed the 'Guidelines for Nigerian Content Development in Information and Communications Technology (ICT)'[38]. This document introduced restrictions on cross-border data flows. It also required that all subscriber, government and consumer data be stored locally[39]. Mauritius and South Africa may be inadvertently restricting global trade as will a number of other countries undertaking harmonisation of data protection laws that have localisation effects[40].

Cyber and information security is already a major challenge in Africa and issues related to it are more acute in the context of the 4IR. Building good governance and regulatory models in cybersecurity is especially important in areas such as health, infrastructure, transport and FinTech.

Given the recent uptick in cybercrime, addressing cybercrime and information security policy risks must be a priority for African policy makers. Cybercrime cost the continent as a whole an estimated US$3.5 billion in 2017. The Nigerian economy, for instance, is said to have suffered US$650 million in losses from cybercrime in the same year [41].

With non-existent or outdated legal systems, many countries are not up to the task of prosecuting cybercrime or carrying out efficient enforcement of cybercrime laws. Article 24 of the Africa Union Convention stipulates that states have to design and implement a national cybersecurity policy. Today, however, only 28 African countries have legislation in place and 11 are still at a draft stage[42].

African countries have not invested in building trust and resilience through the development of their national cybersecurity infrastructure and skills development for a fully-fledged cybersecurity workforce. This vulnerability in data governance is aggravated by the added applications and products that are typically rendered accessible by the 4IR. Cybersecurity and data protection governance are often used as indicators in global competitiveness rankings and are suggestive of how ready a country may be for the 4IR. Thus, inadequate cybersecurity and data protection governance can be a restraint to full participation in the 4IR. At the same time, the need for data localisation and data sovereignty continue to surface in policy makers' speeches and written statements. This suggests that the challenge for national data governance is twofold:

providing for adequate cybersecurity and data protection that enhance the country's trade and investment standing; while securing citizen's data domestically. To ensure that such initiatives are not abused for the purposes of unwarranted surveillance or political control, it is important that legal frameworks underpinning data governance take into account a human rights dimension.

Artificial Intelligence systems are mostly cloud services or designed to interface with them. AI can be readily accessed as an application in the cloud (e.g. Amazon SageMaker) or cloud infrastructure and platforms can be used to roll out AI systems. The agility with which AI can be deployed is currently dependent on the big cloud providers – Amazon Web Services, Microsoft Azure and Google Cloud. While offering almost instantaneous and flexible service with significant cost savings, the use of these services poses regulatory and data governance challenges.

Computer systems that run AI, Big Data analytics and machine learning, can, like humans, have biases and human biases may also be transferred to systems. As systems increasingly make decisions that have an impact on human lives, it must be ensured that these decisions are fair and just. This will involve making sure that human biases are not programmed into systems and giving systems the rules and correct information to make fairer decisions. It also points to the need for a human layer to exist around automated decision-making to feed systems data and rules to make fairer decisions but also to provide human oversight over automated decision-making.

When an automated decision-making system makes a decision that has a significant effect on someone, that person may wish to know the basis on which that decision was made. Individuals' rights under data protection regimes as well as their rights to be treated equally and fairly makes accountability and transparency of automated systems an important factor, especially in the development of, or the implementation of, data protection legislation and regulation.

Having mechanisms for accountability and transparency is not just beneficial for individual rights. As AI is increasingly used in decision-making, the chances that automated decisions can cause loss of and damage to life and property increase. Explaining automated decisions will become increasingly important to civil and criminal liability involving decisions made by automated decision-making systems. At the governance level, employing AI to assist in decision-making and understanding why decisions have been made is important. At a systems level, explainable systems make them easier to fix when bugs arise, easier to upgrade and afford more ownership of the system. A good governance example in this regard is the EU's General Data Protection Regulation (GDPR) that requires companies to be able to explain how algorithms that use the personal data of customers function and make decisions. Such regulation does not exist in Africa.

As the 4IR evolves, the landscape of taxation is shifting drastically. Dominant platforms, such as Google, Amazon, Facebook and Apple, have significant economic presence in national territories, yet their contribution to tax revenue is often negligible. While traditional tax systems have struggled to find ways to extract value from global companies, various proposals in diverse regions (from the EU to the Middle East, Asia and Africa) have attempted to address this issue. Some policy makers have threatened to tax big technology companies to support struggling broadcasting industries[43], while in Africa an increasing number of countries have implemented taxes and other content restrictions ostensibly to protect the revenues of incumbent operators (e.g. Zambia and Kenya).

It is clear that African governments need to satisfy their citizens with access to basic commodities (food) whilst at the same time developing cross-border trade and finance. Yet, this needs to be done while not creating disincentives for investment and adoption of new services that enable greater economic and social inclusion. Accordingly, some analysts have recommended that governments "propose a tax-subsidy scheme to minimize the negative effects of the fourth industrial revolution"[44]. While increases in taxation on stakeholders utilising AI and automation in their business models are likely, the extent of such taxation remains unclear.

Regulatory harmonisation is essential for the integration of markets together with common online payment systems and cross-border trade facilitation and standardised cross-border taxation and duties. While mobile money and other FinTech innovation have resulted in financial inclusion, financial regulation has traditionally constrained financial inclusion and various FinTech innovations. Ensuring consumer protection while enabling innovation are keys to economic development and inclusion. Harmonisation of such enabling environments is essential for creating viable markets not only for investment but to sustain local innovation and business.

A good example of regional collaboration on the continent is the Northern Corridor initiative[45]. In 2013, the presidents of Uganda, Rwanda, Kenya and South Sudan decided to include ICT as one of the strategic areas for facilitating integration within the region under this initiative. It specifically looked at implementing projects in ICT policy, infrastructure implementation and broadband connectivity; cybersecurity and ICT skills and human capital development. The impact of such an initiative, however, needs to be closely examined and analysed. Five years on, other than Kenya, where internet penetration stabilised below 30% in 2018, internet penetration in these countries remains dismally low. At 9% in 2017, Rwanda had the lowest internet penetration rate of the 10 countries surveyed in the RIA After Access survey and Uganda only 13% in 2018, far below the 20% critical mass believed necessary for network effects of broadband to result in economic growth.

3.2.4 Entrepreneurial and innovation support ecosystems

Innovation is a key enabler for the 4IR and is the driving force behind any industrial transformation. In emerging economies, small and medium-sized enterprises (SMEs) and start-ups are the backbone and important sources of innovation. Africa's entrepreneurship and innovation ecosystem has been thriving for the past decade thanks to the development of incubators and accelerators, which have an increasing focus on technology.

Research carried out by GSMA[46] shows that, since 2016, the number of active technology hubs across Africa has grown by over 50%: from 314 in 2016 to 442 in 2018[47](see Figure 14).

According to the latest mapping done by GSMA, five countries (South Africa, Kenya, Nigeria, Egypt and Morocco) host the highest number of hubs (almost 50% of the tech hubs present in Africa). The fastest growing ecosystems in Africa, based on the number of technology hubs created per year, are: the Democratic Republic of Congo, Zambia, Côte d'Ivoire, Togo and Nigeria. The top five ecosystem cities by number of active hubs are Lagos (Nigeria), Cape Town (South Africa), Nairobi (Kenya), Cairo (Egypt) and Accra (Ghana). Africa's technology hub community is still young, as illustrated by the fact that the average age of active hubs is five years old.

Many hubs are linked up through networks. Afrilabs is the largest such network of African innovation ecosystem stakeholders, bringing together 150 innovation centres from across 40 African countries.

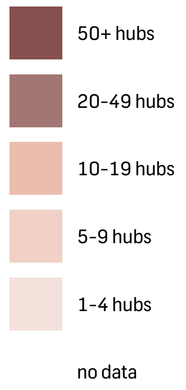
Despite the recent growth, the number of technology hubs in Africa is still insufficient. Moreover, the existing technology hubs often lack specialised knowledge and collaboration with other hubs, academic centres of innovation and the private sector, which would favour cross-pollination of ideas. Yet, according to the World Bank, multi-stakeholder ecosystems have better chances to succeed and develop than networks created and led by governments, the private sector or academia alone.

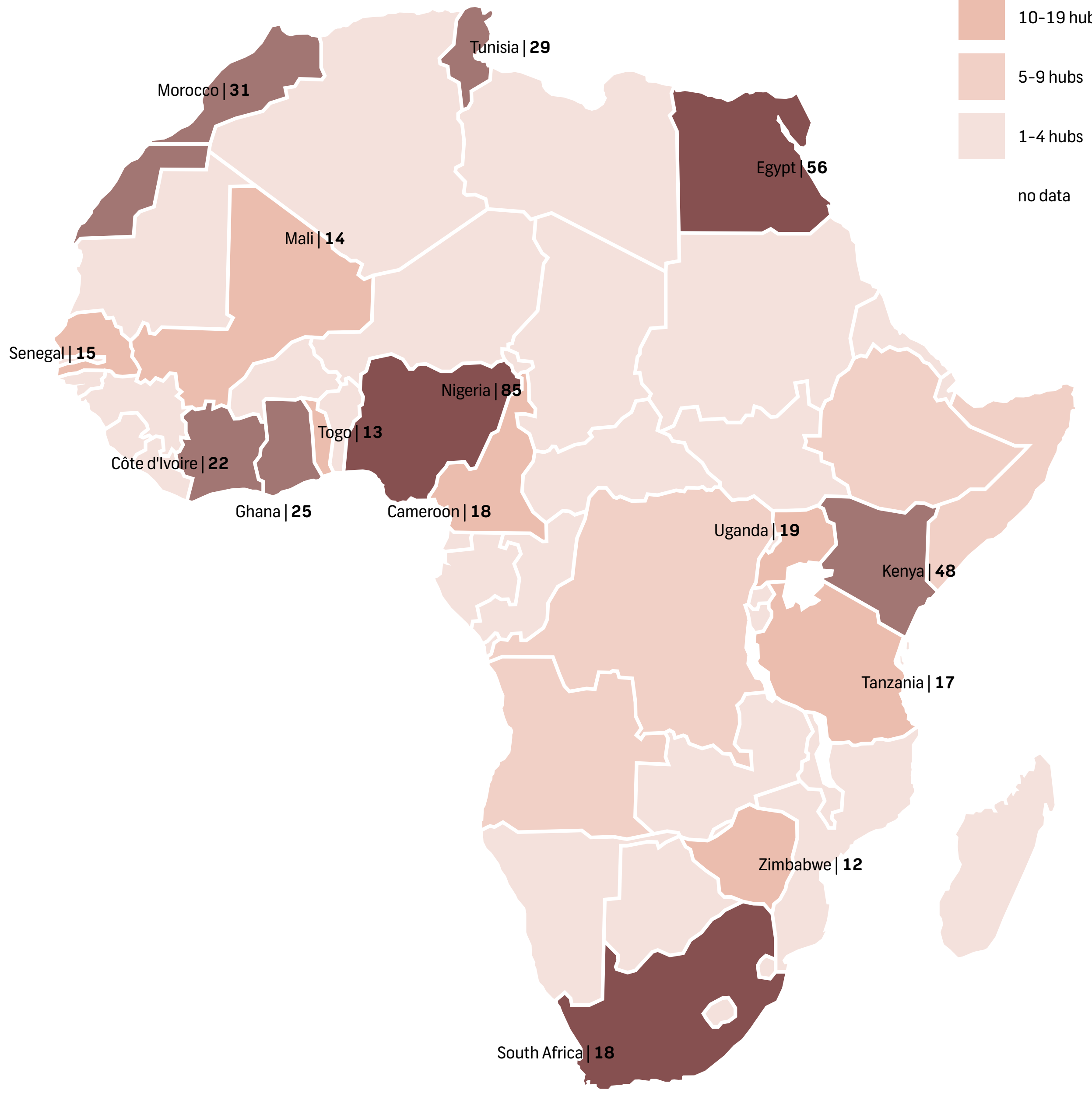
The dynamism of African technology hubs is weakened by the unsustainable business and economic models. In fact, many hubs remain fragile and most are not financially self-sustainable. They therefore mainly rely on grant funding from development and international donor partners. GSMA 2018 mapping reveals that over 50% of all hubs resort to public or corporate partnerships.

Sub-Saharan Africa is generally behind in terms of entrepreneurship development and support systems, especially because of the use of older technology, low

figure 14

ecosystem accelerators in Africa - Tech Hubs Landscape 2019





ADAPTED FROM
GSMA

internet speed and access (except for Kenya and South Africa)[48] and the lack of appropriate business skills.

French-speaking countries tend to have more difficulties boosting their entrepreneurship ecosystems because of the language gap: their lack of English fluency limits their market scope, their partnership opportunities and their ability to build their skills (as most of the online content is in English).

The Fourth Industrial Revolution in Africa will rely on a generalised knowledge and technology transfer and absorption, which includes a number of activities. In the industrial sector, it involves learning how to operate, maintain and repair machines, implementing minor innovations, designing and developing new products and processes, etc. In the research and academic sector, it refers to the formal transfer of skills, knowledge, ideas, know-how and technology resulting from university research to industry and their commercialisation as new products and services. In all instances, technology transfer also relates to organisational and managerial arrangements, especially when it comes to the 'acquisition capability', i.e. "a minimum level of domestic institutional and industrial capacity to enable late starters to take advantage of the potential for catching up [...] [depending] on public and private competence: infrastructure, education, the financial system and the quality of government institutions"[49].

The United Nations Framework Convention on Climate Change (UNFCCC) considers that technology transfer capacity must recognise and be pegged to the following capabilities[50]:

- Ability to utilise/manage imported proprietary hardware;
- Comprehensive understanding of imported proprietary technology involving the ability to alter, improve or otherwise retrofit the technology for local conditions or to bypass a problem without recourse to the supplier;
- Ability to originate technology at all levels, research and development, bench scaling, piloting and commercial transfer;
- Ability to influence global thinking on local technology and foreign technology development programmes – this being the most superior capability.

Sub-Saharan Africa has demonstrated the widest technology gap compared to other developing regions[51]. And even though north Asian and Middle Eastern countries had approximately the same economic starting point in the 1960s, their development patterns have been quite different. Today, Middle Eastern and Asian countries foster fast-paced economies and host a number of high-tech companies that grew exponentially very quickly. This contrasting development is due, among other reasons (such as economic and educational policies), to a limited ability to absorb external knowledge to fill the technology gap.

Universities are increasingly considered as engines of innovation through their technology transfer offices[52]. South Africa is the most advanced African country in this regard: of the 24 institutions (higher education institutions and Science Councils) surveyed, 23 indicated that they have a dedicated office of technology transfer or are members of a regional office[53]. Between 2011 and 2014, an average of 100 new technologies were annually added to the portfolio each year. However, the rest of the continent is lagging behind mainly as a result of a lack of resources, capacities, incentives and funding: technology transfer is capital intensive and mainly profits the licensee rather than the institution itself[54]. With the social and economic benefits being proven, technology transfer now requires academia to shift its research approach: beyond the sole publication, it ought to prioritise technology transfer as a core activity, by identifying market gaps, harnessing institutional skills and understanding the needs of a population.

Still, a clear set of public policies, guidelines and incentives is lacking, hindering the prospects for knowledge and technology transfer[55]. Technology licensing and the development of start-ups/joint ventures was not common due to the absence of protection, ownership and transfer of publicly funded research protocols.

Another issue is public funding. In fact, the amount dedicated to research and development in developing countries is significantly lower than in developed countries. South Africa is the only African country listed in the top 40 largest research and development spenders in the world, as it provides 44% of the investment needed while industry funds 41%[56]. The other countries are lagging behind: they primarily focus on products and processes to improve the state of the local community as they are often plagued with famine, drought, scarce potable water supplies, diseases, corruption and violence. Besides, focusing on social and infrastructure programmes enable a better access to capital through taxation and donor cooperation[57]. This has influenced the way governments invest and shape their policy: industry is mainly owned by the state, limiting relative technology transfers. There is no policy on science or technology, which also hinders the capacity to develop and implement appropriate policy support instruments.

In addition to public funding, the private sector ought to support R&D efforts. However, the absence of a defined mechanism to collaborate leaves the resources fragmented and leads to inefficiency and missed networking opportunities.

Finally, very few companies are investing in emerging technologies and are prone to embracing risky and disruptive business ideas. On average, executives also think that government purchasing decisions foster innovation in emerging technologies to a modest extent (WEF, 2018b).

3.2.5 Infrastructure

The following section outlines the current status of several areas of infrastructure relevant to the 4IR in Africa. Each subsection is dedicated to a type of infrastructure, as follows: ICT infrastructure (internet adoption and penetration; mobile and broadband internet); urban infrastructure and potential for Smart City development; energy infrastructure (in particular: potential for renewable energy – climate change considerations, fuel efficiency and energy storage).

ICT infrastructure

Essential information and communication technologies (ICTs) are positively associated with development[58]. Much has been written about Africa's ICT infrastructure and recent reports continue to highlight the low levels of fixed phone line subscriptions. A recent study showed that, on average, there are less than three landlines per 100 persons across Africa and, in line with that, there are sparse broadband services that serve a low proportion of individuals. There are other factors related to fixed lines too. The ageing fixed-line networks that do exist are expensive to maintain, making it difficult for the state-owned corporations to do so in a cost-neutral or profitable manner[59].

By contrast, mobile connectivity is widespread. Data from the World Bank[60] show that cell phone subscriptions are highly prevalent, ranging from approximately 12 subscriptions per 100 people (South Sudan) to 161 subscriptions per 100 people in South Africa. Cell phone subscriptions are most prevalent in southern Africa and in the Maghreb, as well as in the major countries of eastern Africa. This is in line with the presence of data centres on the continent[61]. Cell phone subscription is similarly positively linked with development in Africa[62] and some studies suggest that developing countries are more mobile than their developed counterparts due to the surge in cell phone subscriptions[63].

Urban infrastructure and potential for the development of Smart Cities

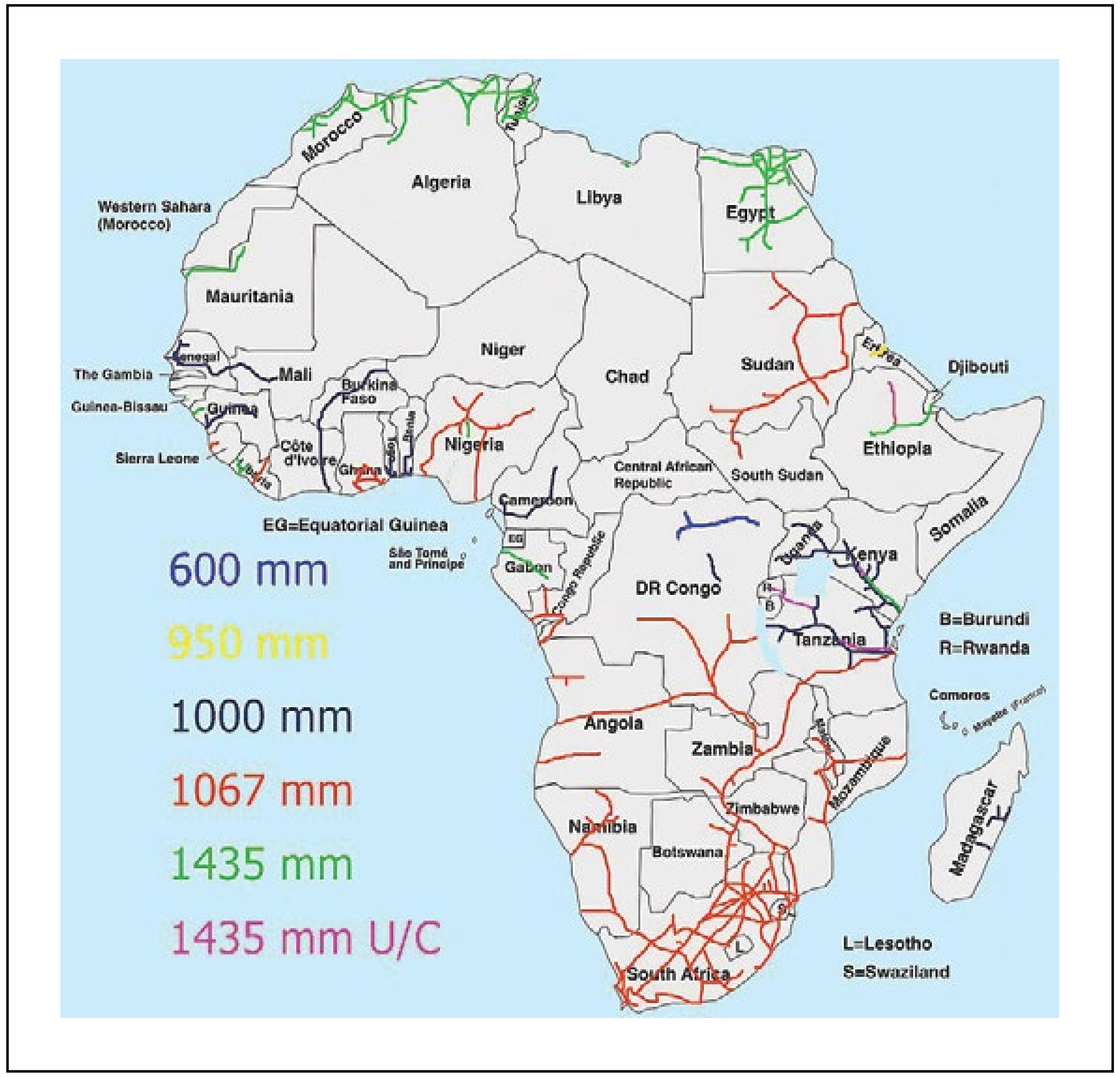
Africa's infrastructure deficit is well-documented in the literature and African cities are short of built capital of all kinds, from housing provision to road and rail connectivity, but also have limited sanitation and access to electricity[64].

Infrastructure is broadly regarded as a basic requirement for ensuring a globally competitive economy. However, recent reports show that the quality of infrastructure in Africa is stagnating[65]. Indeed, figures from the World Economic Forum in 2017 show that Africa's performance in transport infrastructure quality had dropped 6% over the preceding decade[66]. In addition, recent Bloomberg data[67] show the varied nature of rail connectivity across the continent, with notable density in southern Africa and increasing sparsity further north (see figure 15).

f

figure 15

rail connectivity in Africa



SOURCE
Wikipedia
NOTE. *colours represent different railway gauges*

Despite these factors, there is acknowledged potential for implementing Smart Cities across the continent. Along with rapid urbanisation and increasing efforts to secure better connectivity, a 2016 report from Deloitte noted that the 'booming' young population of Africa is a significant enabler of doing so, while in many cases there is no need to upgrade existing fixed-line ICT infrastructure, which is sparse[68].

As new cities appear on the African continent, a number of Smart City projects are emerging. Examples include the planned Konza Technological City (Kenya), which aims to be a world-class technology hub with a mix of businesses, workers, residents and urban amenities with an integrated urban ICT network to support the delivery and management of connected urban services[69]. Other examples include Eko Atlantic (Nigeria), whose roots lie in a land reclamation project. The development of Eko Atlantic aims to address a shortage of prime real estate and will provide a new financial headquarters for Nigeria while being a low carbon city[70].

Energy infrastructure

The inadequacy of power supply in Africa is also widely documented. A recent report highlighted that energy supply quality had dropped 3% over the preceding decade. The report also noted that, in many cases, energy supply was barely keeping up with demand[71].

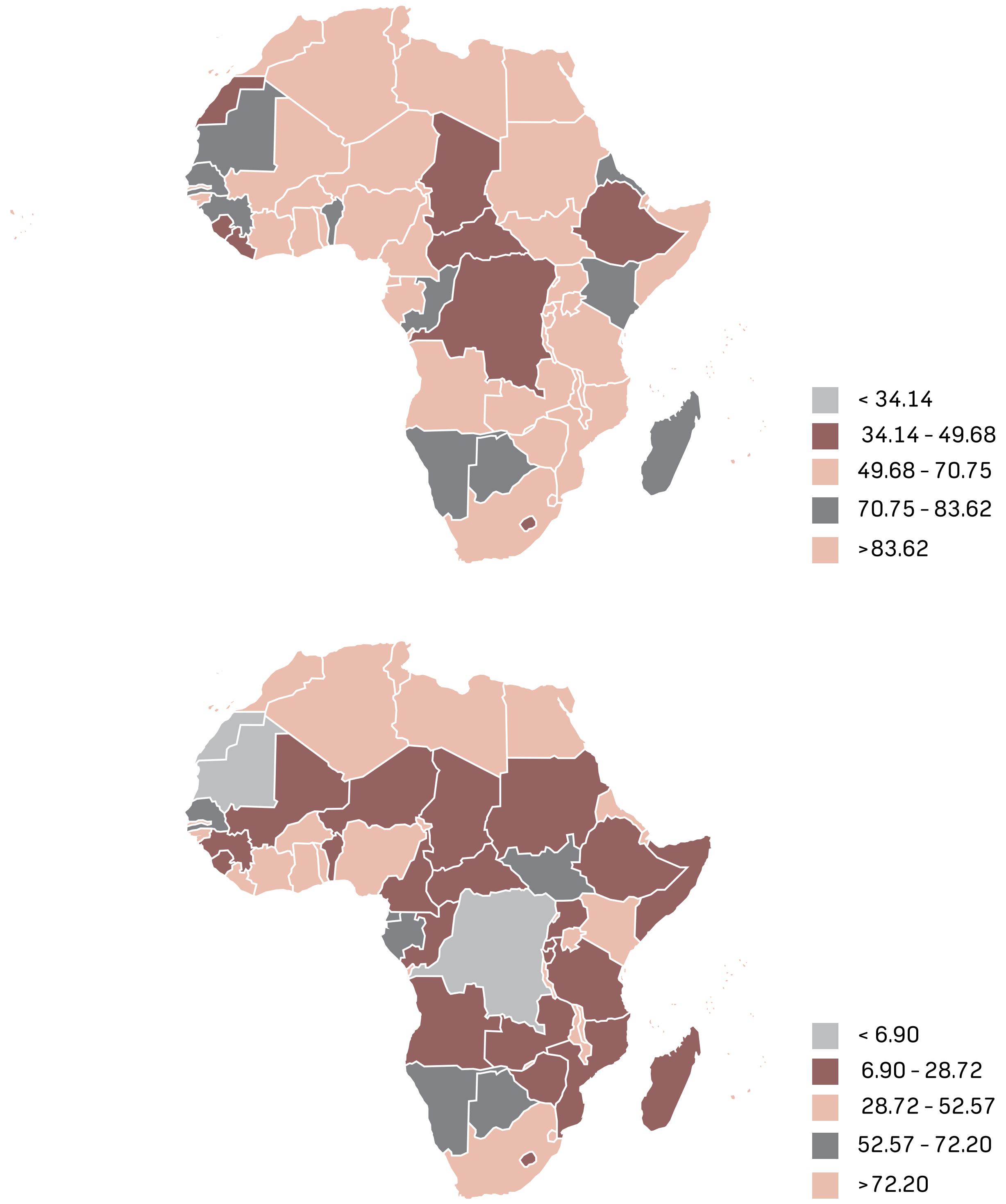
A lack of access to power and high energy costs in local markets sit alongside fast-increasing demands in almost all African countries, to the extent that peak demand is often met by power from privately owned diesel generators[72]. As shown in figure 16, World Bank data from 2016 show that, while high proportions of the urban population have access to electricity in countries within the Maghreb, plus South Africa, Zimbabwe and many parts of eastern Africa, this proportion is as low as 22% in other countries (i.e. South Sudan). Rural access to electricity is worse. The same World Bank data show that, while a relatively high proportion of the rural population in the countries of the Maghreb has access to electricity, the rest of the continent sees a significant drop, even in more well-provisioned countries. In some cases (i.e. the Central African Republic) less than 1% of the rural population has access to electricity.

Nonetheless, it has been suggested that Africa has high potential in terms of renewable energies[73]. Figure 17 and figure 18 show mapped Bloomberg data on the present state of power plants across northern Africa and Sub-Saharan and southern Africa, broken down by energy source. These maps show that, despite a strong presence of fossil fuels, a significant number of power plants – particularly in Sub-Saharan and southern Africa – are based around renewable sources such as water, solar, and organic waste.

f

figure 16

access to electricity (% of population - urban top, rural bottom, 2016)



ADAPTED FROM
World Bank, Sustainable Energy for All (SE4ALL) database from the SE4ALL Global Tracking Framework led jointly by the World Bank, International Energy Agency, and the Energy Sector Management Assistance Programme

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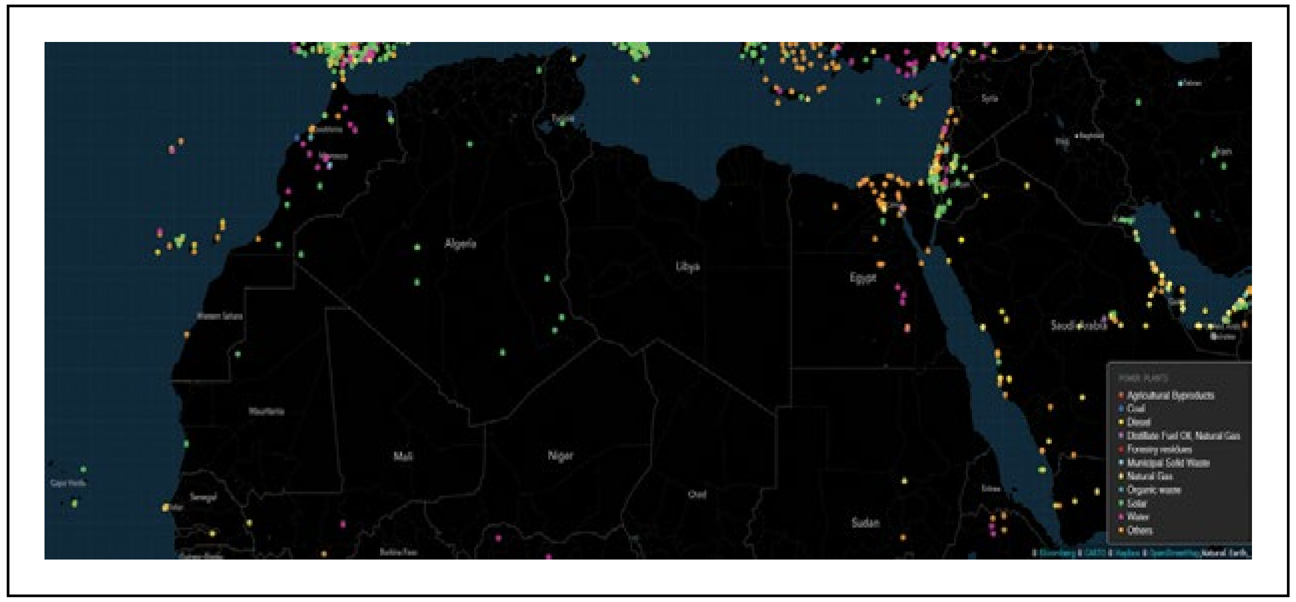
figure 17

presence of power plants in northern Africa (by type)



SOURCE
Power plants in northern Africa, retrieved February 6, 2019 from Bloomberg terminal

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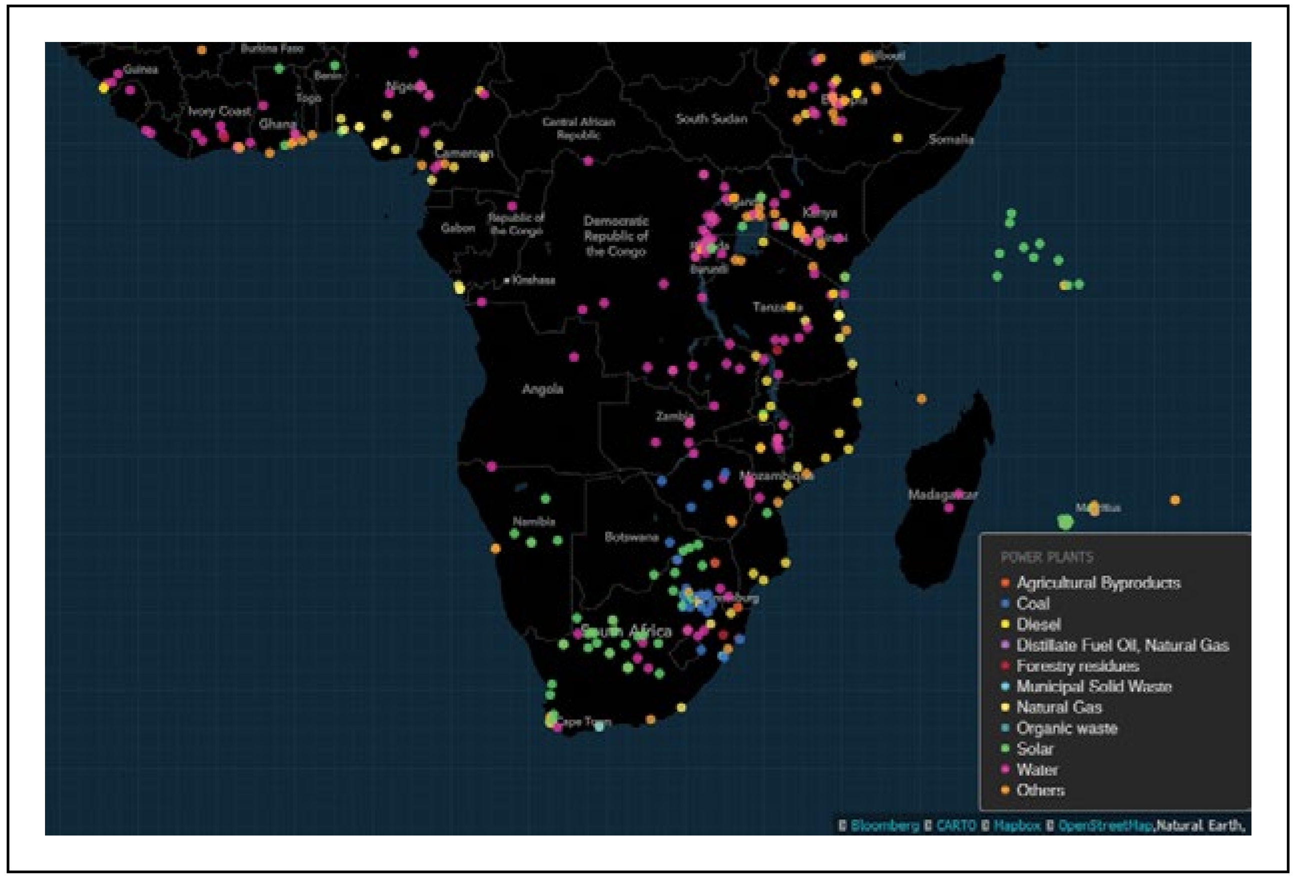
figure 18

presence of power plants in Sub-Saharan and southern Africa (by type)



SOURCE
Power plants in southern Africa, retrieved February 6, 2019 from Bloomberg terminal

4
policy initiatives for the take-up of the fourth industrial revolution in Africa

While Fourth Industrial Revolution technologies are steadily taking hold in Africa, they generally remain at an embryonic stage of development. To accompany this development, there are a number of policy initiatives which are either exploring the feasibility or preparing the ground for the adoption of 4IR technologies. Most continental and regional initiatives are aimed at regulating the ICT sector for better mobile and internet access, an important enabling factor for the adoption and use of 4IR technologies.

4.1 CONTINENTAL INITIATIVES

As part of the High-Level Africa-Europe Forum which took place in Vienna in December 2018, and in line with the New EU-Africa Alliance for Sustainable Investment and Jobs, the European Commission and the African Union (AU) Commission launched an EU-AU Digital Economy Task Force. The Task Force is composed of 20 African and European decision makers, and representatives from the private sector, the international financial sector and civil society. The EU and AU also engaged in an Africa High Level Policy Dialogue on Science, Technology and Innovation as well as a large-scale programme for linking European and African incubators and Technology Transfer Office (TTO) platforms.

The Smart Africa Alliance has launched the One Africa Network initiative which aims to create a free mobile roaming zone across Africa. The overall objective is to increase socio-economic and business exchanges significantly whilst bringing down the cost of communication within and between the participating countries.

Smart Africa can therefore act as a key enabler for the African Continental Free Trade Agreement by driving continental integration through the digital economy.

Within Smart Africa, the Council of African Regulators (CAR) brings together the regulatory authorities and agencies of the telecommunications sector in Africa (EACO, WATRA, ITC etc.). The CAR's mission is to strengthen African collaboration; enable regulators to work more closely; support the digital transformation agenda; stimulate the technological revolution on the continent and create a single common digital market in Africa.

Furthermore, Smart Africa country members develop flagship projects on various themes related to 4IR, as shown in Table 4 . The idea is for participating countries to share and draw from experiences elsewhere.

The **Smart Africa Alliance** is a pan-African organisation which includes 24 African countries that represent a market of 600+ million people. The initiative is supported by the African Union (AU), the ITU, World Bank, AfDB, ECA, the GSMA, ICANN and the private sector.

Smart Africa is an innovative commitment from African Heads of State and Government to accelerate sustainable socioeconomic development on the continent, ushering Africa into a knowledge economy through affordable access to Broadband and use of Information and Communications Technologies.

It rests on five pillars (policy; access; e-government; private sector/entrepreneurship; sustainable development) and four enablers (innovation; communications and advocacy; capacity-building; resource mobilisation). It was initiated with the adoption of the Smart Africa Manifesto document by seven African Heads of State (Rwanda, Kenya, Uganda, South Sudan, Mali, Gabon, Burkina Faso) in October 2013.

In January 2014, the Smart Africa Manifesto was endorsed by all of the Heads of State and Government of the AU. This development places the Manifesto at the heart of the ICT agenda in Africa and extends its reach to all African countries.

In East Africa, under the Northern Corridor Agreement, the One Network Area (ONA) roaming initiative aims to promote regional integration by bringing down the high cost of mobile roaming. This could improve the enabling environment for 4IR technologies in this part of eastern Africa.

ONA is based on a set of regulatory interventions, specifically: i) eliminating charges for receiving voice calls while roaming in Kenya, Rwanda, South Sudan and Uganda

t

table 04

smart Africa flagship projects

Flagship project	Country
High tech parks	Angola
Innovation and knowledge cities	Benin
Capacity building	Burkina Faso
Creative economy	Chad
Cybersecurity	Cote d'Ivoire
Data centres	Djibouti
Innovation and entrepreneurship	Egypt
ICT industry development	Gabon
Smart e-payment	Ghana
Intra-African cross-border connectivity	Guinea
Digital economy	Kenya
Entrepreneurship, youth innovation and job creation	Mali
Smart villages	Niger
Smart cities and communities	Rwanda
Africa digital literacy	South Sudan
Access (broadband) and green economy	Senegal
Smart energy and blue economy	Togo
Big Data and data measurement for development	Uganda
Start-up and innovations ecosystem	Tunisia
4th Industrial Revolution: Innovation and Artificial Intelligence	South Africa

if the call originates in one of these countries; ii) a waiver of excise taxes and surcharges on incoming

ONA voice traffic while establishing wholesale and retail price caps on outbound ONA traffic; iii) requiring mobile network operators to renegotiate with their roaming partners to reduce wholesale tariffs.

ONA has brought the East African Community (EAC) Member States closer together and makes a strong contribution to the drive for integrated regional economic development. Regulators and mobile network operators have begun to solve problems more cooperatively. Most importantly, the public has benefitted from reduced tariffs for mobile roaming, reflected in the growth of cross-border traffic volumes. Cross-border voice traffic has grown rapidly since ONA implementation, tripling in both Kenya and Uganda and witnessing a nearly five-fold increase in Rwanda and a thirty-fold increase in South Sudan[74].

In west Africa, ECOWAS has set up a harmonised regional regulatory framework which lays the foundation for the development of 4IR technologies, namely those related to cybersecurity, data protection and e-commerce[75]. This regulatory framework is envisioned to be reviewed and revised in the future due to recent technology advances.

In 2013, the Presidents of Uganda, Rwanda, Kenya and South Sudan decided to include ICT as one of the strategic areas for facilitating integration within the **Northern Corridor Agreement** region.

Elsewhere, ECOWAS is planning a number of regional forums on 4IR technologies, for example to foresee the implications of Artificial Intelligence and the IoT in terms of risk and data protection.

The West African Economic and Monetary Union (WAEMU) has developed a regional programme for the Promotion of Digital Uses over the period from 2016 to 2022. This programme is structured around three pillars: i) increasing the digital service offering; ii) improving user access to digital services; iii) strengthening the governance of the digital economy sector. WAEMU is also working on the regulatory framework for the development of emerging technologies, namely: Blockchain, cloud computing and Artificial Intelligence.

The **Economic Community of West Africa States** (ECOWAS) aims to establish a liberalised telecommunications and ICT market by facilitating the deployment of innovative, reliable, secure and affordable communication services for citizens of the community. It plans to use ICTs to realise the Community's Vision 2020 (from an ECOWAS of States to an ECOWAS of People), in particular to facilitate the development of trade and the free movement of people, goods and services. ECOWAS is therefore committed to fostering the digital economy in west Africa.

The **West African Economic and Monetary Union** (WAEMU) aims to create a harmonised regional digital market, promoting the development of goods and services that meet the expectations of businesses and populations of the WAEMU.

International donors are also involved in the funding of digitalisation programmes on the continent. The Strategic Partnership Digital Africa is an initiative launched by the German government to help African partners harness digitalisation opportunities for socioeconomic development. The initiative, operated by the government, represents a network of 130 industrial partners. The partnership focuses on the thematic areas of education, energy, health, good governance, agriculture and mobility. Examples of projects supported include a mobile system to increase tax revenue in Zambia, an e-commerce platform in Rwanda and a digital agricultural solution in Uganda.

FinForward is a FinTech innovation and integration programme organised by the Dutch Development Bank (FMO) and the US-based tech company FinConecta. The programme aims to accelerate the digitalisation of the financial industry in Africa by connecting African financial institutions and mobile money providers with FinTech companies worldwide.

In terms of human capital development in Africa, the Africa Skills Initiative[76] provides insights and collates the experiences of different businesses on an online platform, to act as a learning tool to address skills development.

The initiative uses a set of analytical tools that includes the Human Capital Index, which measures and benchmarks countries on their human capital endowment; the Future of Jobs analysis, which provides sector-level diagnostics on key trends and disruptions to the job market and their effects on employment and skills; and the Disrupting Unemployment portal, which consolidates information on business-led solutions for addressing skills gaps, fostering entrepreneurship and facilitating the talent market.

The **Africa Skills initiative**, championed by the World Economic Forum's Africa Regional Business Council, supports public-private dialogue for reform of education systems and labour policies in order to prepare African workforces for the 4IR.

Leveraging knowledge gathered about skills gaps, the initiative aims to identify what can be done today to disrupt the employment crisis now while at the same time preparing for the future.

4.2 NATIONAL INITIATIVES

At the national level, relatively few countries have started developing 4IR strategies alongside existing ICT policies (South Africa, Morocco) or created technology centres (Morocco, Rwanda).

The South African Department of Trade and Industry formed a Chief Directorate for Future Industrial Production and Technologies in 2017 to examine the impacts of emerging digital technologies, including the Internet of Things, Big Data, AI, robotics and new materials[77]. The unit aims to build government capacity to partner with industry to enhance South Africa's readiness. The government's Intsimbi programme, which was set up in 2018, focuses on the development of skills and SME competitiveness[78]. This new initiative is very close to what a dedicated 4IR strategy at the national level would look like. It builds on a White Paper from 2016 on National Integrated ICT Policy[79]. The government also plans to invest more in research and development, support for entrepreneurs and skills development. In addition, a Digital Industrial Revolution National Coordination Committee has been set up. Partnerships preparing for the 4IR are emerging between the government and industry associations and export councils representing the manufacturing sector. South Africa is also a member of a Brazil, Russia, India, China, South Africa (BRICS) working group on the future of work[80], focusing on the development of skills. There is growing interest in the country in 4IR technologies, such as robotics, to improve the safety and efficiency of the country's mining industry. The South African Presidency recently announced the establishment of a 4IR Commission, which comprises 30 experts, to optimise technologies for economic growth and job creation.

In 2017, Rwanda, in partnership with Inmarsat, the provider of global mobile satellite communications, set up a centre for the Internet of Things (IoT) to facilitate students' learning, to develop IoT prototypes and to carry out academic research in the field of potential IoT solutions[81]. The programme aims to accelerate the deployment of the IoT and smart city solutions[82]. Rwanda's government also launched the Irembo platform to provide e-government services such as registering for driving exams and requesting birth certificates[83]. Rwanda has long shown an interest in these types of initiative, adopting its first National Information and Communications Infrastructure plan in 2001[84].

In March 2019, Morocco and UNIDO signed the Programme for Country Partnership for Morocco (PCP Morocco) document, which will support the implementation of the government's Industrial Acceleration Plan 2014-2020. The PCP is based on a multi-stakeholder partnership between development partners, UN agencies, financial institutions and the private sector, under the overall leadership of the government. Through the PCP, UNIDO provides policy advice to the government, delivers multidisciplinary technical assistance focused on selected industrial sectors and areas, and facilitates overall PCP coordination and the convening of partners. PCP Morocco will focus on several priority industrial sectors and areas, namely industrial zones, agro-industry, energy, the circular economy, Industry 4.0 and e-commerce. The programme will also integrate cross-cutting issues such as statistics, gender mainstreaming, partnerships and South-South and triangular cooperation.

The **UNIDO Programme for Country Partnership for Morocco** is structured around three areas of intervention: i) the creation of a smart factory and the development of partnerships with international agencies to enable rapidly changing sectors (aeronautics, automotive, biomedical, etc.), local industries (textile, agro-industry, etc.), universities, associations and private companies to innovate together in order to improve industrial production; ii) the establishment of an Industry 4.0 integration platform for national cooperation and coordination to enable collaboration and partnerships between the various Moroccan organisations involved in Industry 4.0 and to follow the adoption of technologies and practices of this industry; ii) the development of skills and curricula in areas related to Industry 4.0: the focus will be on building a strong and internationally recognised pool of talent in certain subsectors of Industry 4.0 (Additive Manufacturing, robotics, automation, etc.).

PART 03
emerging technologies and their market applications in Africa

5
development of emerging technologies in Africa

According to our survey to African stakeholders and respondents' own assessments, the level of readiness of African countries to take up technologies varies. Figure 19 illustrates the results.

Artificial Intelligence, 3D printing and Big Data/IoT are associated with a 'high readiness' index (according to 36% of the responses obtained) while Blockchain and drones have the highest 'not ready' scores.

The following subchapters present each of the technologies, discuss readiness and opportunities and recommend a way forward.

5.1 ADDITIVE MANUFACTURING

For several decades, printing technology has developed from a 2D technique to a 3D technique. Now 3D printing technologies and processes have developed to the point where adoption for the purposes of production is becoming increasingly widespread in industrialised countries. Additive Manufacturing (AM) is the application of this 3D printing technology on an industrial scale. It is the process of fabricating products by the computer-aided layer-by-layer addition of material(s). This way of generating products is significantly different to traditional production, which typically removes material to create an object. The process used by AM allows for much more freedom in the form and function of products.

The following sections, we will (i) introduce AM technology, (ii) give an overview of AM potential impacts and global use trends, (iii) explain the reasons why AM is important for Africa and discuss the opportunities, (iv) present the current applications and markets of AM in Africa, and finally (v) recommend actions for the take-up of AM in Africa.

5.1.1 Introducing Additive Manufacturing

AM can be considered a disruptive technology as it fundamentally alters the processes by which products are produced.

AM is facilitated by 3D Computer-Aided-Design (CAD) data. Products are designed as 3D models and then sent to a 3D printer, enabling the production of almost any structure that can be modelled in 3D. In that sense, one could say that AM is "the revolution of turning data into things" (Van Barneveld & Jansson, 2017).

AM has shown a steady and slow process of maturation. The origin of the technology of 3D printing can be traced back to the 1980s, when it was discovered that, with adaptations to inkjet printers, ink could be replaced by solid materials. In the following decades, innovations in 3D printing have proceeded rapidly alongside developments in related fields such as communication, imaging, architecture and engineering (B. Ramalingam, 2016; GE, 2019). Factors that are speeding up the development and processes related to the application of Additive Manufacturing are: i) improving technologies, ii) lower raw material costs, iii) broader applicability of 3D printing across economic sectors; and iv) a larger interested community and more support on the distribution-side of this new business model (OECD, 2017; Ramalingam, Hernandez, Martin, & Faith, 2016).

Recent breakthroughs that further accelerate the development of this technology include the ability to produce objects through 3D printing with multiple types of materials, including plastics, metals, ceramics and biomaterials (Van Barneveld & Jansson, 2017) as well as concrete (De Schutter, et al., 2018). It has also become possible to print objects consisting of various parts, for example drones (OECD, 2017).

AM means that designers of products and parts can convert concepts into prototypes and models swiftly, with increased flexibility in shapes (European Commission, 2014). AM also permits the mass customisation of products. The design and production of goods via AM can be completely geographically separated owing to data models being the main input. In fact, design and production can take place anywhere in the world independently, as long as they are connected through the internet. This fact allows for local production and thus the reduction of transport costs.

It is important to note that 3D printing is not a synonym for AM. Indeed, AM is broader than 3D printing technology alone. AM requires and includes 3D printing at the heart of the process, but also includes the design of the 3D model and the post-processing of the product (Zelinski, 2017). In general, AM consists of three phases:

1. The design phase, which requires 3D model data and designs and data transfer;
2. A building phase, which requires 3D printing techniques and material options ;
3. A post-processing phase, in which left-over material and support structures are removed and the surface of the object is treated to reach the required level of quality.

A paper by the Imperial College of London (Wu, Myant, & Weider, 2017) has identified major needs concerning each of these phases (figure 20). Innovations in computer-aided design and engineering and efficiency in computational files are necessary in the design phase. In the building phase, there is a need for more materials and reduction of waste. In the post-processing phase, there is further need for automation and certification of parts, through for example better industry standards.

AM has already reached maturity in various sectors. The technology is in the final technology readiness level of market adoption in high-value sectors, with many potential economic, societal, technical, legal, political and environmental advantages (B. Wu, 2017) or threats, which will be addressed in more detail in the following section.

5.1.2 Overview of Additive Manufacturing potential impacts and global use trends

AM has the potential to restructure the global economic system, which could significantly impact people's lives, positively or negatively.

POTENTIAL ECONOMIC IMPACTS

Additive Manufacturing can offer solutions to current issues around production, such as increased functionality and complexity of parts, reduction of the necessity for large inventories and improved delivery times.

AM changes production processes and equipment use. The production equipment use in AM is flexible and able to produce all kinds of products (Van Barneveld & Jansson, 2017). This flexibility lies in the fabrication of a variety of

figure 19

stakeholders' assessment of Africa's readiness to take up technologies

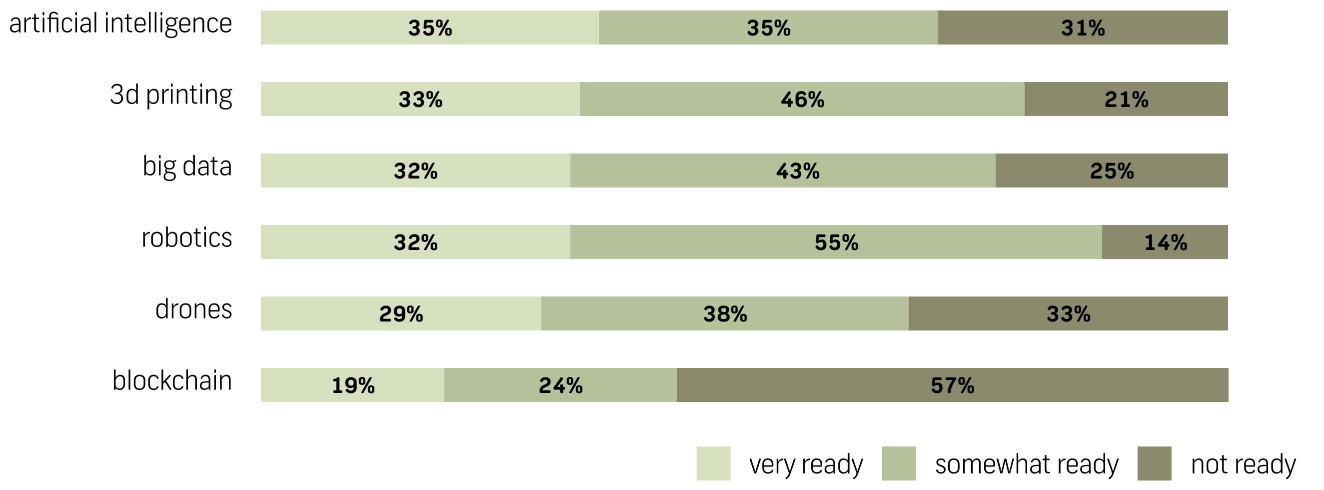


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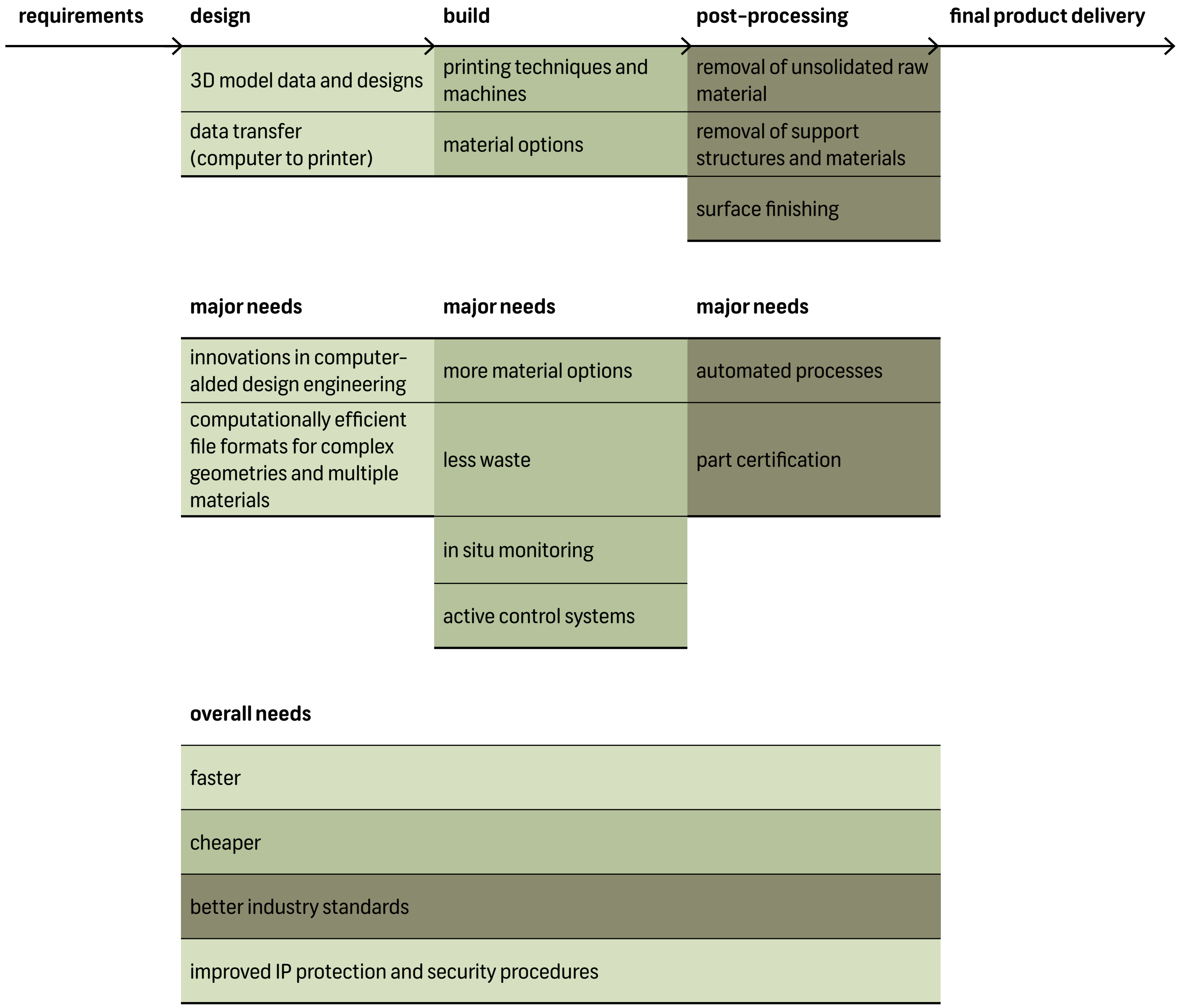
figure 20

general aspects of the AM process chain and the associated major needs of the industry



ADAPTED FROM
Wu, Myant and Weider (2017)

products with a single machine. This differs from the more traditional manufacturing of standard products, where a single machine is optimised to produce many similar goods. This could result in more multi-purpose factories instead of the more specialised factories that we currently see in the manufacturing industry (Van Barneveld & Jansson, 2017). AM may promote the reduction or perhaps the disappearance of the traditional (mass) production lines and a corresponding localisation of production (closer to the customer), which has the benefit of cutting transportation costs. It could also allow for personalisation and customisation of production. Labour costs could also be drastically cut. Therefore, AM has the potential to disrupt the established forms of design and manufacturing by localising and democratising production. Printing single items may be as cheap as having a dedicated factory producing thousands of items (Pierrakakis, 2015). This in turn would disrupt value chains and provide new economic opportunities.

Whereas the current economic system creates value through production, value in a system where every individual can print products through their own 3D printers is bound to raise the relative importance of the resources and intellectual property of the designs used. In addition, a flourishing open source market may appear, which, in turn, further democratises this aspect of AM.

Another likely implication of the introduction of AM is the re-shoring of manufacturing by developed countries, which may prefer to produce closer to their own consumer markets once the factor of cheap labour is removed. On the other hand, a process of off- or on-shoring may occur, depending on the capability of lesser-industrialised countries to develop their capabilities to adopt AM as well as a consumer base that can afford (possibly cheaper) 3D printed products. Without these developments, however, a concentration of specialised AM centres might develop that are then transported around the globe (Hallward-Driemeier, 2018).

AM offers the possibility for less-industrialised countries to manufacture customised products with lower capital investment, creating economic opportunities for their populations (T. Johnston, 2018). For example, the previously mentioned qualities of AM have led it to be applied in India for the construction of parts for automobiles. Parts for different models of automobiles have different specifications, which requires the flexibility that 3D printing has to offer (Hallward-Driemeier, 2018).

In terms of economic threats, there is a risk that, with a widespread adoption of AM, there might be less need from high-wage developed economies for manufacturers from African and other low-wage countries. As AM is expected to manufacture goods at the current speed of traditional manufacturing processes, there might not be that much need for the type of labour-intensive manufacturing that African countries currently deliver. On the other hand, several African countries are already actively engaged in AM, which might also enable those countries to reap future economic opportunities (Raji, 2017).

The scope of economic (sub)sectors, in terms of adopting AM technologies, varies widely. This is also the case for the potential of re-shoring production and increased manufacturing efficiency through automation and worker lay-offs. For instance, several capital intensive industries are already heavily locked in to regionalised supply chains, and the expectation is that these will be disrupted less heavily than others (Hallward-Driemeier, 2018).

POTENTIAL SOCIAL IMPACTS

Additive Manufacturing removes technological barriers, giving more freedom to product developers and innovators. Technologically, attention will shift to the design of products. As processes are more similar, the complexity of production is now shifting towards the designing and modelling of products and the associated coding. IT and industrial engineering personnel will be more important than before, as will ICT and creative skills.

The World Bank has identified several scenarios of possible societal consequences based on the pace of adoption of AM and the sharing of prosperity. In the case of quick adoption and sharing of benefits, emerging economies can catch up with developed economies through the traditional development path. This would hinge on growth and good education and training of skills, with strong international collaboration. As workers are upskilled, they might be required to work fewer hours in a formal occupation, but instead pursue creative or societally minded activities. In addition, through an expanded social safety net, people who are not employed in the sector will still be ensured of decent living conditions. On the other hand, with quick adoption of AM and a decrease in the sharing of prosperity, mass job losses may follow, resulting in reskilling in developed countries. With unequal distribution of private capital, developing countries may find it harder to industrialise and young people in these countries will be unable to catch up with the rapidly advancing skills and knowledge (World Bank Group, 2018).

Policy choices made nationally and internationally can, however, steer the impacts of AM on society (T. Johnston, 2018). The adoption of AM can lead to greater customisation of products and differentiations, better catering to the needs of consumers. One feature of 3D printers that speaks well to societal impact is affordable, desk-sized printers. This allows 3D printing at home of, for instance, products bought online that are tailored to an individual's specific needs.

POTENTIAL LEGAL IMPACTS

The development of AM will pose various legal challenges and requires a thorough review of the legal framework.

The increased reliance of manufacturing on data files, such as 3D designs, implies that protection of intellectual property will be more important but also more difficult. The creation of a data file can be protected by intellectual property law, but this protection may be difficult to enforce (Mayer Brown, 2013). Just as has been the case for the music industry, a lack of enforcement in many countries and the volume and ease with which music is downloaded illegally makes protection of intellectual property of data near impossible. Open source variants of popular products may be introduced, which could undermine the need for intellectual property as a system of economic incentive. In response, the creation of an online licensing system is considered very likely (Mayer Brown, 2013). Some exceptions may exist however, such as repair of an item through the production of a spare part as well as items for non-commercial use (Wright, 2017).

Civil liability issues are another area with legal implications that is often mentioned. Currently, selling products which are unsafe for consumers can be judged a criminal offence (Wright, 2017), however, with the 3D printing of parts by others, there is no legal precedent yet. Governments are therefore working to adopt new legislation or tailor existing laws to the possibilities of AM (European Parliament, 2018; Wright, 2017).

POTENTIAL POLITICAL IMPACTS

Appropriately managing the introduction of AM is necessary to ensure that the benefits are shared equally, both within countries and internationally (Johnston, 2018), and the potential for democratisation, decentralisation and personalisation of AM is unleashed.

Another impact often mentioned in the literature is an increase of (national) security threats (Pierrakakis, 2015; Johnston, 2018). In terms of national security, serious challenges are expected to arise due to the already emerging evidence of successful 3D printing of guns, assault rifles and high-capacity magazines. In the United States for instance, Defence Distributed – a not-for-profit aiming to distribute CAD-files for 3D printed guns – was initially successful in court before being blocked by a federal judge on account that these 3D printed guns do not have a serial number (Paul, 2018). The increased ease by which offensive weapons can be created is expected to warrant a response from governments through regulation and monitoring (Pierrakakis, 2015).

Furthermore, in the case that the distribution of future jobs is unequal and workers in the traditional sectors are not reskilled to take up work in AM, populism may also increase as a response to the worsening levels of unemployment and inequality, which can lead to increased protectionism (World Bank Group, 2018).

The re-shoring of manufacturing by developed countries may provoke a political response. One such worst-case response mentioned in the literature is that resource-rich, low- and middle-income countries could refuse to cooperate in the new global value chains by limiting the distribution of raw materials towards industrialised countries as well as increased protectionism (Mayer Brown, 2013; World Bank Group, 2018). The availability of the material inputs is essential to re-shore production to the largest consumer markets (Pierrakakis, 2015).

POTENTIAL ENVIRONMENTAL IMPACTS

Additive Manufacturing demonstrates considerable potential for contributing to resource and energy efficient manufacturing and, as such, to achieving the Sustainable Development Goals. AM could cut global energy use by 27% by 2050 (The Economist Intelligence Unit, 2018). In terms of resource efficiency, AM is even more promising (Peng, 2018). The simple principle of AM that it adds material with high precision means that, as opposed to subtractive manufacturing, left-over or waste material will be next to none (Van Barneveld & Jansson, 2017). Production through AM in terms of material use is more efficient. Another aspect is the potential of more efficient and lightweight designs. By creating lighter products through AM, the stress on resource consumption in the manufacturing sectors can be reduced. As an example, a competition launched by General Electric for the design of a bracket for a jet engine through AM resulted in a product that was 84% lighter in weight (The Economist Intelligence Unit, 2018).

Additionally, the possibility of producing products on-demand is expected to lead to less production of non-essential products, lowering consumption overall (Pierrakakis, 2015). Transportation of products could also be reduced if products with AM are produced more locally, closer to customers. Less transportation will also have a positive effect on the use of resources and the environment.

MARKET SIZE OF AM TECHNOLOGIES

The potential of Additive Manufacturing has been recognised by both governments and the private sector, who are investing heavily in the technology. It is estimated that the global AM industry was worth $6 billion in 2016 and it is predicted to grow to more than $26 billion by 2022 (Wohlers, Campbell, Diegel, & et al., 2017). The global direct economic impact of AM is estimated to be $230 billion to $550 billion per year in 2025[85].

AM is gaining importance particularly in high-value sectors, such as in the medical, aerospace and automotive industries (Wu, 2017). The largest application of 3D printers worldwide is in the production of functional parts (34%), followed by fit and assembly (16%) and education and research (11%). On a sector basis, most 3D printers were sold for the production of industrial machinery (19%), aerospace (18%), automotive (15%), consumer products (13%) and medical and dental services (11%) (ING, 2017; EY 2016). Particular effects on production can be observed for each sector. In the production of industrial machinery, the production time is shorter and cheaper, whereas in aerospace there is less need of stock and sometimes faster and cheaper production. For the automotive industry, assembly lines for specific tools or parts will disappear and, in consumer products, it significantly speeds up the design process.

In fields that still rely on the mass production of standard products, AM may not be competitive with current production techniques. Companies producing such products are still hesitant to adopt AM as it requires considerable investment, while direct benefits are not obvious (Ponfoort, 2015). AM is a better fit for customised products and not so much for mass production of standard products.

Government support for the technologies that underpin AM is also growing. The European Commission already funded related projects in its first Framework Programme (1984-1987) (European Commission, 2014). In FP7, the EU contributed a total of €160 million to projects around AM, with a total budget of €225 million. In the current framework programme, Horizon 2020, AM receives funding under the Key Enabling Technologies.

Table 5 provides an overview of sectors and the current application of AM therein, with some examples of applications.

t

table 05

markets and application domains of additive manufacturing worldwide

Current application of AM	Sector/industry	Examples
High	Aerospace and defence	AM is used to produce parts and ultra-light designs for air and space applications, but also for military use, such as in weapons.
Medium	Medical and dental	AM is used to make implants that fit well to patients, such as replacements of bone or dental implants or all sorts of prostheses for people with a disability. Printing of biomaterials is used for in vivo applications and tissue replacement.
	Automotive	AM is used for concept models and rapid prototyping.
	Electronics	AM is used for the printing of electronic components and (thin) casing.
	Fashion	AM is used for the production of perfect fitting sport shoes.
	Chemicals	AM is used for the production of polymer products.
	Pharma	AM is used for the production of tablets, drugs, drug delivery devices and the bioprinting of tissue.
Low	Mechanical and plant engineering	AM is used for the production of (spare) parts of machines/equipment with tailor made specifications from all sorts of materials.
	Oil and gas	AM is used for the production of low-volume, high-quality components and to reduce the number of bots and welds in equipment.
	Wholesale and retail	AM is used for the production of highly customised consumer products, fulfilling the specific demand of consumers.
	Logistics	AM is mainly impacting logistics, as production will be more local, simplifying the logistics chain, but also logistics companies can offer the production of parts as a service.
	Power and utilities	AM is used to produce spare parts for critical energy infrastructure, to print batteries, complex parts of turbine blades and may also be used for parts that otherwise need to be shipped to remote/rough environments (e.g. off-shore wind turbines).
	Food and beverages	AM is used to produce food in all kinds of forms, such as cake toppings, chocolate, fried food and yeast structures.

ADAPTED FROM
based on EY (2016), examples collected from several sources

AM is applied around the globe. According to the 2018 Digital Manufacturing Trends report from 3D Hubs[86], the United States has the largest market share in 3D printing (38.1%). This is followed by the UK (15.7%), the Netherlands (6.7%), Germany (6.3%) and Canada (5.7%). The top 10 countries in 3D printing consist mainly of the United States and Europe, with the exception of Australia (position 6, 5.7%), Singapore (position 7, 3.9%) and India (position 10, 1.4%) (3D Hubs, 2017).

The map in Figure 21 shows the worldwide distribution of 3D printers in the 3D Hubs network (3D Hubs, 2017). The highest density of 3D printers can be observed in Europe and north America. The map also shows that over 550 3D printers are operational in Africa within the network. Large concentrations are observed in the southern and western parts of Africa.

India is one of the countries where AM is playing an increasingly important role in industrialisation. Most entrepreneurs have limited resources available and so shared maker spaces are provided by the Indian government and research institutes such as the Indian Institute of Information Technology and Management as well as the local innovation promotion agency in the state of Kerala. This way, innovation is kickstarted by providing infrastructure needed by entrepreneurs.

5.1.3 Why is Additive Manufacturing important for Africa? What are the opportunities?

Opportunities for Africa

AM has the potential to address many of the problems of industrialisation in the least developed countries (LDCs), namely isolation, distance from major markets and low economies of scale. AM has the potential to speed up industrial development in Africa. Traditional industry requires higher capital investment in equipment, infrastructure and personnel than those needed for AM. By comparison, one of the biggest advantages that AM has to offer emerging countries is to lower the barrier for entry into manufacturing for small businesses.

Companies and individuals can produce a wide range of products with only a 3D printer, a computer, some software and some production materials. Small, one-man production shops are (in principle) easily set up with only a small investment and no costs for tooling or employees. These companies can slowly start to scale up their business. As the number of clients grows, or one or more products sell to volumes of over a thousand, production can be further extended with additional AM capacity or other production methods, such as more traditional injection moulding. In this way, small business can grow to larger business – once they are successful – with only small start-up costs. This could be a way to foster private sector development in emerging countries (UNIDO, 2017).

In addition, the nature of the costs of AM compared to current manufacturing (subtractive or moulding) are different. There are several reasons for this difference (Thomas & Gilbert, 2014). First, with AM the product can (often) be made in one piece without the need for the assembly of parts and components, which reduces one step in the supply chain. Second, AM does not require expensive moulds and structures specific to a single product. Instead, different 3D models are needed that can be directly sent to the 3D printer. Moulds are also produced based on 3D models but form a much more expensive intermediate step because of the use of expensive materials. Third, AM can sometimes require more post-processing than current manufacturing. Fourth, AM requires less material and less stock and storage. Overall, this has the potential to reduce costs for more customised products and is associated with lower business start-up costs than current manufacturing. Currently, the production speeds of AM are, however, slower and the input materials quite expensive. This makes AM more expensive per product for small batch production. The level of technological know-how of the workforce, which is generally low in Africa, can be relatively easily circumvented as training in AM and open-source designs can be found for free online. Even the cost of importing inputs may not be insurmountable. Some products can be 3D printed using recycled plastics rather than expensive foreign polymers. AM can, similar to automation, increase the proximity of the producer to the market and effectively lower transport costs. In Africa, AM could make products or machine parts available that were very expensive to import before, thus making access to machinery for manufacturing much easier and more affordable. In

figure 21

distribution of 3D printers within the 3D Hubs network

SOURCE
3D Hubs (2017)

addition, AM creates a whole new field of work – designing printable products. Therefore, there is a high potential return from investing in capacity and building skills in the creative economy in Africa.

AM allows producers to be closer to the end market. Africa can benefit in particular by supplying its regional market with products that previously had to be imported – effectively out-competing suppliers from other continents. African manufacturing is certainly the sector which has the potential to benefit the most from AM, but potential applications exist in other sectors.

The application of AM in the medical and dental sector could be interesting to Africa. AM can produce prosthetics that fit perfectly to the user. Depending on the materials used, the prostheses can be produced at low cost. This may bring good prostheses to people that are less fortunate, while at the same time local producers benefit from the production of these goods.

AM can facilitate building and construction in the housing sector, for example by producing housing stock that uses existing natural and recycled materials, is adapted to local climate conditions and incorporates features like solar panelling. There are already several development organisations that look to use AM to produce cost-effective emergency shelters and sustainable housing in areas with rapid urbanisation or areas experiencing conflicts or natural disasters (Ramalingam, 2016).

AM could also be beneficial in remote areas or other locations where traditional supply chains are slow or not functioning well. In those contexts, products are difficult to obtain, at least within the needed timeframe. Local production, with AM, could produce those products or spare parts. Especially in areas that are hard to reach due to disasters or in humanitarian settings, local AM could quickly supply products for critical infrastructure and parts (e.g. wheels, pipes, etc.), tools (e.g. clamps/ clips, wrenches, tweezers, etc.), or medical support (e.g. prostheses, medical equipment, etc.). AM could reduce time, complement supply chains and offer solutions to specific needs (Ramalingam, Hernandez, Martin, & Faith, 2016; Gahren, 2018; Saunders, 2017).

Based on our analysis, summarised above, there are potential business cases for AM in Africa. We believe that AM could have business potential, especially for producing dedicated products for local markets. AM has most potential to industrialise Africa in the sense that manufacturing companies can start up and might eventually grow into larger companies with fairly low levels of investment. Regarding innovation in AM in Africa, collaboration with schools, universities and larger foreign companies could be a good investment to transfer the needed knowledge and skills and could be a good investment for customers for dedicated products or spare parts. Connecting these businesses to local societal needs could be wise as well, as AM could provide solutions in care and healthcare, in disaster relief, and in supplying (spare) products to remote areas.

5.1.4 Current applications of Additive Manufacturing in Africa

The market adoption of AM in Africa is still nascent. In fact, in 2016, the share of investments in AM in African countries was below 5% of the global total (Banga & te Velde, 2018a). As shown in Figure 21, the concentration of 3D printers in Africa is low.

Even though AM is in its inception in Africa, interesting market applications have been identified.

The desk research and interviews identified 27 companies using AM in nine African countries (Egypt, Ghana, Kenya, Morocco, Nigeria, South Africa, Tanzania, Togo and Tunisia). This number is not exhaustive but gives an idea of the use trends in Africa.

Current applications of AM are found in industrialisation, smart cities, health and education where some start-ups have successfully raised venture capital funding. As evidenced by Crunchbase[87], one Moroccan industrial company was funded up to a sum of $46,821,742. One Egyptian education company received $150,000 and one South African education company raised $10,000. It should be noted that investigations conducted did not show funding in countries other than those noted on the map. Figure 22, illustrates the trends in market applications and investments. The map is only used for illustration purposes and is not intended to give an exhaustive overview of current AM applications and investments in start-ups across the continent.

Some significant use cases of AM in Africa identified through country case studies and interviews are presented below. We have not found any applications of AM in agriculture, energy or regional integration. The immediate benefits and potential of AM in these sectors are weaker.

In 2016, an Additive Manufacturing strategy for South Africa was drafted, which is part of the country's efforts to capitalise on 4IR technologies. South Africa also has the world's biggest 3D printer, which uses titanium powder to print aeroplane parts. Box 1 presents the South African AM strategy and world's biggest 3D printer in detail.

Morocco is one of the countries that has already started working with AM. With the support of UNIDO, Morocco has developed a programme that will support 4IR technologies in industry, including AM among other things. The automotive and aeronautics sectors have been using AM as a form of rapid prototyping (Rouaud, 2017) and examples of initiatives in these areas include the opening of a 3D printing site for aeronautical and spatial components by Thales Group and the 3DS Learning Lab that was established by Dassault Système and ESSTI Rabat, an engineering school. The lab focuses on educational research that is performed together by higher education institutions and companies.

Technological hubs are also contributing to the traction that AM is gaining in Africa by providing 3D printers, ideation, R&D and experimentation space for innovators and start-ups. For example, WoeLabs, a technology hub in Togo, made a 3D printer from e-waste (a scanner, a printer, and computer parts). The idea for this 3D printer came about as a challenge for the hub innovators to replicate a 3D printer with what they had to hand. With the success of the printer, WoeLabs is looking to give 3D printers to local schools as a way to encourage technology learning (Matsinde, 2018). E-waste is a growing problem across much of Africa and unwanted e-equipment ends up on the street. The WoeLabs 3D printer is an example of how e-waste can be recycled.

AM is used in the health sector to produce prosthetics for amputees. For example, in Sudan, Not Impossible Labs printed low-cost arm and hand prosthetics for an amputee. So far, the lab has created arms for other patients at a cost of around $100 for each prosthetic (Newman, 2014).

Concerning the value chain, in the AM market, several stakeholders are active. Globally, the value chain is organised around the following actors: AM materials suppliers, 3D printer hardware and software suppliers, 3D modellers, AM companies, retailers/intermediaries, recycling companies and marketing and salespersons. Some of these roles are often combined in one business, small or large, such as 3D modelling, printing, sales and marketing. There seems to be the most potential for Africa in 3D printing and 3D modelling companies, i.e. making products for local markets and local needs. Software, hardware and materials can be imported from leading companies, although there could be potential for the recycling of AM materials (mainly plastics) or making cheap 3D printers in Africa.

5.1.5 What needs to be done to take advantage of Additive Manufacturing in Africa?

Previous sections have shown the potential for African businesses to use AM technologies and the opportunities that they may offer in terms of expanding the manufacturing sector in Africa, generating productivity gains and addressing market and consumers demands.

However, taking full advantage of AM and scaling up the take-up of AM in African businesses are still challenging (Figure 23).

As for every 4IR technology, reliable access to an electricity network and high-speed internet is key (Naudé W. , 2017). However, a number of challenges need to be tackled that are specific to AM technologies. Our analysis, based on country case studies and interviews, allowed us to identify key enabling factors, actions and policies that must be enacted in order to unlock the potential of AM in Africa.

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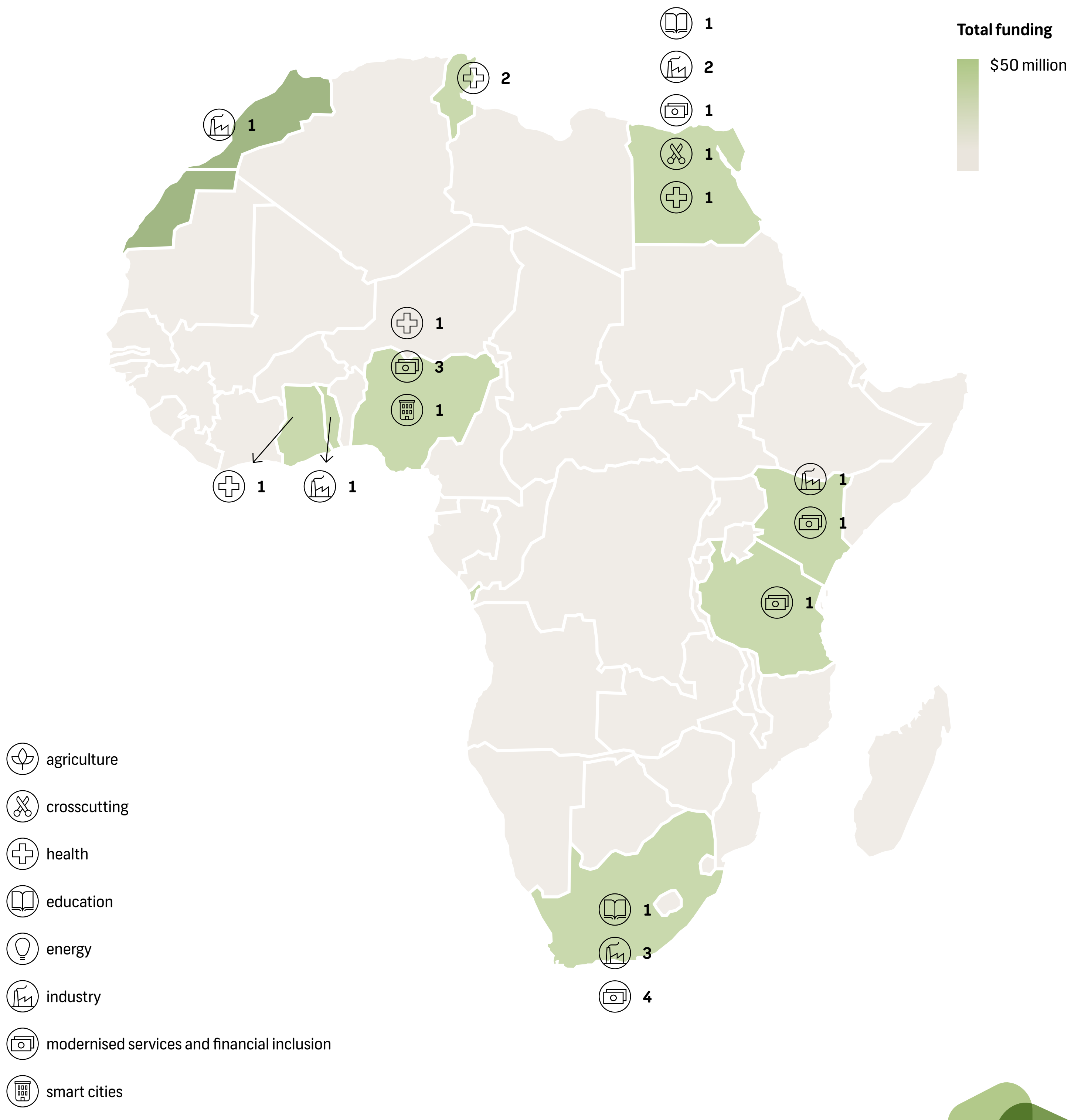
figure 22

additive manufacturing market applications and investment in startups: trends in Africa



ADAPTED FROM
Technopolis Group (2019), based on desk research and interviews

b

box 01

South Africa's additive manufacturing strategy and world's biggest 3D printer

The Additive Manufacturing Strategy was introduced by South Africa's Department of Science and Technology (DST) and is aimed at positioning South Africa as a global competitor for 3D printing technologies through the identification of future market and product opportunities.

South Africa's public sector has invested a total of R358 million ($24.75 million) into Additive Manufacturing research and development since 2014. As part of the AM strategy, the DST commits R30.7 million ($2.12 million) towards a collaborative R&D programme geared towards 3D printing research, development, innovation and infrastructure (Tess, 2016).

The AM programme supported by the DST focuses on advancing 3D printing technologies in the field of titanium medical implants and aerospace parts, as well as polymer AM for design.

The strategy also helps to promote the adoption of 3D printing technologies among various sectors. Among the institutions participating in the collaborative AM programme are the Vaal University of Technology, which has a particular focus on the tooling and casting sectors, Stellenbosch University and Bloemfontein's Central University of Technology (CUT) Centre for Rapid Prototyping and Manufacturing, which works with the medical sector and on the development of plastic and metal 3D printing materials.

South Africa also has the world's biggest 3D printer, which uses titanium powder to print customised parts. The 3D printer was built with a dual goal: to produce parts and undertake R&D. The printer was designed and built as part of a collaboration between Aerosud Innovation Centre, a private supplier of aero structure & aircraft interior components, and the Council for Scientific and Industrial Research's National Laser Centre, a public research organisation. It was funded by the South African Department of Science and Technology.

The 3D printer already has clients in industry, notably in aeronautics, allowing the country to supply South African parts from South African machines to South African aircraft (Wild S., 2018). The country intends to continue to invest in cheaper 3D printers for industrial use.

Awareness of AM technologies and their potential is relatively high, in particular among manufacturers in South Africa. The technology is being used in rapid prototyping, to test design options and to reach a better understanding of engineering problems (Deloitte, 2016).

SOURCE Technopolis Group (2019), South Africa country case

Skills and human resources

Additive Manufacturing is just one of the technologies that is associated with the digitalisation of industry and work. Collaboratively, they may challenge current labour market and labour intensity. The latter is mainly related to automation but the former is associated with changing manufacturing jobs due to the adoption of AM. Different knowledge is needed and digital skills become important. A lack of expertise in 3D printing tends to slow down the development of this technology in Africa.

The first challenge is to reskill people in current manufacturing jobs and to provide the right digital skills to operate, maintain and repair 3D printers. The second challenge is to train industrial engineers. With AM, the focus in manufacturing shifts from knowledge about manufacturing processes to knowledge about modelling and design (Van Barneveld & Jansson, 2017), the materials used and the post-processing of the products. This requires skills in industrial engineering and design (Van Barneveld & Jansson, 2017). One would need to be able to transfer ideas into a digital model or adapt existing digital models for products. This would require some technical and creative skills. Some level of understanding of code and being able to code could be relevant as well. This is at the heart of AM. Other knowledge and skills are related to the equipment and materials used for AM, most importantly the 3D printer. Understanding how this machine works and how it should be set up for specific products as well as understanding relevant parameters for the production of products with different materials is important. Quality control and technologies used for post-processing are similar to those for 'traditional' manufacturing.

Creativity is also an important skill. With AM, international competition on low costs of labour cannot be sustained in manufacturing. The factor of labour in AM is rather limited and mainly related to the design of models and post-processing. The former is, however, a global market due to the internet and many designs can be easily produced elsewhere or taken from online repositories. In that sense, competition on 3D models is more based on creativity. The case study in South Korea has shown that the government is especially investing in improved creativity of workers – as

f

figure 23

SWOT analysis for large scale adoption of additive manufacturing in Africa

strengths	weaknesses
setting up AM business is fairly easy and less capital intensive than traditional manufacturing industries	high-speed internet infrastructure (mobile or cabled) not available throughout Africa
already some use and experience with AM in several African countries that can be used to further expand the take-up of AM	lack of available financing for starting up AM businesses in some countries/regions
AM can produce customised products (for many applications) at low cost compared to traditional manufacturing	lack of innovation ecosystems and strong manufacturing sector in several African countries may result in slow take-up of AM

opportunities	threats
4IR promotes the local production of products leading to opportunities for AM in many sectors in Africa	international competition on low-cost labour not sustainable with AM
AM useful technology for production of wide variety of products in remote areas	reskilling might be needed in many countries, as digital and creative skills are needed for AM as well as specific technical skills
applications of AM can be useful for many (societal) challenges in Africa (healthcare, disaster response, etc.)	increased automatisation through AM may have effect on labour market and skills needs when replacing existing manufacturing companies in Africa
AM has the potential to bypass traditional industrial development by setting up small scale generic AM production facilities	

digital skills are fairly developed in the country – which is also related to the development of new products for AM. More established training and funding from governmental agencies, industry, NGOs and research institutes could spur rapid growth in the development of the technology.

Fostering the expansion of AM technologies therefore means supporting the development of digital skills in the curricula at school, in the higher education system and at the vocational training institutions. Development of relevant local content and applications in local languages, along with the enhancement of students' digital literacy skills, but also higher level engineering, coding and economic and creative capacity, are all vital to creating an enabling environment needed to harness the opportunities offered by AM. Between and within regions in Africa these conditions are currently highly uneven. Such curricula and education and training programmes should be developed in close collaboration and with the participation of the private sector to adapt the curricula to the needs of businesses.

Hardware and equipment

As mentioned previously, there are only around 500 3D printers in Africa that are associated with one of the largest 3D printing networks in the world (see Figure 21). African businesses' investment in the acquisition of hardware is obviously instrumental and needs to be supported and incentivised. In addition, and specific to AM, R&D and product design focus more on designing and 3D modelling, which requires high-end computers and data centres. Similarly, software to test/simulate product performance (dynamics, fatigue, durability, etc.) or processes are sometimes used to optimise product and process (Gramstra, 2018).

Acquisition of high-capacity computing systems are capital intensive for smaller firms, such as start-ups and innovators. To overcome this constraint, the establishment of technological platforms or technology incubation hubs that offer shared facilities and equipment to innovators to develop prototype products and components and that bring together innovators, established manufacturing businesses, academia and other key stakeholders should be supported and promoted, as is done in the United States or in Europe. Interestingly, the National Industrial Research and Development Agency (NIRDA) in Rwanda is looking to implement such a facility (called a STEM Lab Facility) of which the core functions will be to: i) identify (homegrown) solutions for local needs (supporting the development of specific ultra-modern technologies as part of the 'Made in Rwanda' brand), ii) incubate young Rwandan innovators with a keen interest in STEM-related industrial product development, iii) enable industry to outsource R&D to a lab with the right equipment, standards, service provided (encouraging industry to commission applied research and development projects at commercial prices), and iv) inspire the wider community through the investment in emerging technology (encouraging industry to invest in R&D and manufacture modern hardware products on an industrial scale).

Access to finance

The investment costs for an AM system came to approximately $73,000 in 2011, but the machine costs are decreasing (Thomas & Gilbert, 2014). The costs for AM with polymers are lower than for metals by roughly a factor of 10. The capital cost for 3D printing equipment depends on the type of products that are produced and the scale of production. Whereas some 3D printers currently cost around $1,000-$2,500, bigger 3D printers – required for instance in the aviation industry – may cost 1,000 times that amount (A.L. Abeliansky, 2015). The investment in equipment may thus be rather limited for a start-up in its early stage.

For more established African manufacturing companies that want to transition to AM technologies, depending on the type (and complexity) of products that will be produced, the type of materials that will be used and the wished-for number of 3D printers in the factory, costs can increase significantly. In addition, other significant costs are related to buildings and personnel (training) and may vary by location (country). There is also a perceived risk associated with the introduction of a new technology that bankers are uneasy to take when lending money to businesses.

Providing debt financing (e.g. through a guarantee fund to take the risk element away from banks) to mature manufacturing companies to invest in AM technologies (tangible and intangible investment) will be instrumental to scale up the take-up of AM in the African manufacturing sector.

5.2 DRONES

The following sections will (i) introduce drone technology, (ii) give an overview of drones' potential impacts and global use trends, (iii) explain the reasons why drones are important for Africa and discuss the opportunities, (iv) present the current applications and markets of drones in Africa, and finally (v) recommend actions for the take-up of drones in Africa.

5.2.1 Introducing drones

Drones, or Unmanned Aerial Vehicles (UAVs), are essentially an umbrella term for a range of various types of unmanned, flying vehicles controlled remotely. To break down the concept a little further, a distinction is sometimes made between UAVs and UASs. UAVs, unmanned aerial vehicles, refer to the physical aircraft itself whereas the UAS, unmanned aircraft system, is slightly broader as it includes the UAVs as well as the ground controller (human or computer), the communication system between the controller and the vehicle and other surrounding systems of guidance, navigation and control elements. The overarching category of drones can be broken down further into more specific subclasses. This is usually done on the basis of their weight and size, which results in a spectrum from micro and small-scale vehicles up to larger aircraft[88]. A further distinction can be made, based on whether drones are equipped with fixed or rotary wings. One key difference in this regard is that rotary-winged drones, sometimes referred to as quadcopters, can both take off and land vertically whereas fixed-wing drones do so horizontally[89].

Another characteristic of drones and therefore a basis for further categorisation is the level of control that the pilot or operator has over the vehicle. The different levels of control can be described as follows[90].

- Full manual: the pilot has full, unaided control of the aircraft;
- Aided manual: the pilot is in control but is aided by aircraft-mounted sensors, such as accelerometers, tilt sensors or GPS sensors;
- Partially automated: the pilot is typically responsible for setting up the flight, including parameters such as waypoints (an intermediate point or place on a route or line of travel) and speed when launching the drone. But, once the drone is airborne, the autopilot takes over and the pilot is only needed in case of an emergency or a change in flight plan;
- Fully automated: once the aircraft is launched, the pilot does not maintain any form of control.

Drone technology has its origins in the military where it has been developed and used for the purposes of intelligence, surveillance, reconnaissance, etc. Military uses of UAVs go back to the latter half of the 19th century[91]. However, since then the technology has been increasingly applied for commercial and recreational purposes in a civilian context[92]. These applications, however, are relatively recent. As a result, drone technology is still seen as somewhat immature in the global north[93]. On one hand, the technology can be regarded as mature in the sense that multiple commercial models exist today for which there is a relatively clear and growing market. On the other hand, the wide adoption of these is simultaneously held back by the lack of or restrictiveness of regulatory frameworks. Interestingly, drones appear to be more prevalent in Africa due to regulations being less restrictive there as well as a more accepting approach towards testing the technology on behalf of national governments[94].

5.2.2 Overview of potential impacts and global use trends

Drones have frequently been described as 'game-changers', having an impact in a multitude of different fields. This section will describe the impacts of drones, both potential and observed, along the following dimensions: politics, economics, society, the legal context and finally the environment.

POTENTIAL ECONOMIC IMPACT

Drones are expected to have a major economic impact in multiple domains. This is also why drones have been discussed in relation to the idea of 'leapfrogging' in terms of stages of economic development[95]. Firstly, the current sentiment is that UAVs will partly address future mobility needs by replacing services on ground, rail, water and in the air[96]. The level of integration between drones and manned counterparts still remains to be seen but at least some degree of integration is to be expected. One example of this is the use of drones in freight transportation. Within the private sector, there seems to be particular interest in the use of drones for the purposes of cargo carrying[97]. Economic impacts are not limited to new technological possibilities but will also include effects on employment. The proliferation of drones and their integration into airspace, for instance, will have impacts on the workforce in the aviation industry by generating new jobs in manufacturing and services sectors.

Secondly, drones will play a more and more important role in decision-making processes in various economic sectors by providing aerial mapping and measurement technologies[98]. One such sector that is of particular significance to the African context is agriculture. In fact, agriculture has been described as one of the primary sectors in which drones are likely to be deployed commercially[99]. The benefits of drones have already been demonstrated in fresh water management in terms of labour and time savings[100]. Beyond this, they are also capable of providing benefits to farmers on several levels. At the most basic level, they can give farmers aerial images of their crops which allows them to visualise changes that could otherwise never be seen from the ground. Going one step further, drones can be easily equipped with sensors at a relatively low cost. By doing so, drones will also have the ability to collect multispectral imaging data. For agricultural purposes, this refers to data such as the Normalized Difference Vegetation Index (NDVI) and infrared (IR) images. This multispectral data can be used to gain additional insights and conduct crop inventories and yield estimates. Furthermore, the data collected by drones can also be used for agriculture planning in surveying, conducting volume estimates and modelling draining and irrigation as well as generating maps. In Nigeria, for instance, drone imagery has been used to inform the construction of rice paddies and water management systems[101].

POTENTIAL SOCIAL IMPACT

With regard to the societal impact of drones, the focus of the public discourse has been on relief provision as well as the distribution of humanitarian aid[102]. Specifically, there is widespread consensus that drones can strengthen humanitarian work through quick and high-quality localised need assessments in particular[103]. Drones have already been used for several purposes, including the provision of real time information and situation monitoring, public information and advocacy, search and rescue, mapping, logistics and package-delivery in Haiti and the Philippines[104]. In the future, one of the most likely areas of application for drones will be the delivery of small medical supplies such as vaccines. However, more research is needed as to the comparative advantages of UAVs in this way, particularly for integrating aerial observation data, needs and damage assessment data, and other humanitarian functions like search and rescue[105].

From a community perspective, another example of societal impact is that drones could offer remote and indigenous communities the opportunity to create more social equity as these typically have to cope with high costs of living. On the other hand, there is also a risk that certain drone-based services become premium services, in which case access is exclusive and inequality could be maintained[106].

On a more general level, drones will also have societal impact by creating challenges regarding their everyday use. For instance, challenges are likely to arise in matters of access to airspace, standards and best practices regarding the use of drones, and licensing and training requirements for those who operate them. These issues will have to be addressed by frameworks for regulation and governance in order to provide clarity and stability on the corresponding rules and transparency of decision-making[107]. The regulatory and governance sides of these questions will be discussed below but they will ultimately shape the social impact that drones will have by determining what is possible and how drones will be used in society.

POTENTIAL LEGAL IMPACT

Their legal impact is still relatively limited at present but will become more pronounced in the near future. In essence, legal and regulatory implications stem from the simple fact that the developments in drone technologies and the application thereof across different contexts has occurred at a faster rate than the corresponding legal and regulatory frameworks have adapted[108]. This has created a simple but increasingly pressing need for appropriate legal and regulatory frameworks to be developed in order to govern and guide the operation of drones and to provide a degree of certainty to all stakeholders intending to introduce or adopt them. The necessary aspects of these frameworks will be discussed below but they must at least balance the encouragement of drone use against the integration with existing vehicles and aircraft, address exemptions that may be needed in special cases as well as ensure the protection of citizens' privacy.

At present, typical responses entail the extensions of existing regulatory frameworks. For instance, in some cases commercial drones fall under existing regulatory frameworks intended for the aviation sector. However, given that the latter have been designed based on older and different technologies, they are largely ill-equipped to deal with issues related to the use of drones and are at risk of being rendered obsolete by future developments[109]. The increased proliferation of drones is therefore raising concerns regarding security and public safety, for a large part because drone activity is inherently more heterogenous than that of manned aircraft and therefore harder to detect[110]. These challenges mean relevant regulatory frameworks either need to be updated or developed.

Some tentative regulatory responses can already be observed around the world and these commonly address administrative rules regarding licensing, training, registration and insurance; operational limitations in terms of weight, flight altitude and VLOS (visual line of sight); and airspace management issues such as flight authorisation and the designation of flying or non-flying zones[111] (see, for example, Figure 24, which shows no-fly zones in South Africa). In sum, the responses that can be observed today can be considered on a spectrum. At one end are explicitly restrictive responses in which the use of drones is banned altogether, as is the case in Algeria, Libya, Egypt, and Ethiopia. At the other end of the spectrum are more permissive regimes in which drones can be used relatively freely once certain basic requirements are met, as is the case in China[112]. Along the middle of this spectrum are mixed approaches in which there are restrictions in terms of VLOS, the number of drones per pilot and flying zones.

POLITICAL IMPACT

The proliferation of drones is already having a political impact around the world by putting pressure on public administrators, regulators and policy makers to develop new policies and regulations and adapt existing systems for the domains in which drones are already being used or will be used in the future. In many countries, dedicated regulatory frameworks to govern the use of drones are missing altogether or are explicitly restrictive. Therefore, the adoption of drone technology goes hand in hand with the development of appropriate governance and regulatory frameworks.

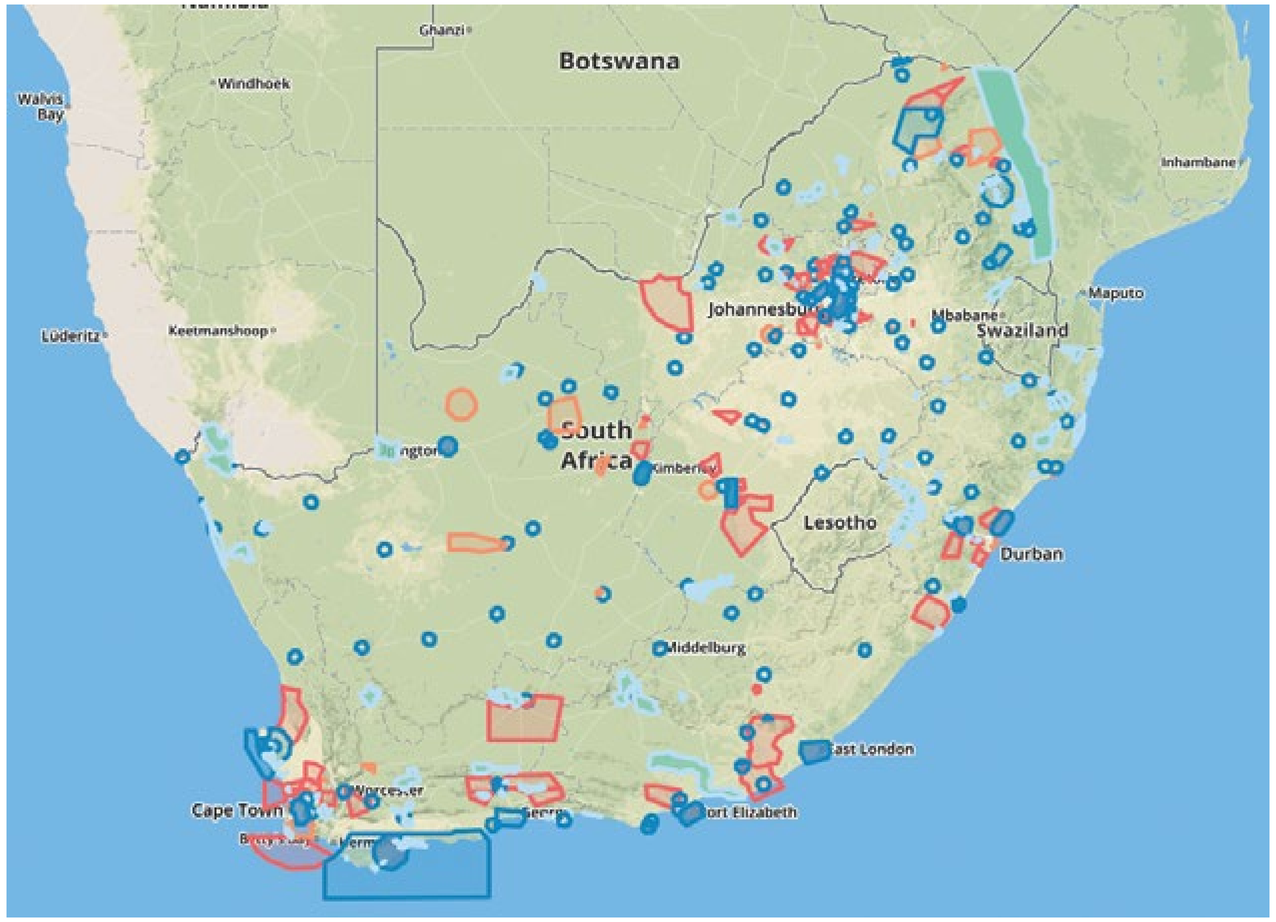
Furthermore, another political impact of the adoption of drone technologies especially relevant to the African context would be in the area of land registration[113]. Based on figures from 2013, only around 30% of land in developing countries is formally registered. From an administrative perspective, the lack of formal land registration implies that land-owners are also missing out on certain benefits. Effective land registration would improve land tenure security, real estate markets, access to credit, taxation, dispute resolution and urban planning. Drones could improve access to these types of benefits, especially in developing countries.

Digitalising land registration. In Kenya, the existing land registration system is largely based on aerial photographs in which parcel boundaries marked by hedges and fences have to be identified manually. In this context, the adoption of drones would provide a significant opportunity to improve land registration processes and systems, thereby enabling citizens to gain access to the associated benefits.

f

figure 24

an overview of no-fly zones for drones in South Africa



SOURCE
Mapbox (2019)

ENVIRONMENTAL IMPACT

The impact that drones will have on the environment is somewhat debated. On the one hand, there are some concerns regarding the environmental impact of drones. These concerns are primarily related to increased levels of noise pollution and vibrations as well as light pollution and the impact that this will have on both humans and wildlife[114]. In urban areas in particular, this is an area for concern as noise volumes are likely to exceed desired or even legal limits and this therefore also has a bearing on the acceptance of the technology amongst civilians.

Similarly, there are also concerns regarding energy consumption, emissions and the overall sustainability of drone-based transport[115]. The aviation sector in general is currently a major contributor to global CO_2 emissions. The question is therefore whether drones are actually more energy-efficient than existing modes of transportation used in, for instance, freight delivery. Furthermore, the increased use of drones will also increase the demand for electricity. Studies argue that the energy efficiency of drone delivery is limited to short-distance transportation of lightweight payloads[116]. In addition, energy will also be needed for supporting infrastructure such as distribution centres, warehouses and battery charging facilities. Currently, researchers are studying efficient set-ups for drones to minimise their environmental impact.

More positive environmental impacts are associated with precision farming. Drone-supported precision farming could reduce pollution through the more precise targeting of pesticides and fertilisers[117]. It also reduces water waste through improved efficiency in the use of water as compared to other irrigation systems.

MARKET SIZE OF DRONE TECHNOLOGY

The market for UAVs is clearly growing. Although there is some debate about the precise definition of the drone market and its boundaries (i.e. military, civil, commercial, leisure), there is a general consensus that it will grow into a multi-billion dollar market within the next five to ten years[118]. As an indication, estimates by Goldman Sachs predict a global market size worth $100 billion by 2020, which includes a $13 billion forecast for commercial and civil operations as well as an estimated total spending on military and civil drones of $17.5 billion in the US, $4.5 billion in China and $3.5 billion in the UK[119]. Within the commercial drone market segment, agriculture is considered to be the most significant, dominating other drone sectors[120]. At the moment, Europe and north America are currently leading the market while the rest of the world, including ACP[121] countries (African, Caribbean and Pacific Group of States), are lagging behind in terms of demand and production[122]. Military manufacturers are primarily based in the US, Europe, South Africa and Israel[123]. Some of the key actors in the commercial drone market are Lockheed Martin, DJI, AeroVironment Inc., General Atomics, Israel Aerospace Industries and Parrot SA[124]. Regarding the take-up of drone technologies, projections by Gartner indicate that there will be 10 times more commercial drones than manned aircraft by 2020[125]. This would approximately equate to 230,500 commercially operated drones around the globe. Leisure drones are already much more prevalent, as estimates indicate there were some 3 million operative units in 2017[126].

5.2.3 Why are drones important for Africa? What are the opportunities?

Drone production is growing extremely fast. In 2017, with almost three million drones produced worldwide, this number was 39% higher than in 2016. While commercial drones only accounted for 110,000 units in 2016, their growth is even faster than the growth of personal drones, with nearly 60% growth in 2017 when production reached 174,000 units. The total market for commercial and personal drones combined is expected to be worth $11.2 billion by 2020. Worldwide, the most dominating segment by 2030 is expected to be drones for industrial inspection in oil and gas, energy, infrastructure and transportation. Other major markets are the military and agriculture. Delivery drones are expected to play a smaller role in the future compared to industrial applications[127].

Africa also stands to benefit from drones. They can help alleviate transport constraints such as bad road infrastructure and the high costs for land transport by enabling increased speed of delivery at lower cost. For instance, the advantages of drones can be observed when it comes to the delivery of vaccines compared to traditional transportation methods[128]. In general, drones, both autonomous and remotely controlled, have a large potential in bridging the transport infrastructure gap. While drones will not remove the need to build roads for the transport of heavy goods and people, they do offer the opportunity to design transport infrastructure in new ways and to reduce the need for 'last mile' road connectivity.

In the African agriculture sector, they have the potential to scout crops and to reduce the work involved in seed planting and fertilisation, thereby raising yields. Automated irrigation systems can enhance precision and reduce manual labour. Furthermore, drones can support precision farming in providing data for various purposes such as farm area measurement, general monitoring, yield estimation, crop health management, disease and pest identification, as well as providing early warning signs. Precision farming therefore represents a major economic opportunity for improving crop production and generating profit[129]. In addition, employment is also a major area where drones are likely to have an impact. In the case of precision farming, employment can be affected in both positive and negative ways. On the one hand, employment could be affected for those involved in the monitoring of natural resources, crops and assets as at least some of these tasks can be automated to a degree. Having said that, drones would also open up areas of activities that are not currently being carried out by humans. For instance, few are involved in patrolling, scouting and inspecting particularly remote areas, making drones a welcome addition. The creation of new drone-enabled or drone-related activities would therefore also create desirable employment opportunities and have also been cited as a way in which communities in rural areas of Africa can retain young people[130].

Similar to the use of drones are airships, which could not only help to reach more consumers due to their high transportation capacity but could also work as relays for mobile broadband[131].

5.2.4 Current applications of drones in Africa

The desk research and interviews identified 59 drone-related companies present in 16 African countries. This number is not exhaustive but gives an idea of the use trends in Africa. Current applications are found in modernised services and financial inclusion as well as in agriculture, health, industry and energy. Figure 25 illustrates the trends in market applications and investments. The map is only used for illustration purposes and is not intended to give an exhaustive overview of current drone applications and investments in start-ups across the continent.

Drone-related start-ups have successfully raised venture capital funding. Examples of this are Crunchbase, a financial service company in Tunisia which was funded up to $7,838,822, and two companies in South Africa, which were funded up to a total of $4,754,861, and one Nigerian delivery company, which was funded up to $1,000,000. It should be noted that investigations conducted did not show funding in countries other than those noted on the map.

In South Africa, the South African Federation of Unmanned Aircraft Systems (SAFU) – a new UAV industry association – was launched in Johannesburg in June 2019. As a link between regulatory authorities, such as the South African Civil Aviation Authority (SACAA), and its members, its intention is to grow and shape the future of the UAV industry.

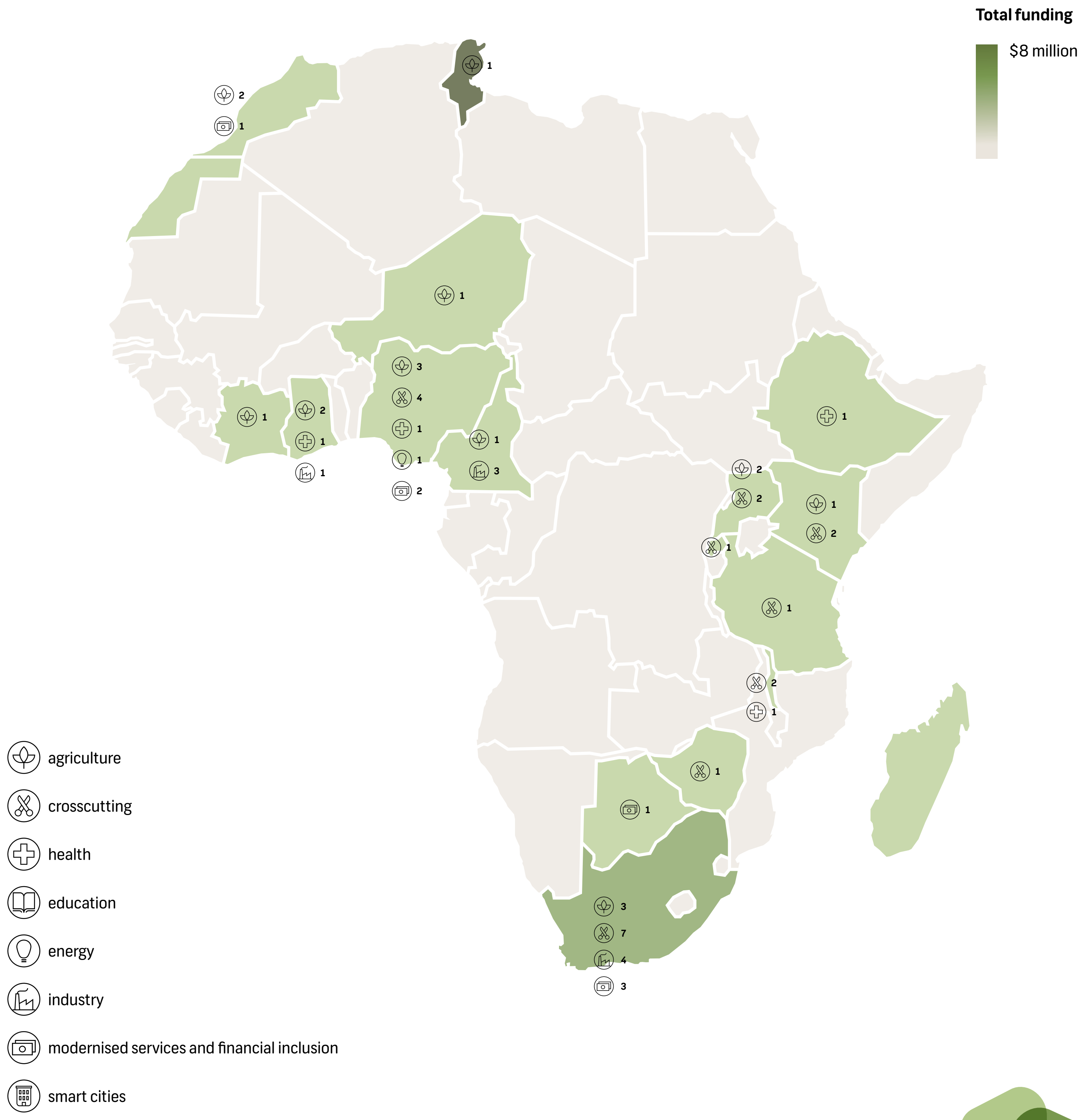
In terms of applications, Google is, for example, researching and testing both airships and also high-altitude balloons to provide cell and internet coverage[133]. There are also applications in energy, agriculture and health. In terms of energy, the use of drone technology is mostly focused on the oil industry. This can be seen especially in Nigeria, where companies such as Beatdrone as well as Oando Plc are located (see box 2).

In the area of agriculture, the take-up of drones is significant and there are many examples from across the continent that illustrate different use cases. In many cases, this also presents an overlap with other 4IR technologies. Morocco, for instance, is home to several applications of 4IR technologies in agriculture involving the deployment of drones in combination with big data analytics and Artificial Intelligence.

f

figure 25

drone market applications and investment in startups: trends in Africa



ADAPTED FROM
Technopolis Group (2019), based on desk research and interviews

b

box 02

drone applications for energy in Nigeria

Beatdrone is a multi-sector drone service provider primarily operating in oil and gas. It provides detailed optical imagery in case of flare stack head inspections without the need to shut down the facility as well as early detection of weak pipelines while providing real time security surveillance. Specifically in the oil and gas sector as a sensitive sector, where companies lose millions of dollars every day, they use drones for detailed optical imagery in case of flare stack head inspections without the need to shut down the facility as well as early detection of weak pipelines while providing real time security surveillance. A normal inspection of a flare stack takes about 1-2 weeks for an offshore rig, and hundreds of thousands of barrels are drilled per day, so the company loses millions when it is shut down. However, with drones, they do not need to shut it down. Beatdrone also uses their technology, which can go down to the seabed and collect data by mapping the sea floor and be used for the analysis of equipment used for drilling. This limits the time which divers spend under the water to do this, saving time and increasing the value for money.

Concerning the infrastructure sector, it can carry out topography mapping for construction companies, map and identify dump/mining sites for mining companies, do mast structural integrity inspections for telcos and carry out inspection of large solar installations for renewable energy projects.

As for agriculture, they help farmers spray pesticides on their farms (spraying a hectare with a drone takes about 15 minutes compared to the 10 hours which farmers cover through subsistence farming), engage in crop supervision and map farmlands. Farmers can request for drones and schedule a date for drone deployment and then make their payment. At the moment, they are covering over 30,000 hectares of land in Nigeria.

SOURCE Technopolis Group (2019), Nigeria country case

French start-up Airinov expanded to Morocco with an exclusive partnership with Etafat, a Moroccan company specialising, among other things, in topography, and is using drones with sophisticated sensors for the diagnosis of the vegetation without contact, thanks to the overflights operated by the company Etafat. It transmits this data to Airinov, which is responsible for transforming it into agronomic advice via certified algorithms, optimising inputs and improving yields through optimal use of fertilisers[134].

Furthermore, Nigerian Orbital Solutions uses Big Data from digital farmer profiles using the geospatial platform Agroexchange and drone technology to provide small scale farmers with technology driven advisory services. The ultimate goal is to facilitate aggregation and reduce post-harvest losses for smallholder farmers by using geospatial data and farmer profiles to provide information about the optimal location of farming production and processing. In Cameroon, the start-up Will & Brothers is working on an Artificial Intelligence (AI) system called 'Cyclops', which will enable drones to detect people and identify different types of animals, offering a service of use to Cameroonian farmers.

As can already be seen in the aforementioned examples, drones are a promising enabler of precision agriculture. See Box 3 for an example of the application of drones for precision agriculture in Uganda.

Still in Nigeria, the Lagos-based start-up Track Your Build uses drones to collect data on vegetation, plant counting and yield prediction, plant health, height and field performance, nitrogen content and many other types of data in order to maximise field productivity while reducing environmental impact.

South Africa, Malawi, Rwanda and several countries in east Africa have implemented legislation for the use of drones and are experimenting with their use to deliver humanitarian services. Other countries, including Kenya, Ghana and Tanzania, have issued updated drone regulatory guidelines and announced future initiatives. Current use cases of drones in these countries include the Zipline[136] project in Rwanda and Ghana that focuses on the delivery of medical supplies (see box 4)[137].

b

box 03

drone applications for precision agriculture in Uganda

In Uganda, drones are used in the Technical Centre for Agricultural and Rural Co-operation CTA's 'Eyes in the Sky' project at the Igara Tea Factory. The drones assist smallholder farmers in the provision of a crop inventory (crop count and yield estimations) and management advice. This help farmers calculate yields and their seed and fertiliser needs. Over 4,000 digitalised profiles of smallholder farmers were created. These profiles map farms' location, size and productivity. Based on the data gathered by drones, farmers can apply for credit since the collected information can serve as collateral[135].

This project started as a pilot since 2017 and will operate in coffee plantations, carrying out a census of coffee farms as well as obtaining a geo-reference inventory of coffee farms. Within the extensive approach adopted in the project including policymaking, research, capacity building, enterprise development, etc, the activities with applicability of drones involve: Capacity building focusing on piloting drones and their responsible use, data acquisition and processing and a cost sharing approach for the acquisition of equipment and software for data analysis and interpretation. A total of 30 youth-led enterprises were selected across 17 counties via competitive processes to participate in the project and this number is growing. Over 16,000 farmers will benefit in 2019 and a total of 58 institutions have sought advice and input from consortium members.

SOURCE Technopolis Group (2019), Uganda country case

5.2.5 What needs to be done to take advantage of drones in Africa?

Overall, drone technology is regarded as having considerable potential with particular relevance to the context of African countries (see figure 26). Part of the appeal of drones is that they can be deployed with high manoeuvrability as well as relative ease of use at a relatively low cost. Moreover, they are capable of accessing remote and difficult-to-reach locations. This makes drones highly versatile devices that can be deployed for many purposes in a wide range of sectors. Based on the use cases and applications discussed in this report, agriculture has emerged as an illustrative case of a sector that, particularly in Africa, stands to benefit from the widespread adoption of drones. Notably, this would enable precision agriculture, crop and livestock monitoring, as well as disease identification in vegetation, all of which would contribute towards improving agricultural productivity. Beyond agriculture, compelling use-cases observed in Africa include the deployment of drones in the oil and gas sector for security purposes as well as the delivery of medical supplies.

Despite the potential associated with drone technology, it must also be noted that overall drone adoption in Africa is still in a nascent state. However, based on some of the specific use cases and initiatives that have been reviewed, some recommendations can be formulated for steps that can be taken in support of scale-up.

At a fundamental level, one of the key enabling factors for all 4IR technologies is an adequate ICT and electricity infrastructure. Specifically, in order to function properly, drones, as well as the other 4IR technologies, need reliable access to the electricity network as well as a high-speed internet connection. This is especially important for drones to operate on a relatively large scale in a safe and secure manner. Beyond these infrastructure requirements, however, there are challenges that need to be addressed that are specific to drone adoption. Our analysis combined with the country case studies and interviews helped us identify key enabling factors, actions and policies which must be enhanced in order to unlock the potential of drones in Africa.

RULES AND REGULATIONS

First and foremost, the primary precondition for large-scale adoption is rules and regulations. Amongst other things, these are necessary to govern the overall airspace and determine the place of drones within the broader aviation system, to determine no-fly or restricted use zones and to provide the necessary infrastructure requirements such as dedicated 'droneports' and charging stations. At this point in time, there are around 15 countries in Africa where drone-specific regulations are in place. Outside these, there are either no regulations that cover drone use at all or regulatory systems that significantly restrict their use or maintain an outright ban. Once relevant regulations are put in place that are relatively permissive and transparent, this

f

figure 26

SWOT analysis for large scale adoption of drones in Africa

strengths	weaknesses
drones can be deployed with relative ease and at a relatively low cost	there is a general lack of experience globally concerning the impact of drone crashes and other safety-related concerns
they have the potential to provide access to remote areas or specific locations that could otherwise not be reached	drones are highly dependent on a range of complementary technologies such as geo-fencing, batteries and broadband to function properly
drones are also capable of providing real-time detailed views from above, enabling enhanced situational awareness as well as faster and informed decision-making on the ground	drones have an impact on a range of 'softer' factors such as the invasion of privacy and noise pollution

opportunities	threats (or challenges for increased uptake)
the use of drones in agriculture is already becoming more common in Africa. Opportunities therefore include the use of drones in precision agriculture and real-time weather forecasting	economies typically have a weak manufacturing base, which makes the manufacturing of drone technology more difficult and costly (although this does not necessarily affect the potential take-up of drones)
beyond agriculture, there are emerging applications in energy and healthcare that can be scaled up in the future	whilst being relatively low cost, drones are still not affordable to many potential users, especially smallholders and other small-scale farmers
there is a general awareness amongst African national governments regarding the importance of broadband connectivity, skills development, and the willingness to experiment with 4IR solutions such as drones	relevant regulatory systems are still missing or too restrictive in many African countries, holding back take-up

b

box 04

drone applications for health in a humanitarian context

Zipline in Rwanda can deliver up to 500 deliveries of up to 1.8 kilogrammes of medical payload (such as blood for transfusion) in an 80 kilometre radius within 30 minutes or less. Health workers can order medical products by text message. These are then delivered by the drone by parachute airdrop[138 139]. Drones can also spot landmines by using thermal cameras to detect landmines after their internal explosives get heated up by the sun. This can help to make areas available for land use in post-conflict zones which cannot be cleared by traditional methods. The land can also be cleared of mines in a more efficient way[140]. Moreover, Africa already has the world's largest test corridor for drones in Malawi, with over 5,000 square kilometres. It is specifically dedicated to testing the humanitarian and development use of drones[141 142].

SOURCE Technopolis Group (2019)

provides a measure of certainty needed by private firms to adopt them on a larger scale and for markets to develop. It would therefore be desirable to support dissemination activities in terms of best practices when it comes to drone policy and regulation. For instance, countries such as Morocco, Algeria, Libya, Egypt and Ethiopia, where regulations are either absent or restrictive, would benefit from learning from the permissive approaches that have been implemented in South Africa, Rwanda and Malawi.

HARDWARE AND EQUIPMENT

The vast majority of drone manufacturers are based in the US, Europe or Asia. Therefore, it would be desirable to build up domestic assembly and manufacturing capabilities in Africa. Here, Cameroon may serve as an illustrative example where start-ups such as Will & Brothers have already started offering drones that were partially Cameroon-made to farmers. Cases where these emerging capabilities can already be seen should therefore be supported in scaling up so that technological dependence on foreign manufacturers can be reduced in the long run.

SKILLS AND HUMAN RESOURCES

Despite the fact that drones are in principle relatively easy to use, relevant human capital and capacity building is still a necessity. For example, for agricultural applications, farmers will still need language training and technical support in the early phases of adoption[143]. Employment-wise, a workforce interacting with drone technology must be trained so that they have the necessary skills to plan flight itineraries and pilot UAVs but also to use data analysis software and GIS[144]. In the African context, this may represent somewhat of a challenge as there is a general lack of licensed drone pilot schools on the continent, with the only exception being South Africa[145]. Capacity building also involves technology intermediaries that provide UAS-based advisory services and actionable information. This implies capacity building of pilots and other stakeholders as well as the incorporation of GIS remote-sensing experts and agronomists. providing agronomic or spatial planning advice[146]. In order to provide guidance in this context, regulations for the harmonisation of training and licensing will also have to be developed.

ACCESS TO FINANCE

Due to the fact that drone technology originates from the military, the vast majority of the cost of its technological development has also been 'absorbed' by the military[147]. After the underlying technology was developed to a relatively mature level, technology transfer to civilian or commercial unmanned aircraft and operation systems in non-military settings was made possible. This means that, today, drones (both civilian and military) are comparatively cheaper to use than commercial aircraft, fighter jets, police helicopters and even ground personnel[148]. Furthermore, the costs of drones are expected to further decrease in the future since the personal and commercial drone markets are expected to overlap more and more, allowing the use of cheap leisure drones for commercial applications[149].

However, at the moment, there are still question marks about the affordability of the technology in the context of small-scale agriculture in developing economies. Despite the relatively low cost of drones, there is a lack of evidence about the returns on investment for smallholders. While larger agribusinesses in countries such as Mauritius, Morocco, South Africa and Sudan have already adopted the technology, smallholdings are more likely to be able to afford it only as part of a collective[150]. Therefore, in the case of agriculture, more research is necessary regarding the types of interventions that are needed to make drone technology.

5.3 ARTIFICIAL INTELLIGENCE

Artificial Intelligence (AI) applications are quickly becoming an integral part of nearly all areas of our daily lives. While AI applications already affect society and the economy today, there is general agreement that what we see is just the beginning of AI disruption and that changes still to come will represent one of the biggest technological revolutions in human history. AI offers the potential to significantly increase the agility of information processing. This is due to an increased ability to process large and complex data sets at speed, reducing the scope for human error. This is facilitated by both an increase in the number of decisions that can be made on the basis of relevant data and improved decisions. This may bring significant benefits for any organisation that relies on the processing and analysis of information.

The following sections will (i) introduce AI technology, (ii) give an overview of the potential impacts and global use trends for AI, (iii) explain the reasons why AI is important for Africa and discuss the opportunities, (iv) present the current applications and markets of AI in Africa, and finally (v) recommend actions for the take-up of AI in Africa.

5.3.1 Introducing Artificial Intelligence

AI can be considered a disruptive technology. It is likely to affect all parts of the economy, many aspects of society and the ways in which we work and live. The concept of AI is constantly evolving and often what would once have been considered AI is now taken for granted as something that a computing system can do.

It is useful to distinguish some key terms related to AI. Firstly, there is a distinction between narrow AI, which refers to purpose-driven specific AI systems simulating certain cognitive functions of humans, such as problem solving or making decisions. This is separate from a general AI system, which would be truly autonomous in its reasoning and able to self-improve entirely independently from humans. This is an as yet unreached milestone, which is referred to as 'singularity'[151].

AI is built on and linked to various technologies and methods, as presented in table 06. There are also direct links between AI and several of the other technologies under investigation in this study.

The term AI encompasses so many evolving systems and applications that it is not possible to attach this technology to a specific technological readiness level (TRL). Rather, some AI applications are already at a high TRL, including natural language processing and chatbots, fully self-driving cars (considered to be at a TRL of 7). Other AI systems are still in their infancy, at lower TRLs, such as autonomous surgical robotics, robotic personal assistants and cognitive cybersecurity. At a very low TRL are systems such as real time emotion analytics (Robotics Society Japan, 2015).

5.3.2 Overview of the potential impact of Artificial Intelligence and global use trends

AI is likely to have a significant impact in almost any field where (human) intelligence has a role to play. AI therefore has the potential to restructure the global economic system.

Potential economic impacts

The economic gains associated with AI technology are major drivers in its adoption, in particular when it comes to related productivity gains.

Productivity gains will come from business automation (including through robots) and enhancing the existing labour force's capabilities through assisted and augmented intelligence (PwC, 2017). AI will significantly boost the productivity of capital and labour as inputs of production by improving prediction, planning and decision-making. AI also has the potential to reduce error margins and the time spent on decisions. Big businesses are already reaping the rewards from AI solutions, from Amazon's AI-powered warehouse robots[152] to General Electric's use of AI for predictive maintenance of its industrial equipment. At the same time, only 20% of firms are using AI at scale, with another 40% experimenting with it (Bughin, Chui, &

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table 06

glossary of elements of AI

Elements of AI	Definition
Machine learning	Building a mathematical model or algorithm of data that improves performance in a given task with more and more experience or data to the point where they can perform them without this activity being programmed by humans.
Data mining	Collecting and studying large amounts of data for testing hypotheses or recognising patterns.
Information retrieval and semantic web	Gathering, saving, converting and connecting documents in such a way that machines can read and learn from it.
Speech recognition and natural language processing	Recognising and processing human speech.
Image processing/recognition and computer vision	Recognising objects and understanding the content of digital images and videos.
Robotics	Programmable or autonomous machines that can execute physical tasks, applying AI in real world scenarios.
Search systems and methods	Search systems compiled of algorithms that are developed to search for information in a complex database, in multiple (unstructured) sources or on the internet.
Knowledge representation and knowledge databases	Presenting information in such a way that a computer system can use this information to make choices and execute complex tasks.
Logic reasoning and probabilistic reasoning	Using logic and probability calculation to cope with uncertainties and use this to make decisions or to understand information.
Expert systems	Systems that can mimic decisions made by humans and subsequently solve complex issues.
Fuzzy systems	Logic systems producing organised outputs from incomplete, ambiguous, distorted or inaccurate inputs.
Planning and decision-making	Automated sequences of decisions making use of advanced algorithms.
Neural networks	Computational approach modelling the way a human brain solves problems with large clusters of connected neurons.

SOURCE
Technopolis Group based on Ming-Hwa Wang (2017), Elsevier (2018) and own definition

McCarthy, How to make AI work for your business, 2017). AI may allow the automation of many processes currently performed by humans, allowing finite human resources to focus their activity elsewhere. AI can also augment information provided for human decision-making, such as better predictions about the likelihood of a certain outcome. Private sector organisations may use this to gain a competitive edge in the market, while public sector or civil society organisations may use improved and faster analysis and decision-making to improve social outcomes. The biggest business benefits are expected to emerge in two business functions, namely supply chain management/manufacturing (by improving demand forecast accuracy) and marketing and sales (by personalising customer promotions) (Chui, Henke, & Miremadi, 2018). AI will likely generate personalised, enhanced and new products and services, which in turn will stimulate consumption and allow businesses to explore new opportunities and develop new revenue streams.

The impact on inequality between and within countries is a major concern linked to AI and the assumed threat that it poses to jobs, especially those involving many routine tasks. At this stage, there is no consensus as to whether AI will mostly displace or enhance existing jobs by automating routine tasks (Petropoulos, 2018; McKendrick, 2018; OECD, 2018). Nevertheless, there is a concern that AI will endanger the employment prospects of workers with low levels of skills or a lack of formal education.

Apart from AI's impact on individuals, it may also contribute to inequality between firms. The cumulative advantage of existing AI may act as a barrier to market competition unless adequate cloud-based services are available to new market entrants and small and medium enterprises (SMEs). What appears clear is that there is an important role for government and the state to play in channelling the AI disruption and cushioning its economic impact.

Potential social impacts

AI has both the potential to deliver considerable societal benefits and to exacerbate social inequalities.

When it comes to possible societal benefits, algorithmically-driven processes could expand economic opportunities for low income communities and support better outcomes for students (The Executive Office of the President, 2014). Applications in education may include tailoring lessons to a student's learning style or opening up courses through online platforms, making classes available to more people. Furthermore, AI could bring societal benefits such as improved quality of healthcare and faster drug discovery (Manyika, et al., 2013).

Possible applications of AI benefitting public health include the analysis of combinations of large data sets to predict outbreaks of epidemics such as dengue fever or tuberculosis and using machine learning to detect malnutrition using photos as data inputs (Abbany, 2018). Against the background of a predicted 57% increase of chronic disease prevalence by the World Health Organization, advancements in detecting and diagnosing such diseases are welcome. Other benefits of applying AI in healthcare include the advancement of treatments, the possibility of using virtual assistants, reduction of costs and the design of treatment plans. There are, however, also risks involved in using AI in healthcare, such as the potential for relatively new AI technologies to be less accurate and reliable, putting doctors and patients at risk and the fact that a programme will only be as good as the data that feeds it and will therefore need to be trained and constantly updated to identify new or exceptional diseases (Abbany, 2018).

Negative impacts of AI on society can arise from the potential for encoding discrimination in automated decisions, algorithmic bias and the possibilities for data exploitation (The Executive Office of the President, 2014; The Executive Office of the President, 2016). As AI systems are often trained on real-life data, they can include prejudices and stereotypes that currently exist or have existed in the past in decision-making.

Furthermore, AI may result in increased automation of knowledge work, which subsequently will change the nature of work for many people. Employees working in large-scale working environments will find routine tasks being automated, changing roles and work profiles. Education and retraining of workers will be necessary to get them ready for the jobs of the future. On the other hand, while more automation could bring more autonomy for workers, the increased use of sensors will also subject workers to more monitoring, lessening their autonomy in some respects.

Governments around the world will need to develop policy solutions for these challenges, which may include targeted efforts to remove bias from AI algorithms and data sets, investments in the development of skills and the creation of new regulations and standards (Dutton, 2018).

Potential legal impacts

The large number of possible applications of AI make it necessary for governments to adjust existing legislation and implement new laws and regulations in order to anticipate and respond to future challenges. There are a number of different ethical and regulatory aspects that need to be taken into account in the context of the rise of AI. These concern responsibility, digital security, privacy, autonomy and human dignity, competition and antitrust.

In 2018, the European Commission High-Level Expert Group on AI released a draft Ethics Guideline for Trustworthy AI, with a final version subsequently released in April 2019. The document sets out fundamental rights, principles and values that should be complied with when using AI technologies. The document also provides a list of requirements for trustworthy AI, an overview of technical and non-technical methods that can be used for its implementation and a non-exhaustive assessment list for trustworthy AI. The guideline addresses all relevant stakeholders developing, deploying or using AI (The European Commission's High-Level Expert Group on Artificial Intelligence, 2018).

There are also potential impacts in the field of law, too. The use of computers that can scan thousands of legal briefs and precedents to assist in pretrial research can save hundreds of thousands of hours of paralegal work for law firms.

Potential political impacts

AI could have multiple impacts on governments and politics, but policy makers also have a role to play in actively shaping AI.

It is claimed that AI could soon be used in political campaigns (Christou, 2018). Big Data analytics and machine learning for advertising (Datarama, 2018) have already been used in the 2016 US presidential election campaign and the 2017 French presidential campaign (Datarama, 2018) where the use of bots resulted in leaked emails. Thus far, most examples of these technologies being used in political campaigns are problematic, with algorithmic tools being used to misinform, mislead and confuse voters. However, AI could also be used to run campaigns in a more ethical and legitimate way, including educating voters on political issues or detecting misinformation. It is important that AI tools serve citizens and the general public rather than to aid dissemination of fake news.

Furthermore, AI could also be applied to understanding and analysing geopolitical risk. The company GeoQuant has, for example, developed a machine learning model to identify, track and price political risks based on real time events (Geoquant, 2019). The software scrapes the web for large volumes of relevant data and the machine learning model enables the identification and quantification of risk indicators. These kinds of developments allow risk managers to monitor how geopolitical risk events and political exposure will impact business and investment decisions. Outcomes could be tracked and predicted, to be used by governments, citizens and firms (Datarama, 2018).

Governments can influence the development and impact of AI. They can develop ethical codes and standards for the use and development of AI and make agreements on the global governance of AI (Ding, Triolo, & Sacks, 2018). Furthermore, they can spur innovation in this field by investing in the development and application of the technology. A number of countries have already formed a national strategy on AI, in which they commit to investing in fundamental and applied research, human capital, digital infrastructure and technology development.

Potential environmental impacts

According to the World Economic Forum (WEF), AI provides opportunities to address environmental challenges worldwide but, left unguided, it is also capable of accelerating the degradation of the environment (World Economic Forum, 2018b).

AI could help meet the challenges of climate change, biodiversity and conservation, maritime pollution, water security, clean air and weather and disaster resilience. Currently, most of the focus lies on automated and assisted intelligence to tackle these challenges with input from large and unstructured real-time data sets. The WEF warns governments that they should not only scale these pioneering innovations but should also put sustainability considerations at the centre of wider AI development and usage.

The WEF highlights several 'game changers', where AI is applied in combination with other Fourth Industrial Revolution technologies, with the potential to deliver transformative solutions. These are (1) autonomous and connected vehicles that might transform short-haul mobility while reducing greenhouse gas emissions, (2) distributed energy grids that could result in decarbonisation of the power grid, increase energy efficiency and expand the use of renewables, (3) smart agriculture or precision agriculture that allows for early detection of crop diseases and issues to optimise agricultural inputs and returns, (4) weather forecasting and climate modelling, (5) community disaster-response data and analytics platforms, increasing the speed and effectiveness to which people can respond to disasters, (6) using machine and deep learning to optimise water resource management, (7) AI-designed intelligent, connected and liveable cities, with better urban planning resulting in minimal air pollution and environmental impact, (8) an oceans data platform that improves decision-making in species management, national resource management and climate resilience and (9) the Earth Bank of Codes, which uses a combination of Blockchain, AI, advanced sensors and the Internet of Things to register natural products and processes that should enable the replication of products and processes from nature (bio-inspired innovations such as blood pressure medication derived from viper venom).

A lot of work is underway in relation to the above game changers. Several government agencies are already using data to improve their decision-making and large technology companies such as Microsoft, Google and Amazon are investing in programmes to apply technology to tackle environmental challenges. Microsoft, for example, has committed $50 million over five years to their AI for Earth programme in which they award grants to projects that put Microsoft cloud and AI tools into use to address climate, agriculture, biodiversity and water issues (Microsoft, 2019).

Market size of AI technologies

AI is expected to have a very significant, transformative impact on the world economy, by one estimate increasing global GDP by up to 14% between 2018 and 2030 – the equivalent of $15.7 trillion (PwC, 2018). Another study estimates global economic activity to increase by 16% by 2030 compared to 2018 thanks to the adoption and absorption of AI (Bughin, Seong, Manyika, Chui, & Joshi, 2018). A third study sees AI doubling annual economic growth rates by 2035 in 12 developed economies, while increasing labour productivity by up to 40% (Accenture, 2019).

AI will have a major impact on a large number of markets, as it has many possible application domains. Table 7 provides a comprehensive overview of sectors and the current application of AI therein.

Adoption rates per sector differ. Sectors such as the high-tech and automotive industry together with the finance industry are known for their rapid adoption of AI solutions. Automotive was one of the first sectors that implemented advanced robotics at scale for manufacturing and is also using AI technologies to develop self-driving cars. Earlier adopters are often digitally mature, larger businesses. Less digitalised industries such as the energy sector and transportation sector are slightly slower to adopt AI, but adoption in service operations is taking place. Sectors that are among the slowest to adopt AI are healthcare and education. This is because practitioners and administrators are concerned that customers will not accept the technology or that there might be regulatory issues (Bughin, et al., 2017).

When we consider the potential impact that AI could have per sector, we see a different order of industries (PwC, 2017). Most impact is actually expected in the healthcare sector (3.7 on a scale from 1-5). Other industries where impact is expected to be high are automotive and financial services.

5.3.3 Why is Artificial Intelligence important for Africa? What are the opportunities?

Opportunities for Africa

AI is expected to offer vast opportunities in several important sectors for Africa. Sectors such as healthcare, agriculture, education, government, finance and transportation are expected to experience positive changes with the application of AI. In particular, AI may change the current situation in which African working productivity has stagnated.

Process automation can enable businesses to run on leaner models. Rather than displacing employees, machines can empower low-skilled workers and equip them to take on more-complex responsibilities. This, in turn, can help meet an urgent need for countries lacking widespread access to education and skills training. The ability to use and analyse data is going to be one of the biggest drivers of business in the future. This enables a better understanding of one's business and customer requirements. The shift towards a more mobile-centric landscape that sees people expecting to have access to real-time information for informed decision-making is one major driver in this area. Countries in Africa are in a strong position to benefit from this as they have long been mobile-first marketplaces.

In addition, AI's role in an African context is not so much in helping to improve education itself but rather education on AI and its potential applications is needed to take full advantage of this technology for socioeconomic development. AI can also plug skills gaps, for example by carrying out tasks for which the local workforce lacks the appropriate skills.

In the healthcare sector, AI can help create better tailored, higher quality and more accessible healthcare solutions, improving public health outcomes. By making use of digital health records, AI can help make the provision of public health more efficient and responsive to citizens' needs.

Furthermore, AI has great potential for disrupting and modernising agriculture in Africa. There can be a virtuous cycle in agriculture when combining some of the technologies listed above: drones can survey fields and collect data that is then aggregated alongside sensor data to create a pool of Big Data that can be analysed using AI and IoT solutions. This allows for precision farming and the smart application of fertilisers, all of which in turn increases yields and reduces the cost of inputs to farming. All of this is of paramount importance in countries such as Nigeria, where large swathes of land are affected by climate change, more volatile rainfalls, soil degradation and desertification whilst food demand is increasing rapidly in line with a population boom.

There is a big opportunity in Africa for AI in the field of renewable energy solutions. Predictive user behaviour that relies on learning algorithms is an emerging technology that can effectively balance consumer demand and utility supply. For example, where power batteries often have difficulties powering homes through the night, AI software can learn the energy needs of a home and adjust the power output in such a way that electricity is available when needed, for example by dimming lights and TV screens and slowing a fan's motor.

Other sectors where there are opportunities for AI in Africa are retail and e-commerce. E-commerce is on the rise in Africa and might bridge several gaps, including economic integration, cross-border transactions and also cultural integration (in particular for youth that use novel platforms more). AI might stimulate e-commerce by using data analytics to determine marketing strategies, to gather information on what customers are asking for and to improve customer services (Oyekunle, 2019).

Finally, Africa is considered to be **fruitful ground for AI start-ups**[155], with several companies across the continent providing AI tools and attracting investor interest. Furthermore, global industry (e.g. IBM Research Africa, Microsoft and the Google AI Research Centre) has made

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table 07

markets and application domains of artificial intelligence worldwide

Current application of AI	Sector/industry	Examples
High	Finance	AI is used for risk assessments for recommendations of loans and credit offering, fraud identification, personalised financial planning.
	Telecom and High-tech	AI is used for product and/or service development.
	Aerospace and defence	AI is used for cybersecurity, logistics and transportation, target recognition, robotic surgical systems and threat monitoring.
	Automotive	AI is used for robotic process automation in manufacturing and self-driving cars.
Medium	Energy	AI is used for monitoring energy consumption, minimising energy consumption with smart houses, smart metering and predictive infrastructure maintenance.
	Transportation and logistics	AI is used for service operations.
	Retail	AI is used for marketing and sales, personalised design and production, inventory and delivery management.
	Agriculture & food	AI is used for yield monitoring, diagnosing insect pests, measuring soil moisture, diagnosing harvest time and monitoring crop health status[153].
Low	Healthcare	AI is used for surgery, diagnosing diseases, early identification of potential pandemics, imaging diagnostics.
	Education	AI is used to anticipate job market demand, automate teachers' routine tasks and personalise learning.

SOURCE
Technopolis Group (2019), examples collected from several sources

significant investments to conduct research and develop AI in Africa and Africa's emerging technology industry and technology hubs play an essential role in stimulating African growth.

Based on our analysis, summarised above, there are potential business cases for AI in Africa. We believe that AI has most potential to improve business processes in Africa, increasing working productivity. Together with increasing access to education and skills training there are opportunities for Africa to reap the rewards of AI. It must be noted that AI and automation can also pose a threat to Africa. A strong negative relationship exists between skill levels and the probability of automation. Jobs with a low risk of being computerised usually require higher skill levels and share the common attributes of creative and social intelligence. AI and robotics will reduce the competitiveness of low-cost and low-skilled labour. Furthermore, AI is also expected to result in the reshoring of manufacturing to industrialised economies and to possibly eliminate the traditional paths of industrialisation and the advantage of cheap labour.

5.3.4 Current applications of Artificial Intelligence in Africa

The market adoption of AI is in a nascent stage in most African countries. However, even though AI is in its infancy in Africa, our research identified interesting market applications.

The desk research and interviews identified 124 companies using AI in 13 African countries (Cameroon, Congo, Egypt, Ethiopia, Ghana, Kenya, Morocco, Nigeria, South Africa, Rwanda, Tanzania, Tunisia and Zambia). This number is not exhaustive but gives an idea about usage trends in Africa. In South Africa, there are some examples of companies using AI programmes to improve efficiency in manufacturing plants, in mining and in the automotive sector. In Morocco, use cases are scarcer. Companies are rather working on data, trying to collect, digitalise and analyse it. This is the step that precedes the implementation of an AI system, where access and quality of data is the key issue, and is a prerequisite to a successful deployment of AI in industries. Similarly, use cases in Cameroon and Nigeria are scarcer.

Current applications of AI are found in modernised services and financial inclusion, but also in areas related to agriculture, health, education, smart cities and energy. As shown by Crunchbase, one South African education company managed to raise $3,800,572, an Egyptian health company $17,000 and one Nigerian company in a cross-cutting field, $1,000. It should be noted that investigations conducted did not show funding in countries other than those noted on the map shown in Figure 27, which illustrates trends in market applications and investments. The map is only used for the purpose of illustrating trends and is not intended to give an exhaustive overview of current AI applications and investments in start-ups across the continent.

A number of significant use cases of AI in Africa were identified through country case studies and interviews.

In Nigeria, AI is used for e-commerce by the company Versus.ng. The AI tool performs a sentiment analysis based on the monitoring of news sources and social networks across different brands. It checks whether a brand is mentioned and provides sentiment and popularity reports to help brands and companies make decisions (EnterFive, 2019).

In Cameroon, the start-up company Will & Brothers is working on an agriculture AI solution called 'Cyclops' to benefit Cameroonian farmers. The tool enables drones to detect people and identify different types of animals. With this, the company is the first start-up providing services with civil drones (Will & Brothers Consulting, 2019).

In Kenya, several start-ups also use AI for precision farming. Vital Signs analyses the value and colour of pixels from satellite imagery data to estimate rainfall and drought patterns (Vital Signs, 2019). Arifu provides curated access to information via SMS to help farmers determine, for example, what fertiliser matches their specific needs (Arifu, 2019). FarmDrive offers credit for farmers in need of supplies (e.g. fertilisers) by relying on data such as the size of land, location and crops to determine the risk and corresponding interest rates (FarmDrive, 2019).

Citizens in regions without primary healthcare facilities in South Africa are often reliant on the services of mobile clinics. The company Numberboost is working to develop a system to allow citizens to locate nearby mobile healthcare clinics, which could help to improve citizens' access to healthcare (NumberBoost, 2019).

AI is actually a disruptor of traditional value chains and we see companies adopting AI across their value chains. AI can be adopted in IT, customer services, marketing, sales, finance and accounting but also within core business functions. Global stakeholders range from big technology companies like Google and Microsoft that are quick to develop the latest and most advanced AI solutions, to start-up companies and SMEs that provide specific and tailored AI services. There are opportunities for Africa to grow its own companies, with the examples above illustrating this happening already. In addition, there will be foreign companies interested in opening offices in Africa, allowing for the establishment of regional value chains in Africa (Cilliers, 2018).

There are several examples of emerging countries that have recognised the possibilities that AI technologies can bring them. Some have started adopting measures accordingly. South Korea (Korean MSIP, 2016) and India (NITI Aayog, 2018) both adopted a national AI strategy. Whereas in South Korea, the focus lies mostly on human resources, technology and infrastructure, the Indian government identifies five sectors where AI has the greatest potential for impact: agriculture, healthcare, education, smart cities, smart mobility and transportation.

In Africa, Kenya and Tunisia have formed task forces that encourage the development and adoption of AI.

- The task force in Kenya aims to provide recommendations on how the government can leverage new technologies (including AI) in the next five years. Further milestones are set for 2027 and 2032 to situate the strategy in areas of overall public service delivery, financial inclusion, land tilting, election processes, single digital identity and cybersecurity (Kenyan Wallstreet);
- The task force in Tunisia was created together with a steering committee to develop a National AI Strategy for Tunisia, which is scheduled to be published in 2019. The goal of the strategy will be to facilitate the emergence of an AI ecosystem. This system should act as a lever for equitable and sustainable development and job creation. The task force has established multi-stakeholder and thematic working groups that help identify priority areas and policies that should be included in the strategy (Agence Nationale de la Promotion Scientifique).

5.3.5 What needs to be done to take advantage of Artificial Intelligence in Africa?

Previous sections have highlighted the potential for African businesses to use AI technologies and the opportunities offered in terms of productivity gains and economic growth. However, taking full advantage of AI by scaling up the take-up of AI in African businesses is still challenging. Figure 28 presents a SWOT analysis for the adoption of AI.

As for every 4IR technology, reliable access to an electricity network and high-speed internet is key for AI. However, a number of challenges need to be tackled that are specific to AI technologies. Our analysis, combined with the country case studies and interviews, helped us to identify key enabling factors, actions and policies which must be enhanced to unlock the potential of AI.

Skills and human resources

It is important to invest in human capital and to expand the provision of training and education in areas such as machine learning and data analytics for AI solutions to be adopted across Africa. Currently, there is limited AI education in Africa and there is a lack of AI experts. In order to reap the rewards from the widespread use of AI technology, countries need to ensure that they have education and skills systems in place to make society ready to work with these technologies.

Hardware and equipment

Compared to hardware technology, AI has a lower barrier to entry for new solutions as it is software-based. Nevertheless, successful adoption of AI technology

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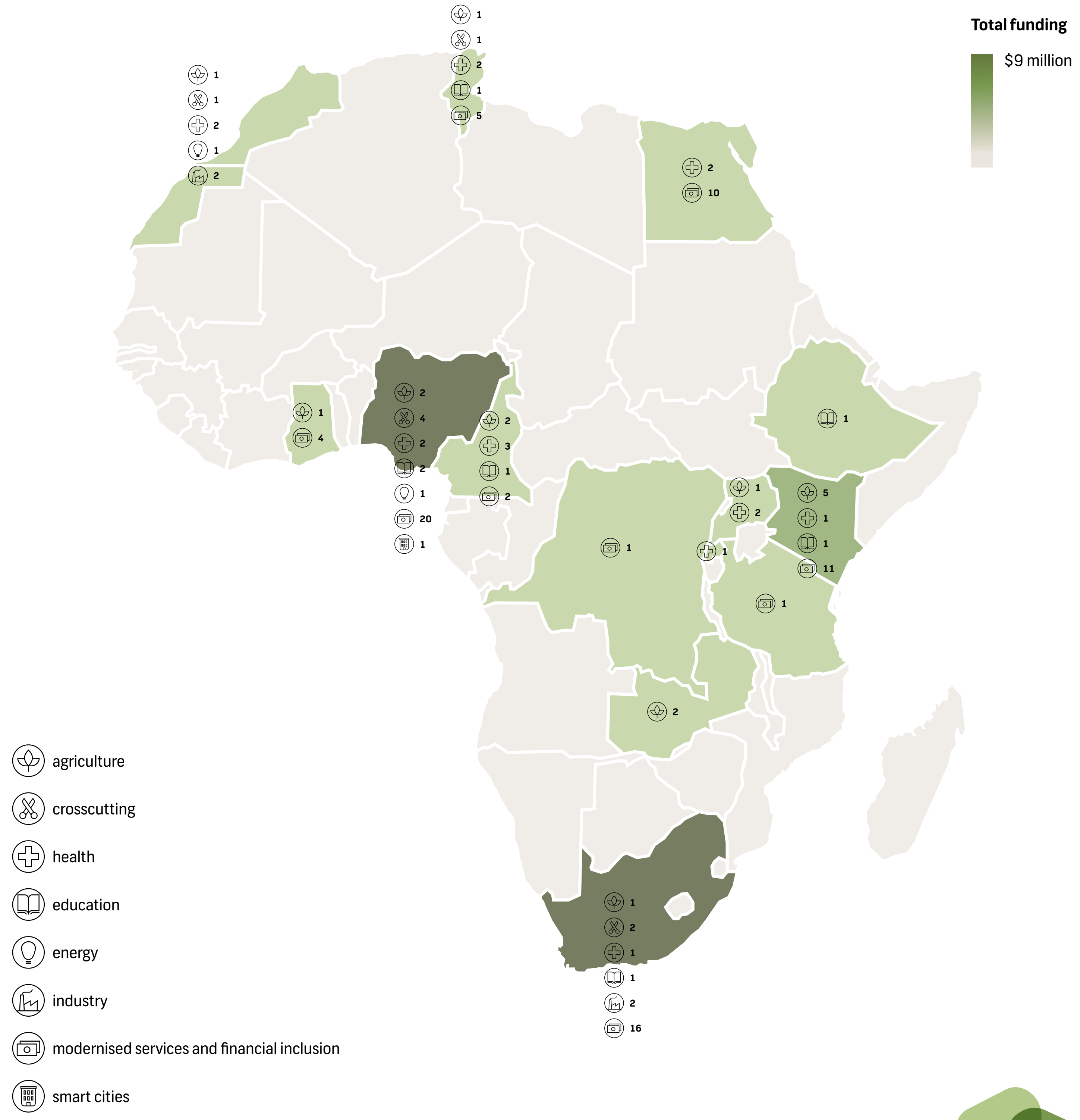
figure 27

artificial intelligence market applications and investment in startups: trends in Africa



ADAPTED FROM
Technopolis Group (2019), based on desk research and interviews[155]

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box 05

examples of artificial intelligence use cases in health care in Cameroon

Since 2017, the Bonassama District Hospital in Douala has integrated SOPHiA (AI developed by Sophia Genetics, a multinational company) into the clinical workflow to advance patients' care.

By using this AI solution, the hospital now forms part of a larger network of 260 hospitals in 46 countries that share clinical insights using big data analytics across patient cases, feeding a knowledge base of biomedical findings to accelerate diagnostics and care. This allows the hospital to rapidly analyse genomic data and decide on the most effective care.

Another example of AI and machine learning for the healthcare sector comes from the Songhai Labs. The Yaoundé-based start-up is working on the DataREACH project in partnership with the World Health Organization (WHO) in Cameroon and a start-up from UCLA, California. Within this project, the HSPC polyclinic in Kumba, a private hospital in south west Cameroon, was provided with a digital application which helps it to compile data on patients for epidemiological surveillance via AI.

SOURCE (Business in Cameroon, 2017; Journal du Cameroun, 2017; AllGreen, 2019)

depends on a range of enabling factors being in place. Firstly, availability of high-speed internet through broadband and mobile connections is a necessity for organisations to make use of AI, which makes use of cloud computing, along with the complex algorithms and high volumes of data flows needed. Secondly, the heavy reliance of AI on data also implies that data need to be made publicly available by those holding it or opened up in other forms. Several African countries already have policies on open data, but the implementation of these policies is limited.

Access to finance

The current take-up of AI across businesses globally is still fairly low. With the stimulation of businesses in the field of AI in Africa, it is important to keep in mind the potential impact on equality. There is a risk of smaller firms falling behind if they are not able to make similar investments and attract the same human resources as larger firms. Moreover, it is too early to assess the impact of AI on jobs in Africa. While there is some indication that AI could reduce the cost advantage of African workforces compared with industrialised countries, there is also the prospect of AI plugging crucial skills gaps in the workforce, enabling African firms to compete globally where this is currently not possible.

Furthermore, African governments might consider the merits of the public-private partnership (PPP) model for infrastructure projects. In countries outside Africa, the model has proven successful in helping to compensate for low public sector investment in key areas. African countries can benefit from the experience of such countries in developing robust PPPs that channel the necessary resources to key areas for the development of infrastructure for connectivity.

5.4 INTERNET OF THINGS AND BIG DATA

5.4.1 Introducing IoT and Big Data

The Internet of Things (IoT) is a form of distributed computing that is based on networks of objects that are embedded with electronic hardware and have internet access. These two characteristics permit IoT objects to communicate and interact with one another using standard communication protocols such as, most importantly, the World Wide Web. The IoT can best be thought of as a technological platform or network that combines multiple technologies such as automation, wireless sensor networks, radio frequency identification tags (RFIDs), microcontrollers, actuators, GPS, satellite technologies, internet protocols, etc[156]. An IoT system therefore consists of multiple devices connected to the same network that are continuously collecting, transmitting and receiving data.

In the context of the IoT, the constituent 'objects' are typically discussed in general terms for the simple reason that, in principle, almost anything could conceivably be connected to the IoT. In many conceptualisations of IoT 'ecosystems', the aforementioned technologies are embedded in everyday objects and common devices[157]. Typical examples of said 'everyday objects' include sensors such as thermostats and speed meters, as well as actuators that open or close valves, control light switches or run

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figure 28

SWOT analysis for the large scale adption of artificial intelligence in Africa

strengths	weaknesses
great potential for enhancing economic productivity across all sectors, including healthcare and education	risk to jobs, especially for low-skilled workers and consequently to social equality
AI can also help increase transparency around political decision-making	market distorting and unclear impact on competition of firms, including small enterprises
AI combined with Big Data has lower cost implications than hardware-based 4IR technology such as drones & 3D printers	risk of algorithmic bias in decision-making

opportunities	threats (or challenges for increased uptake)
Africa already has a fairly large science, technology, engineering and mathematics (STEM) and ICT talent pool	risks to economic competitiveness due to AI reducing costs of production in high-wage countries and Africa lagging behind in terms of AI take-up
AI can also plug some skills gaps in Africa & help firms make use of other advanced technologies	risks to jobs and risk of skills mismatch (gap between the supply and demand of AI-related skills in Africa)
in terms of one of the enabling factors for AI take-up, availability of data, Africa is reasonably well-positioned as data is available from mobile operators, telecoms providers & (mobile) banks in Africa	lack of AI-related research institutes and training opportunities in Africa
AI has great potential to modernise agriculture, education and healthcare, three very important sectors in an African context	lack of stable power supply and internet connections across the continent, especially in rural areas which risk falling further behind with the rise of AI
AI works best in combination with Big Data and IoT solutions	

motors. Together, these embedded objects can perform specific tasks across different environments. For instance, an IoT platform in a private home or office space could be based on machines such as refrigerators or cars but can also be extended to larger scales such as factories, urban systems or road infrastructure and may even include the human body in the future. Some of these are much more realistic in the near future than others but the point is that the possibilities for the different 'things' constituting an IoT system and the functions that this can perform are virtually endless.

One major implication of the large-scale adoption of the IoT will be the generation of large amounts of data which brings us to the second topic, Big Data. The latter generally refers to collections of data that are impossible or impractical to analyse with traditional database tools due to their vast size, variety and speed of creation. A common way of characterising Big Data is by the so-called '3Vs' which are; volume, variety and velocity. Based on the 3Vs, we can only speak of 'Big Data' where there are extreme volumes (in the order of magnitude of petabytes[158] and exabytes[159]) of data that appear in a wide variety of types and forms, all of which is being generated at high a velocity[160]. Naturally, what constitutes an 'extreme' volume of data is a relative concept and will shift upwards over time as computing technology and storage capacity continues to develop. It also varies by sector, depending on the software tools and sizes of data sets commonly used in a particular industry or public setting. Besides the quantities of data, the Big Data concept also applies to the analytical solutions that deal with the capture, curation, management, processing and analysis of these large data sets. Nowadays, consumers unwittingly produce most of the data being generated and this is no different in Africa. When individuals communicate, make payments, take pictures or simply move from one place to another they are constantly generating data that can in principle be collected and processed somewhere else, for both commercial and non-commercial purposes.

5.4.2 Overview of potential impacts of IoT and Big Data and global use trends

The implementation of IoT and the advent of Big Data are often heralded as 'redefining' a broad range of sectors and industries. In the context of the developing world and the African continent in particular, however, it must be emphasised that the transformative potential of Big Data has yet to be realised[161]. This section will therefore discuss the types of impact associated with IoT implementations and resulting data, as well as cover scenarios that, while being somewhat hypothetical, are still relevant to the African context.

Economic impact

In economic terms, impacts are anticipated specifically for the development of rural areas in Africa and IoT technologies and have been proposed as a way of contributing towards sustainable rural livelihoods[162]. Firstly, the impacts of IoT technologies are frequently discussed in the context of supply chain management. This entails the real-time tracking of items, monitoring of stocks and communicating this to relevant stakeholders, such as shop keepers for instance[163]. In pharmaceutical manufacturing, drugs can be tracked throughout the entire supply chain to monitor their condition and ensure quality. Second, IoT technologies can drastically improve efficiency in transportation. Examples of this include goods and passenger screening, traffic jam monitoring and passenger and luggage tracking[164]. Intelligent transport solutions are increasingly being investigated in order to address challenges associated with growing urbanisation[165].

Third, IoT technologies can also have an impact on sectors generally regarded as low-tech, such as agriculture. This is a crucial consideration given that many rural communities in Africa rely on subsistence farming[166]. For instance, the implementation of IoT technologies would enhance irrigation and crop protection by providing temperature alerts and improving access to alternative water when primary sources become depleted or have been contaminated through monitoring ground water levels[167]. In Kenya, insurance companies have started monitoring weather patterns in order to provide insurance to small-scale farmers[168]. In addition, the use of IoT and Big Data can also support precision agriculture and smart farming. In this case, an IoT system, possibly including UAVs as one of several components, can generate a wealth of data related to crop yields, soil mapping, fertiliser applications, weather conditions, machinery and animal health, as well as enabling precision livestock farming (PLF), nutrient management and prescriptive planting[169]. Combined, this serves to increase agricultural productivity. Future uses of Big Data in smart farming include yield measurement and quota systems, plant and livestock disease monitoring and remote machine control and diagnostics[170]. Precision agriculture is regarded as an application area of major potential for Africa as the continent accounts for a quarter of the world's arable land, of which 80% is either underutilised or not used at all[171].

Societal impact

Social impacts are mainly associated with healthcare and ageing. Here, an IoT platform including a combination of Wi-Fi and sensors could be used to monitor bodily functions such as temperature, blood pressure, heart rate and cholesterol in patients[172]. In terms of ageing, it can also provide benefits in terms of supporting independent living amongst the elderly. In this context, an IoT application would include, for instance, a system of wearables and ambient sensors[173]. This area of impact can be particularly significant in the near future for countries with ageing populations. This also applies to the African continent as the population of elderly people is expected to grow to 163 million in 2050 from 43 million in 2010 in sub-Saharan Africa alone[174]. IoT platforms can also provide value within intelligent home-care systems in which hospital services are integrated into the home environment, enabling intelligent health monitoring and potentially affordable e-health services in developing countries[175].

Legal impact

Privacy is the first and foremost area of legal impact for Big Data and the IoT. Many of the primary producers of data are individual private users of various services, social media in particular, without being fully aware that they are doing so[176]. Safeguards will eventually have to be put in place in order to prevent the privacy of individual citizens from becoming compromised on a large scale. However, these concerns are anticipatory rather than a current reality given that IoT systems are not yet a ubiquitous component of the everyday life of the average citizen. On the other hand, privacy concerns regarding (Big) Data analytics are currently more of a pressing issue, especially in the context of online consumer activity. This, however, is too broad a topic to discuss within the scope of this report and tangible legal impacts of the adoption of the IoT and Big Data in Africa have yet to materialise.

Political impact

Regarding political impact and governance, adoption of the IoT at a national level and the resulting generation of data would be of tremendous value for the purposes of evidence gathering and analysis in public administration. Specifically, the predictive power enabled by the use of Big Data is extremely relevant to policymaking. Leveraging Big Data could reduce the dependence on human inputs, which removes time lags in terms of data production, collection and transmission, meaning that there is more space to focus on analysis and interpretation instead, ultimately resulting in a more effective and evidence-based decision-making process[177].

Connected to this is the concept of 'open data', which is also particularly relevant to public policy. Open data refers to data that is both publicly and freely available and that can be reused continuously[178]. Supposing national governments are in possession of large amounts of data, providing this as open data would have major social and economic benefits as it creates new opportunities for analysis and action[179].

From a developmental standpoint, Big Data has been argued to offer potential support in this context in three main ways[180]. Firstly, by functioning as an early warning system for major events such as outbreaks of disease, famines and humanitarian crises. This is enabled by, for example, the early detection of anomalies in the use of certain digital services allowing for faster responses. Second, development could be supported by real-time awareness informing specific programmes and policies by providing fine-grained empirical data. Lastly, real-time feedback obtained from population monitoring can facilitate the detection of areas of failure, creating opportunities to make necessary adjustments or interventions[181].

Environmental impact

IoT technologies have been deployed to support environmental monitoring as well as utility management. Another significant environmental impact will be in terms of energy. Smart metering is already a relatively common application to measure consumption levels and communicating this with users and energy providers to manage energy more efficiently[182]. While a smart meter of its own would not qualify as an IoT system, it can certainly be regarded as a step in this direction. Domestically, it allows for the real-time monitoring of water usage in private homes, which not only improves data communication with service providers, resulting in more accurate billing, but it also raises awareness of usage patterns[183]. This is facilitated by IoT-type technologies such as smart meters providing real-time and two-way communication with the user and automatic collection of meter readings and other data. Furthermore, the use of these types of IoT applications for resource management purposes can have significant impacts. In the management of water resources, the operation of river basins can be optimised, pollution in underground water can be measured as can levels of sewage and wastewater. Moreover, water pipe management is optimised using GSP sensors allowing the monitoring of hydraulics and chemical parameters as well as locating leaks[184]. Finally, other applications of the IoT in environmental monitoring would allow for predictions of consequences of changes in the climate such as cyclones, floods and droughts[185].

Market size of IoT and Big Data technologies

In terms of application domains, the idea of IoT was first introduced in the context of supply chain management but the concept has recently been extended to many other applications such as intelligent transport systems, smart healthcare, smart utilities and so on and so forth[186]. Further illustrative examples of applications are described in Table 8.

In terms of markets and diffusion, it must be pointed out that IoT is still very much in its infancy, especially throughout Africa and the Middle East, and is still in the early stages of its development in the more developed economies. Nevertheless, one can observe a number of trends that point towards its ongoing emergence in Africa. For example, cellular IoT connections are projected to grow from 20 million to 90 million during the period from 2017 to 2023, notably in the energy, transport, agriculture, and healthcare sectors[187]. Similarly, the number of IoT-connected devices are already on the rise in Nigeria and South Africa[188]. Furthermore, the International Data Corporation (IDC) estimates the IoT market in the Middle East and Africa to reach a value of $12.6 billion by 2021, with a compound annual growth rate (CAGR) of 19.3% over the 2016-2021 period[189]. IDC research has also concluded that the five main industries accounting for IoT spending in the Middle East and Africa in 2021 will be: manufacturing (15.8%), cross-industry[190] (12.7%), transportation (9.9%), consumers[191] (9.6%) and utilities[192] (9.4%). This spending is mainly expected to go towards use cases such as smart grids, manufacturing operations, smart buildings, freight monitoring and smart homes[193]. As for Big Data, between 2005 and 2010, the global stock of digital data already grew from 150 to 1,200 exabytes. In terms of future growth, the stock of digital data is estimated to double every 20 months until 2020[194]. The African Big Data community is small at present but growing[195]. This is especially true for the private sector where, in Kenya and Nigeria, IBM has estimated that up to 40% of businesses are in the planning stages of Big Data projects[196].

5.4.3 Why are IoT and Big Data important for Africa? What are the opportunities?

While the International Telecommunication Union (ITU) reports that Sub-Saharan Africa had, in 2016, only four million fixed broadband subscriptions[197], GSMA data shows that the majority of Africans use mobile internet access. Overall, Sub-Saharan Africa's internet user base is expected to increase from 211 million in 2017 to 495 million in 2025. Moreover, while Sub-Saharan Africa has now achieved 2G coverage for around 90% of its population, only two-thirds are covered by mobile broadband. This leaves around 400 million without a possibility to connect to mobile broadband services[198]. Nevertheless, progress is being made towards providing access to faster data standards. The GSMA forecasts that, by 2025, 97% of Sub-Saharan African mobile users will have access to at least 3G. A total of 23% will have access to 4G and 3% to 5G. The first 5G connections are expected to be launched in 2021[199]. Furthermore, Africa had, in 2017, more than 170 million Facebook users, of which 94% were using mobile devices[200].

With nearly 500 million internet users by 2025 and 97% of mobile connections expected to be using at least 3G, there is a strong case for creating a strong skill and knowledge foundation for Big Data analysis to be prepared for the rapid growth in data volume on the continent. Moreover, the situation that the majority of connections rely on mobile data prevents situations where locked-in fixed broadband infrastructure would need retrofitting, which leads to slower progress towards higher broadband speeds. However, efforts must be taken to further advance the number of internet users. While 495 million users would be a marked improvement from the current 211 million, the penetration rate would still only be 40% (from currently 21%).

Potential applications for Big Data analysis in Africa have already been demonstrated. Smallholder farmers in Africa typically cultivate relatively large areas of farmland, providing a significant portion of the local food supply. Given the high levels of growth rates in terms of mobile cellular and mobile broadband connections, these factors constitute a major opportunity in terms of mass mobilisation and aggregating farm-level data, which could greatly improve the efficiency of the agri-food supply chain[201]. In its Future of Work report, the AfDB highlights that the Accra Metropolitan Authority (AMA) is exploring how Big Data technologies can be used to optimise public transport systems by analysing mobile phone data[202].

There is also a positive outlook for the Internet of Things in Africa. The GSMA estimates that IoT connections will triple by 2025 from around 100 million in 2017 to 300 million[203]. While technologies such as autonomous vehicles and smart interconnected factories often require 5G standards, a lot of IoT applications can be realised with lower requirements of bandwidth and latency, for example sensors in agriculture which measure soil humidity and temperature. Other potential IoT applications include disaster monitoring, smart grids, monitoring vaccines and remote telephone farming[204].

5.4.4 Current applications of the IoT and Big Data in Africa

The desk research and interviews have identified 345 IoT-using companies located in 28 different African countries. While this number is not exhaustive, it does give an idea of the use trends in Africa. Current applications are mainly found in modernised services and financial inclusion but also agriculture whilst crosscutting areas, education, energy, health, industry and smart cities are also relevant sectors. Figure 29 illustrates the trends in market applications and investments. The map is only used for illustration purposes and is not intended to give an exhaustive overview of current drone applications and investments in start-ups across the continent.

According to Crunchbase, South Africa has gathered the most funding ($105,634,534) while Ghana was the least funded ($100,000). Companies in Nigeria ($71,984,302), Egypt ($24,358,880), Ethiopia ($12,850,000), Algeria ($1,700,000), Kenya ($1,606,315) and Mauritius ($200,000) were also funded. It should be noted that investigations conducted did not show funding in countries other than the ones noted on the map.

In the area of Big Data, our research identified 140 companies using big data in 17 different countries. Modernised services, financial inclusion and agriculture are the main sectors of activity relying on Big Data whilst education, energy, industry, health and smart cities are also relevant sectors. Figure 30 illustrates the trends in market applications and investments. The map is only used for illustration purposes and is not intended to give an exhaustive overview of current drone applications and investments in start-ups across the continent.

According to Crunchbase, start-ups in South Africa received the most funding ($5,056,901) and start-ups in Ethiopia received the least ($100,000). It should be noted that investigations conducted did not show funding in countries other than the ones noted on the maps.

There are numerous applications in the energy sector based on Big Data or IoT, notably involving solar energy. One promising technology relates to solar home systems (SHS), which incorporate innovative pay-as-you-go schemes linked to IoT-enabled devices, mobile money and cloud services (see box 06).

t

table 08

examples of IoT applications

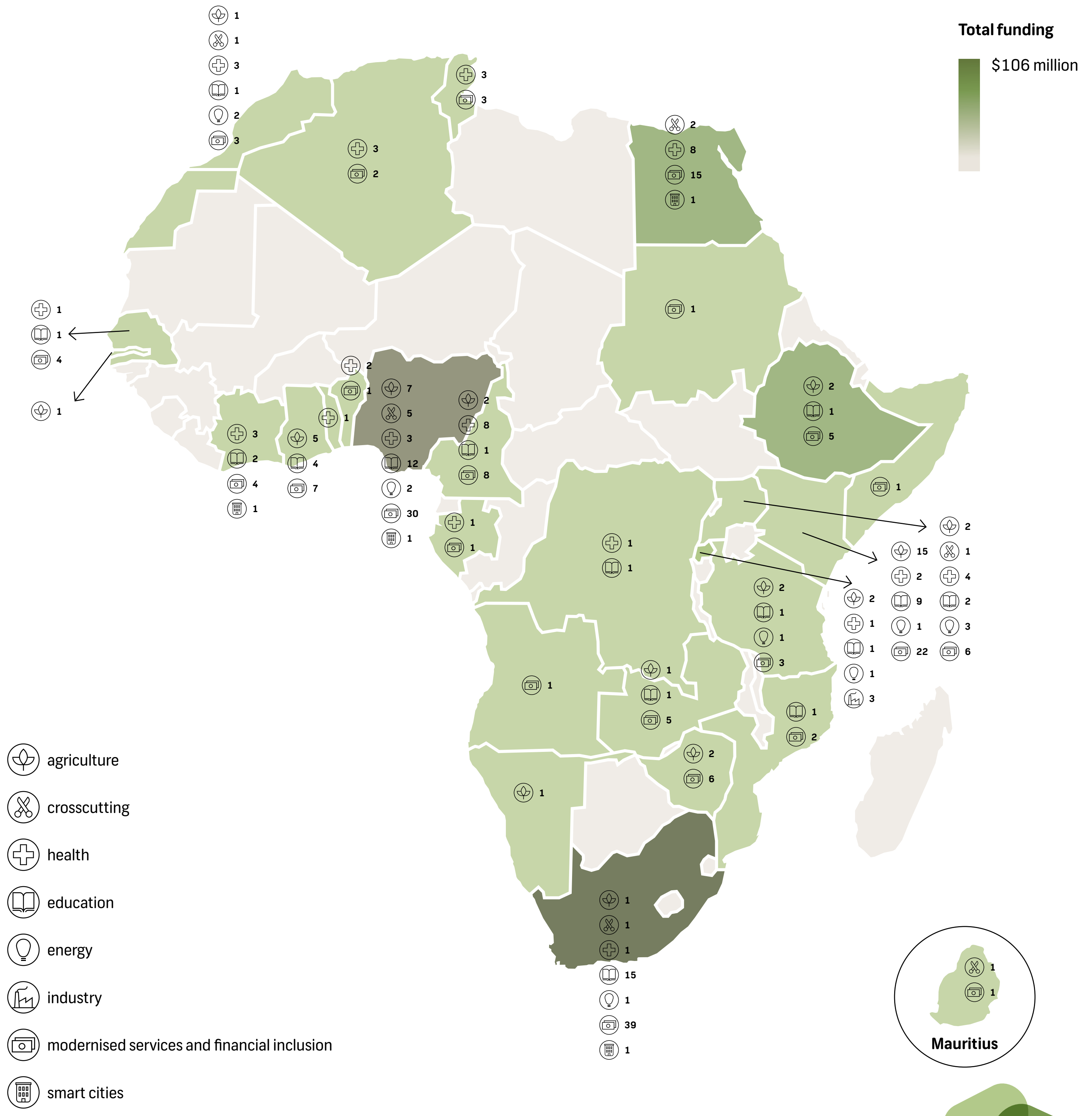
Domain	Function
Industrial & manufacturing	Predictive maintenance, quality control, automation overlays.
Smart buildings and cities	Building automation, energy, utilities, parking, traffic.
Transport and logistics	Fleet management, warehousing, critical shipments, remote asset monitoring.
Agriculture	Irrigation, autonomous machines, connected animals.

SOURCE
adapted from Miazi et al., (2016). Enabling the Internet of Things in developing countries.

f

figure 29

IoT market applications and investment in startups: trends in Africa

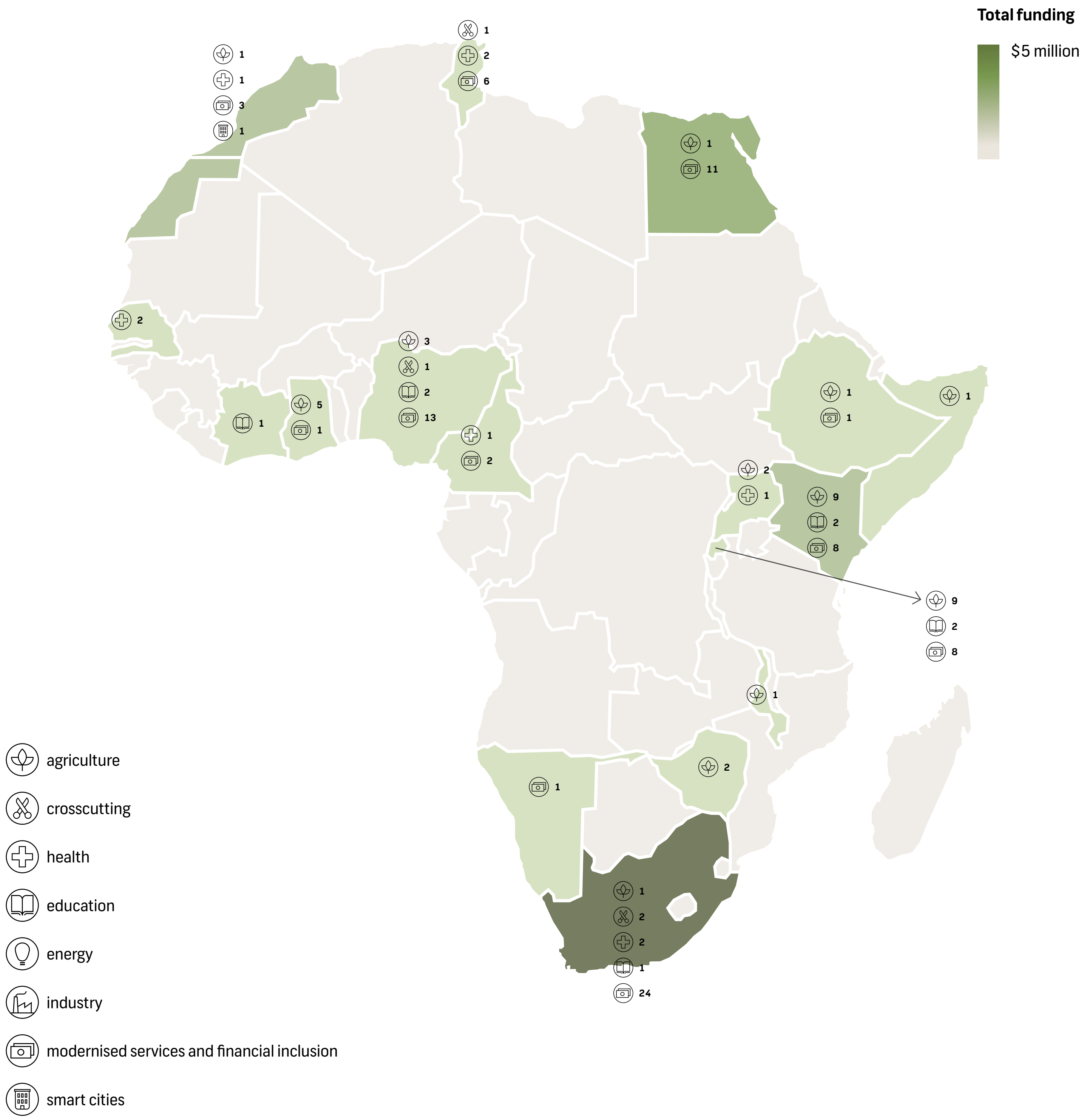


ADAPTED FROM
Technopolis Group (2019), based on desk research and interviews[205]

f

figure 30

big data market applications and investment in startups: trends in Africa



ADAPTED FROM
Technopolis Group (2019), based on desk research and interviews[206]

b

box 06

IoT & big data applications for solar energy

Uganda-based SolarNow – a pay-as-you-go (PAYG) model combining cellular IoT with provision of off-grid solar energy services – is a company that offers affordable cellular connected solar equipment, energy and services to remote, off-grid homes, farms, schools, health centres and business locations across Uganda. Through an IoT solution SolarNow has developed an early warning system to communicate with clients if there is an issue with their IoT device that is connected to the solar equipment. It ensures that its customer's solar equipment is protected from disruptive, malicious and costly service interruptions. Each device and its security are monitored centrally. Eseye collaborates with Solarnow and Amazon Web Services (AWS) to help bring solar energy to remote regions in East Africa.

SolarNow, a social business passionate about transforming lives by providing high quality solar energy, appliances and financing solutions in east Africa successfully utilised IoT while also integrating M2M cellular connectivity and AWS Cloud within its solutions to provide more and better services to SolarNow customers. Through the use of an accessible SIM card, which provides integration to the AWS cloud, it permits SolarNow to remotely and securely activate, provision, authenticate and certify deployed devices over-the-air, in up to 190 countries. By leveraging the power of connected technology SolarNow could address the unmet need for sustainable, quality solar energy through the provision of solar-powered equipment, appliances and services to remote or off-grid home, farm, school, health centre and business locations. In addition, IoT and M2M capabilities further empowered SolarNow to become completely self-reliant and secure in connecting and managing its growing product portfolio.

The start-up UR Power, which is incubated under Active Spaces in Cameroon, is also developing a solution to provide rechargeable solar batteries for households. Their solution integrates Virtual Reality (VR) in the company website so that clients can easily understand their installations in different home types; plus, the device has built-in smart sensors and AI to easily collect data and analyse the functioning of the devices[207].

Another set of emerging technologies in the energy domain is smart meter systems. These systems use sensors that allow remote monitoring of electricity consumption. Predictive user behaviour, which relies on learning algorithms, is another emerging technology that can effectively balance consumer demand and utility supply. These trends reflect innovation in the region's off-grid development, which could be more effective if it were integrated into an energy strategy that incorporates distributed energy resources. African countries have the opportunity to make a big leap forwards in the energy sector by incorporating these technological developments. Big Data and IoT are also deployed to facilitate the supply and distribution of energy. Cellular IoT connections are used in Uganda to enable the functioning of pay-as-you-go (PAYG) solutions for clean energy and water systems as well as in the transport and logistics sector with vehicle tracking and fleet management solutions.

General Electric and the Massachusetts Institute of Technology (MIT) are involved in a second World Bank-sponsored project to put a Reference Electrification Model (REM) into practice in Nigeria. REM is a geospatial package that uses Big Data to identify cost-effective ways to install distributed power with microgrids. It creates unique power plans specific to a location. It can pick the least expensive energy source, such as solar power, where there is enough sunshine or hydropower near a reliable water source. It can even create a detailed project plan, down to how many wires need to run to which buildings — information vital to effective project budgeting and planning. It uses population data, existing grid information, natural resource surveys, satellite-sourced topography data and other variables to optimise the cost and benefit of either extending an existing electrical grid or constructing a microgrid.

Emerging solutions based on Big Data and IoT for agriculture have already been adopted successfully in several African countries in applications such as index-based agriculture insurance, financial inclusion for smallholders, providing access to market information and cloud-based transactional platforms[208].

For instance, OCP Group and the University Mohammed VI Polytechnic (UM6P) have developed a business unit called Agri Edge, which is a platform that works on agricultural data that it transforms into decision-making information for farmers. Agri Edge offers farmers three services: reasoned fertilisation, precision irrigation and integrated pest management. In addition, Agri Edge is also working on the use of smartphones for diagnosing agricultural diseases. This project is under development at the UM6P.

Another specific purpose for which IoT and Big Data can be applied in agriculture is livestock identification and monitoring. In Nigeria, MTN, one of Africa's biggest telecoms providers, has already trialled an IoT-based Animal Identification Management System. This is based on affordable RFID chips that are attached to each type of cattle, mostly cows. The chips provide real-time information on the location of the animals to the farmer, allowing them to manage their livestock more efficiently. Automatic alerts occur if a cow breaks out of a designated area. In the future, this solution could also be expanded to trigger an alert if a cow enters areas that it should not, such as farmland. Another example of an IoT and Big Data application to improve agricultural efficiency is described in Box 7.

With regard to healthcare, there are ongoing efforts to develop IoT solutions based on wearable sensors that communicate an individual's health status. Nigeria-based Gricd is an IoT start-up that provides an affordable and portable cold chain device for efficient storage of vaccines, blood and other health and agricultural products (also to be potentially used in the oil and gas sector, in and around abattoirs, and for fast moving consumer goods like refreshment beverages). The solution improves 'last mile' delivery using a smart, IoT-enabled cold chain box sending real-time data to customers. The data collected includes temperature in the box (automatically issuing an alarm when the temperature exceeds predefined levels), location and battery duration. IoT solutions are also emerging within the healthcare sector in Cameroon. ICT-based tools such as GiftedMom and Happy Mothers are apps which allow mothers and pregnant women in Cameroon to access medical advice in rural communities. In a similar vein, Himore Medical has designed a wireless solution called CardioPad that enables the monitoring of cardiovascular diseases (CVDs). While the majority of CVD specialists practise in Yaoundé, 80% of the country's population lives in rural areas. CardioPad provides improved access to CVD healthcare for patients living in remote areas.

5.4.5 What needs to be done to take advantage of IoT and Big Data in Africa?

Overall, the adoption of IoT and Big Data in Africa is relatively low at present. Having said that, there are specific countries such as South Africa and Kenya where there is a relatively high level of activity in terms of emerging initiatives related to IoT and/or Big Data. In addition, projections about future developments in African IoT-related markets appear to be quite optimistic in that they expect significant levels of growth in the coming years, notably in the areas of manufacturing, utilities and agriculture. For this to be realised, however, our analyses combined with the country case studies and interviews helped us identify key enabling factors, actions and policies which must be enhanced in order to unlock the potential of IoT and Big Data in Africa. Aside from basic requirements in terms of ICT, spectrum bandwidth and energy, there are several specific issues that should be addressed.

Data-specific infrastructure

A key challenge to large-scale IoT adoption is a general lack of dedicated data centres and a system of connections between them that are capable of collecting, storing, transmitting and receiving large volumes of data. As the number of interconnected IoT devices expands, this type of infrastructure will become a necessity. These data centres as well as the number of IoT devices will also create significant power demands. These can be addressed in a variety of ways, relying on a combination of battery technology, remote power sources and solar energy. The extent to which individual countries are able to meet these energy demands is completely dependent on their specific context and cannot usefully be generalised to the level of the African continent as a whole.

b

box 07

other IoT & big data applications improving agricultural efficienty

Nigeria-based Zenvus seeks to improve decision-making for farmers by providing insights into crop status based on data collected from sensors and other means (IoT). The data is stored in the cloud and can be accessed by the farmer regardless of their location. This allows farmers to use fertilisers and irrigation more precisely, increasing the efficiency of farming.

Zenvus is an intelligent solution for farms that uses proprietary electronics sensors to collect soil data like moisture, nutrients, acidity plus also provides farmers with the ability to track everything that is happening in their fields, such as a water pipe leak, irrigation, efficient fertiliser application etc. It then sends the collected data to a cloud server via GSM, satellite or Wi-Fi. Algorithms in the server analyse the data and advise farmers on the best farming techniques. As the crops grow, the system deploys special cameras to build vegetative health to help detection of drought stress, pests and diseases. Zenvus provides clear visibility for precision agriculture by looking at data in the soil and the crop vegetation.

The data generated is aggregated, anonymised and made available via subscription for agro-lending, agro-insurance, commodity trading to banks, insurers and investors. With this AgTech IoT (Internet of Things) innovation, companies like MTN, Airtel, Etisalat and Glo can provide a lot of agriculture data to farmers, banks, insurers and others across the food chain. Telecom operators will aim to improve the connectivity of sensors and other data-capturing devices on the farm to help farmers turn this data into actionable insights through the Zenvus software platform.

Rules and regulation

A regulatory requirement that will eventually have to be met is the need for data protection frameworks. These need to address the protection of data within countries as well as their neighbours. In this regard, Mauritius may serve as a source of best practice as it is an example of an African country with a strong data protection framework in place. Data sharing is another aspect that should be supported from a governance standpoint to maximise the value of the IoT and Big Data. For the purposes of data sharing, the model of Morocco-based Cityzenith for compiling, processing and visualising urban data could be replicated to other data sharing applications. Overall, strong institutions taking action to support the provision of adequate ICT and power infrastructures, open data and data sharing platforms and the establishment of robust frameworks for the protection of data and privacy are needed.

Skills and human resources

The complexities associated with large data volumes and analytics create a number of human capital challenges. In the first place, technically knowledgeable personnel are required to implement IoT. This will be challenging for developing countries due to the comparative lack of related research centres[209]. Engineers, scientists and other practitioners therefore need to be trained in IoT while end users will need to be informed simultaneously about the benefits that it can bring. For the specific purposes of sustainable development, there is the issue of a growing 'digital divide' which must be addressed as well. In the case of agriculture, it has been pointed out that financial investment is needed in terms of the training and capacity building of farmers and other actors before Big Data can be used throughout the agricultural supply chain[210].

Processing Big Data in particular is another issue and creates several analytical challenges in terms of summarising data, interpreting it and detecting anomalies[211]. Currently, it has been observed that analysis activities in African countries are often outsourced to third

f

figure 31

SWOT analysis for large scale adoption of IoT and Big Data in Africa

strengths	weaknesses
Big Data can help communities build resilience in the face of environmental, political, social and economic stresses by providing feedback loops of information and knowledge	adaptation needed to the needs of developing countries so that IoT-devices are robust, modular, energy-efficient, able to run on batteries and charge using solar energy
IoT technologies can drastically improve efficiency in transportation through goods and passenger screening, traffic jam monitoring, and passenger and luggage tracking	the collection and use of massive data sets can create new vulnerabilities and risks, enabling discrimination against individuals, biases, skewed evidence and creating dependencies on centralised infrastructure. The interoperability of IoT systems as well as data is an important precondition
IoT and Big Data have the potential to yield insights at a level and scale that would otherwise not be possible	privacy is a key dimension of Big Data and IoT with legal implications. Many of the primary producers of data are the users of various services, social media in particular, without being fully aware that they are doing so

opportunities	threats (or challenges for increased uptake)
combining IoT, Big Data analytics and drones is a fruitful platform to enable precision agriculture as well as smart farming	the African continent has significantly lower rates of per capita electricity consumption than the rest of the world
the IoT can be applied in smart power grids as well as innovative pay-as-you-go schemes linked to IoT-enabled devices, mobile money and cloud services. It also has strong potential for solar energy development	human capital must be built up through education and training to implement IoT and Big Data analytics
many African countries have a high mobile-broadband penetration, acting as an important enabler for IoT adoption	infrastructure-enabled cloud computing and storage capabilities in dedicated data centres need to be provided with the capability to transmit large volumes of data
	legal arrangements are needed to secure reliable access to data streams as well as access to back-up data for retrospective analysis and training. Arrangements are also needed to address security and privacy issues
	infrastructure gaps in terms of power supply and internet penetration must be solved
	need for local manufacturing capability in order to be able to provide affordable hardware such as sensors

party private firms with specialised capabilities[212]. Furthermore, the need for adequate statistical capacity also represents a challenge. Sub-Saharan Africa has the lowest average level of statistical capacity in the world and this has even declined for some countries[213].

Hardware and equipment

An IoT system is composed of multiple underlying technologies such as location identifiers (e.g. RFID tags), sensors and wireless technologies (e.g. GPS, GSM, and Mesh networks). There are challenges associated with the requirements for the individual components and devices that make up an IoT system. In particular, IoT devices themselves need to be robust, modular, energy-efficient and, in the case of developing countries, need to be able to run on batteries for a prolonged period of time as well as to use solar energy for (re)charging[214]. On a higher level, challenges are foreseen in terms of the interoperability of IoT platforms, the use of different commercial off-the shelf (COTS) products as well as more general requirements in terms of technological standards and scalability[215].

Access to finance

Due to the large yet distributed nature of IoT as well as Big Data, it is extremely challenging to provide meaningful cost estimations. Indeed, the lack of clarity on specific use cases and return on investment figures is creating considerable commercial obstacles[216]. For instance, sensors are one of the primary components of an IoT system and yet these can be expensive when taking into account that they are commonly manufactured by companies located in developed economies and must therefore be shipped[217]. A second financial challenge stems from the fact that many of the available IoT devices are proprietary and come with their own software. Updating this may be associated with additional operation and maintenance costs although these could be mitigated by prioritising open source software[218]. It is argued that implementing Big Data for agricultural sectors in Africa will create affordability challenges for farmers and smallholders[219]. A possible solution is to have co-operative groups facilitating group purchases and hiring services for crop operations, processing equipment and material, and improved know-how in terms of operation and maintenance[220]. Examples of African partnerships include those between Orange and the governments of Côte d'Ivoire and Senegal[221] or between IBM and the city of Nairobi for the development of an IoT-based waste management system[222].

5.5 BLOCKCHAIN

Blockchain technology is an almost incorruptible digital ledger of transactions, agreements and contracts that is distributed across thousands of computers worldwide. It has the potential to be both a foundation of and a springboard for a new developmental infrastructure. A key relevant feature of Blockchain technology which has a high potential for Africa are smart contracts. Smart contracts allow automatic contract enforcement if certain conditions are met. For example, if a good is unloaded in a port then the payment for them will be executed[223]. This has the potential to mitigate issues such as corruption, contract enforceability, information asymmetry or principal-agent problems[224]. Moreover, trust issues concerning third party intermediaries such as banks or government institutions can be circumvented. In addition, having a secure and enforceable contract also reduces credit risks for financial institutions, thus having the potential to efficiently lower the costs of capital in Africa.

The following sections will (i) introduce Blockchain technology, (ii) give an overview of Blockchain's potential impacts and global usage trends, (iii) explain the reasons why Blockchain is important for Africa and discuss the opportunities, (iv) present current Blockchain applications and markets in Africa and finally (v) recommend in which areas action is most required for the take-up of Blockchain in Africa.

5.5.1 Introducing Blockchain

Blockchain can be considered a disruptive technology. It severely alters the processes of digital transactions, enforcement of contracts and storing of contractual information. Blockchain is a form of distributed ledger[225]. In contrast to traditional centralised ledgers, distributed ledgers record and synchronise transactions across a network of independent nodes (computers) and their respective ledgers[226]. Distributed ledger technology (DLT) has the potential to significantly impact and change the financial sector, changing the roles of stakeholders, brokers and interacting parties.

Blockchain – introduced in 2008 – is one of several DLT concepts, alongside blockDAG[227] and others. A Blockchain is a set of agreed, consolidated records ('blocks') that are linked in a 'chain'[228]. Data on a Blockchain are validated in a decentralised way, i.e. by the wider community, rather than by a central authority.

Three principle technologies underpin Blockchain:

- Cryptographic keys, which serve to create a digital identity between transacting partners;
- A distributed, peer-to-peer (P2P) network, which provides a means to approve and authorise transactions;
- A network protocol i.e. rules by which nodes in a network collectively apply an agreed rule.

The use of cryptography provides authentication, proving identity and ownership in transactions. However, authentication must also be paired with authorisation. For this, Blockchain relies on consensus among nodes on a peer-to-peer network[229]. Every modification to data is subject to this consensus, i.e. nodes may agree to or reject modifications according to agreed rules. Once a majority of nodes reach a consensus, modifications are combined into a 'block' with other modifications from the same time period and appended to a 'chain' of previously agreed blocks. A powerful example of this in action is the Bitcoin Blockchain. Bitcoins and their base units must be unique in order to be 'owned' and retain value. The nodes serving the P2P network solve computationally-intense proof-of-work mathematical problems to produce an open record of all data modifications (transactions) that have taken place[230] (i.e. that all participants can see). This effectively solves the problem of 'double spend' in the Bitcoin currency but would have other applications in record-keeping and tracing.

Due to the computational requirements, the larger the P2P network, the better it can operate. An example of this is again evident in the Bitcoin Blockchain, which, in its first 10 years of existence, amassed computing power greater than the 10,000 largest banks in the world combined (3.5m TH/s)[231]. This is largely due to the effectiveness of the ways in which the Bitcoin Blockchain incentivises nodes (individual users) to offer their computer processing power in return for newly-created bitcoins. Even a much younger cryptocurrency – Ethereum – quickly amassed more computing power than Google via its P2P network[232]. The combination of cryptography and the actions of the P2P network ensures that verified data modifications are not tampered with by individuals or groups and that no new undetected modifications are made. This means that – without knowing one another, or relying on a central authority – users can trust the data held on a Blockchain[233]. This is the essence of a Blockchain – the production of 'trustable' data and records without a central authority.

5.5.2 Overview of Blockchain's potential impacts and global use trends

Blockchain is a disruptive innovation that has some advantages over current systems[234]. While Blockchain technology is most-often associated with cryptocurrencies such as Bitcoin and Ethereum, the technology, as described above, enables 'untrusting' parties to rely on data. This means that Blockchain could have a transformative effect on a number of important industries and many commentators have written at length about the potential of Blockchain. One example of this is the reduction of friction in the financial market by enabling the direct transfer of digital assets without the need for an intermediary. Other areas of application for Blockchain technology include, inter alia, banking, payments and other transactions (internal and cross-border), charity donations, communications, healthcare, agriculture, personal identity management, e-government and cybersecurity.

Potential economic impacts

The largest potential impact of Blockchain may be the significant reduction in transaction costs. Economic exchange requires trust and every type of economic exchange outside face-to-face transactions requires the intervention of a trusted third party. Blockchain technology offers the potential to replace trust in such institutions, such as commercial and central banks, with trust in a new, fully decentralised system[235]. **It offers a globally available, verifiable and tamper-proof source of data that offers anyone the possibility to provide robust and trusted third-party services**[236]. As almost any type of information can be digitalised and placed on a Blockchain, it has **the potential to transform the way people and organisations handle identity, transaction and debt information**[237].

The evolution of mobile money offers an example of how rapidly the adoption of a new technology or a new combination of existing technologies can improve economic outcomes. For example, see the success of M-Pesa, which was introduced in Kenya in 2007[238]. Blockchain proponents argue that it will expand opportunities for exchange and collaboration by reducing reliance on intermediaries and the frictions associated with them[239]. The technology could facilitate cross-border payments[240] or supply chain and trade finance via cryptocurrencies such as Bitcoin or Ethereum[241] and has a potential role in facilitating faster and cheaper international payments[242]. This may also apply to crowdfunding and charitable donations[243]. This can also eventually lead to advanced use cases in the banking and trade finance sectors, including development of an interbank system for improved speed and traceability of transactions.

There are benefits for individuals and small businesses too. It is suggested that Blockchain technology may be able to put an end to payment delays, which are among the main causes of business failures. This stems from both improved transaction speed, but also the use of smart contracts that would automatically release payment upon fulfilment of a task by the service provider.

Potential societal impacts

Moving from digitalisation dominated by centralised platforms and siloed data to a digitalisation based on decentralised technologies, there is great potential here for the economy and society. Within the literature, examples of societal impact range from improved identity management to improved livelihoods and prosperity and censorship-free communication. However, this also presents challenges for policy makers in the development of new legal frameworks at the regional, national and international levels[244].

Blockchain could be used for identity management, providing a secure digital infrastructure for verifying identity[245]. There are a number of start-ups and initiatives around the world that focus on **using Blockchain technology to create secure identity management systems**[246] and data portability protocols to standardise data across multiple applications and platforms, giving users full control of their data[247].

Elsewhere, we see projects and initiatives that work to help bring citizens of developing nations out of poverty and help them to gain financial independence[248 249].

Blockchain also has the potential to aid free communication in societies where oppressive regimes use citizen surveillance and censorship. Several emerging projects exist that would enable decentralised, censorship-proof and anonymous communication[250 251], file storage and data transfer[252]. These will allow users to store or share data securely and permanently.

Potential legal impacts

As Blockchain is a nascent technology, much of the relevant global legislation was adopted in an era when digital platforms were overseen by a single, centralised body. As such, there is significant attention being given to Blockchain, as regulators and law-makers seek to work out how legal frameworks can be adapted and applied to decentralised technologies[253].

Over and above the impacts to legislation, Blockchain has the potential to change how legal agreements are undertaken between parties too. Blockchain underpins smart contracts, which are able to operate autonomously, executing at the point where pre-agreed conditions are met[254]. Smart contracts allow for nodes on a distributed P2P network to run decentralised applications, known as 'DApps', meaning that no trusted third party is necessary for an agreement to be made between two users. The applications of smart contracts are themselves broad. They can be used to 'tokenise' real-world assets, such as land and home ownership, as well as high-value possessions. This makes smart contracts relevant to areas such as land and property registries as well as use in insurance agreements and wills. Blockchain means that owners can hold the private key independently and, with the ability to code agreements directly into smart contracts, the need for lawyers is reduced, making arbitration simpler and cheaper.

Blockchain has several legal and regulatory implications that need to be taken into account:

- Since Blockchain knows no boundaries and distributes accountability between the different users, regulators will have to deal with issues of jurisdiction and enforcement;
- Blockchain, if used as an IP management and registry system, will also challenge the centralised system of registering patents, trademarks and industrial designs;
- Its tamper-proof design can be a disadvantage because it is impossible to make corrections in the system even though they might be necessary;
- Interoperability is another key issue. The main question for regulators is how to link different Blockchain systems to the old systems;
- Issues of public access; the Blockchain ledger as in evidence in court/administrative proceedings;
- Also, Blockchain will challenge the roles of some IP intermediaries in the creative industry such as publishers, labels and collective societies;
- Fair use rights might be diminished;
- What do we do when smart contracts contain bad code or errors or contain illegal instructions?
- Also, as with any other technology, Blockchain is limited when human judgment is involved. For instance, Blockchain can be used for patent registration. However, we also know that patents need to be examined and this requires human judgment, something that cannot be easily automated.

Potential political impacts

There are a number of wide-ranging potential impacts of Blockchain technology, from increased transparency in administration and democratic processes to lower corruption and greater accountability. Whole new models of government are potential results of leveraging Blockchain technology. Furthermore, commentators suggest that governments making use of Blockchain technology in administrative procedures could expect higher levels of civil participation. There are examples too where the government's role is changed or reduced, for example, in areas of the economy.

One of the foremost characteristics of Blockchain technology is its ability to support full, secure, transparent records. It is thus clearly envisioned in the literature that this would have a major political impact in both an administrative context and in applications such as vote-counting. Vote counting is one of the most robust ways in which Blockchain technology can help secure a stable and democratic society through tackling voter fraud[255]. A Blockchain system for voting could mean the reduction of operating costs, errors, processing time and more secure voter registration. Afterwards, voters could be provided with a transparent record of all votes cast while simultaneously protecting the identities of individuals. Examples of Blockchain voting systems exist in Korea[256], Thailand[257], Japan[258] and West Virginia (US)[259].

One of the grand visions of Blockchain technology discussed by commentators is the creation of Government 2.0, a new version of governmental structures and cultures. Blockchain offers the possibility to decentralise some government functions ('e-government' and 'government as a service')[260], including the national record-keeping in contexts where citizens have low levels of trust in government – for example the collection and maintenance of citizens' medical records where ownership is brought back to the individual. Government-run Blockchains can provide legal frameworks that are fully transparent, automated and secure. Georgia is currently testing just such a programme[261]. As Blockchain-based systems offer fully transparent, traceable and immutable records, corruption, such as in the form of misuse of funds, can also be addressed. Elected officials may also be held accountable by the use of smart contracts regarding, for example, campaign promises[262]. A project in the EU – led by Spain – aims to develop Blockchain and AI-based applications to stem and prevent corruption in the EU's single market[263]. Another project – in Australia – aims to replace a current system with Blockchain technology to fight fraud[264].

Potential environmental impacts

Authors have speculated in some depth about the impact that Blockchain might have on environmental areas, with most examples falling in the area of energy redistribution. A strong negative environmental impact which is primarily connected to the cryptocurrency Bitcoin is its high levels of electricity needed, suggesting its use predominantly in areas with abundant and unused electricity generation. In July 2019 the production of Bitcoin had a total estimated consumption of around 6.3 gigawatts of electricity and 65 terawatt hours a year[265]. This is the equivalent to the average annual per capita electricity consumption of around 109 million Africans[266].

On the other hand, Blockchain-based systems in energy can enable households to sell excess energy generated by, for example, roof-mounted solar panels. The peer-to-peer nature of Blockchain means that electricity transfer can take place directly between households with a high degree of autonomy[267] rather than relying on selling energy surpluses back into existing energy utilities. Not only does this ensure fair pricing, but it also supports the real time trading of green energy, creating more efficiency in the balancing of supply and demand and supporting the integration of renewable energy into the grid.

Several initiatives aim to accelerate the adaptation of Blockchain technology across the energy sector, such as the Energy Web Foundation[268]. Other small areas focusing on P2P energy trading include LO_3 Energy[269], Power Ledger[270] and PowerPeers[271]. In this area, there is also the example of Solarcoin, which is a cryptocurrency reward scheme for the solar power generation network. Energy Blockchains do not use the same energy-intensive authorisation processes involved in, for example, Bitcoin mining. Energy Blockchains use a less-secure 'proof-of-stake' method. This means that, although Blockchain-based solutions might allow more energy trading, there is, for example in Europe, further need to ensure compliance with General Data Protection Regulation (GDPR) rules, under which consumption, location and financial transactions are sensitive. Furthermore, Blockchain may support automated payments, electrical vehicle charging and sharing and transferable renewable energy credits (RECS). Other environmental impacts discussed by commentators – albeit in less detail – include land conservation, and the production, breeding and distribution of food, to introduce greater transparency in animal and plant supply chains.

Market size of Blockchain

Against the backdrop of all the hype that has developed around the topic of Blockchain in recent years, it must be emphasised that the level of concrete market applications is still lagging behind. Besides the widely publicised use of Blockchain technology with regard to cryptocurrencies, markets in other domains are limited. For instance, in a survey of CIOs conducted by Gartner[272], only 1% of companies reported some level of Blockchain adoption while 77% indicated either having no interest in Blockchain or having no plans for pursuing or developing the technology (see figure 32). A crucial reason for this is the fact that Blockchain is still a largely immature technology[273] and has proven to be challenging to apply in real-life situations.

Nevertheless, as can be seen in the same Gartner study, Blockchain is still a technology that is on the radar for industry. As a result of this, the technology has seen relatively high levels of investment in recent years. In 2017, approximately $1 billion worth of venture capital was invested in Blockchain start-ups[274]. Furthermore, large multinational companies are also investing heavily in this domain. IBM, for instance, has invested £200 million in Blockchain-based IoT[275]. Furthermore, IBM, Microsoft and Accenture currently account for around 68% of Blockchain sales, according to Bloomberg[276].

Looking ahead, the global market for Blockchain is expected to grow significantly in the future. Currently, the market for Blockchain products and services is estimated to be valued at around $700 million[277] but this is expected to grow at a compounded annual growth rate (CAGR) of 62.1% between 2015 and 2025, by which time the market would be worth $16.3 billion[278]. Projections for the growth in business value added are also positive as this is estimated to reach $176 billion by 2025 and $3.1 trillion by 2030, according to Gartner[279]. Examples of the business value

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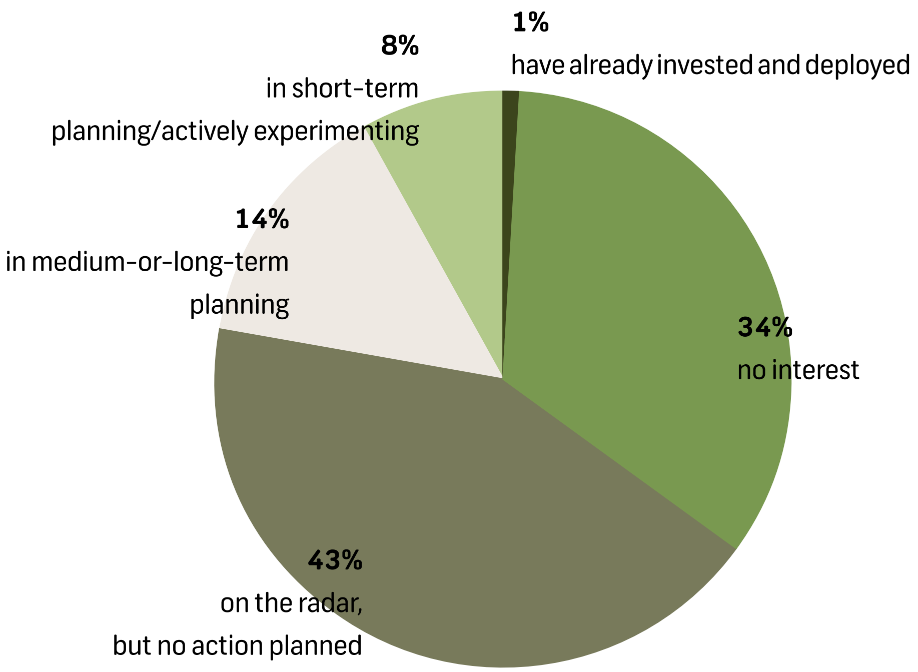
figure 32

worldwide blockchain adoption

Q what are your organisation's plans in terms of blockchain?

Base. total answering, excludes Don't Know n= 3.138



ADAPTED FROM
Gartner (2018)

include reduced handling costs of smart contracts, the provision of microinsurance to farmers in emerging markets for harsh weather conditions and lower costs of fraud detection for insurers in general[280]. More developed economies such as the US, the EU, Australia and Korea are exploring numerous concrete applications in the areas of identity management, data portability, green energy trading, voting systems and anti-fraud measures. Table 9 provides an overview of sectors and the current application of the Blockchain therein with some examples.

5.5.3 Why is Blockchain important for Africa? What are the opportunities?

Most of the impacts of Blockchain described above apply to Africa. Being an incorruptible digital ledger, contract enforcement and the reduction of the need for intermediaries in transactions would be particularly beneficial for Africa.

Smart contracts are a feature of Blockchain technology with high potential for Africa. Smart contracts allow automatic contract enforcement if certain conditions are met[281]. This has the potential to mitigate issues such as corruption, contract enforceability, information asymmetry or principal-agent problems[282]. Moreover, trust issues concerning third party intermediaries such as banks or government institutions can be circumvented. However, having a secure enforceable contract also reduces credit risks for financial institutions, thus having the potential to lower the costs of capital in Africa.

Improving institutions, markets and governance can have a huge growth impact in Africa, effectively enabling the country to make the leap from legacy non-digital approaches straight to a blockchain-based system. Moreover, currently Sub-Saharan Africa has already over 338 million mobile money accounts, more than all other developing regions put together. There is therefore considerable potential to use the existing mobile infrastructure to develop applications based on smart contracts, which make services such as eGovernance, eCommerce, eHealth, and Mobile Finance more secure and reliable. One key area here is the use for digital identity systems. Many African countries have major problems with identity systems for their citizens. Blockchain-based solutions have the potential to reduce identity fraud and to enable African countries to make the leap to a digital identity system.

Moreover, Blockchain also has a high potential in the energy sector where it can enable smart decentralised micro grids which use Blockchain technology to verify peer-to-peer electricity trading[283]. This would also improve the take-up of decentralised grid solutions which can be more cost efficient for remote areas in Africa, which often suffer from poor connection to the centralised grid. The next subchapter presents current applications in Africa but also presents opportunities more on a project basis sector by sector.

5.5.4 Current applications of Blockchain in Africa

Blockchain is already being explored in a number of areas across the African continent. There are already 120 start-ups, which are located in 21 countries, relying on Blockchain. Current applications are mainly found in modernised services and financial inclusion but also agriculture and health, industry and energy. Figure 33 illustrates the trends in market applications and investments. The map is only used for illustration purposes and is not intended to give an exhaustive overview of current Blockchain applications and investments in start-ups across the continent.

According to Crunchbase analysis of companies that have received funding for Blockchain-based applications, companies in Mauritius have gathered the most funding ($7,320,000) while those in Nigeria were least funded ($143,000); in between, companies in South Africa ($6,650,000), Kenya ($1,105,000), Ghana ($450,000) and Egypt ($375,000) managed to be funded. It should be noted that the investigations conducted did not show funding in countries other than the ones noted on the map. While there are many plans and visions with regard to Blockchain, the actual applications that exist are way more limited than what was planned. The following text also highlights some upcoming applications since the technology adaptation of Blockchain is currently mostly not mature enough in Africa, which is visible in the lack of Blockchain applications already in use and not at the planning stage.

More advanced plans and existing solutions for the application of Blockchain can be found in financial services. One existing project is in Rwanda, where I&M Bank Rwanda started with the Norwegian FinTech company Blockbonds, a Blockchain-based mobile banking application called SPENN[285]. In Nigeria, Interswitch is examining Blockchain-based solutions for supply chain finance. Several financial and transportation companies in Morocco are considering the incorporation of Blockchain into their processes. These include Wafacash, Saham Assurances, several banks and large public groups such as Tangier Med Port[286]. Another Blockchain start-up is XendBit, which aims to build a decentralised Digital Asset and Securities Exchange in collaboration with the Nigeria Stock Exchange.

In the area of the supply chain & logistics, the Moroccan Professional Association of Shipping Agents, Ship Dealers and Charter Brokers (APRAM) considers that Blockchain may save up to 20% of the costs associated with international shipping[287]. An important area is the use of Blockchain to validate the origin of goods. An example from Uganda that is already up and running is highlighted in box 08. There is a wide range of other similar potential application areas in Africa, which include for example, using Blockchain to trace the origin of diamonds. This could effectively put a stop to the use of 'blood diamonds', i.e. diamonds which are used to finance conflicts[288].

t

table 09

markets and application domains of the blockchain worldwide

Current application of Blockchain	Sector/industry	Examples
High	Modernised services and financial inclusion	Solutions for supply-chain finance, transport and shipping, insurance Faster, cheaper, and secure international payments Trade finance Blockchain platform to accelerate financing of international trade
Medium	Health	Share clinical trial launches & enrolments in real time to match patients Blockchain-based healthcare records Combination with IoT sensors to manage cold chain of drugs, blood and organs
	Agriculture	Secure tracking of land registration and mortgages & crop trading platforms
	Public sector	Managing digital identity of citizens, ownership of transaction information on assets, reducing fraud Blockchain-based identity records Secure and transparent voting in public elections
Low	Utilities	Managing off-grid power generation networks Smart contracts for more efficient and faster energy trades Streamline supply chain processes
	Industry	Enhanced supply chain management: traceability of goods and services up to usage combined with IoT
	Telecoms	Consumer payment opportunities & novel PAYG schemes

SOURCE
Technopolis (2019), examples collected from several sources

In the commercial field, Blockchain is being adopted in digital consumer services. Nigeria's Customs Service is among the global early adopters of the Oracle Blockchain Cloud Service, which has recently been introduced. The service allows organisations to build Blockchain networks easily to drive more secure and efficient transactions and to track goods along supply chains on a global scale[293]. The Central Securities Clearing System (CSCS) Plc., the Central Securities Depository (CSD) of Nigeria, has successfully completed a pilot using the Quartz Blockchain technology for cross-border corporate action information exchange[294]. Also, one of Nigeria's largest gaming companies, the International Lottery, and Gaming Limited, popularly known as NaijaLottery, signed a partnership deal with Blockchain-based lottery platform Quanta to revitalise the traditional lottery. Quanta is a gaming platform that built on the Ethereum Blockchain and is the first fully certified and licensed Blockchain lottery in the world[295]. Also, in the realm of public services, the Ugandan government announced that it will use Blockchain technology to improve its public services[296].

In the energy sector, there is considerable potential for Blockchain technology to be used in a future decentralised grid solution and smart metering. There are already existing applications in Africa. For example, in Nigeria, Solar Bankers launched a full-scale smart grid project using its Blockchain-enabled P2P energy trading platform. The

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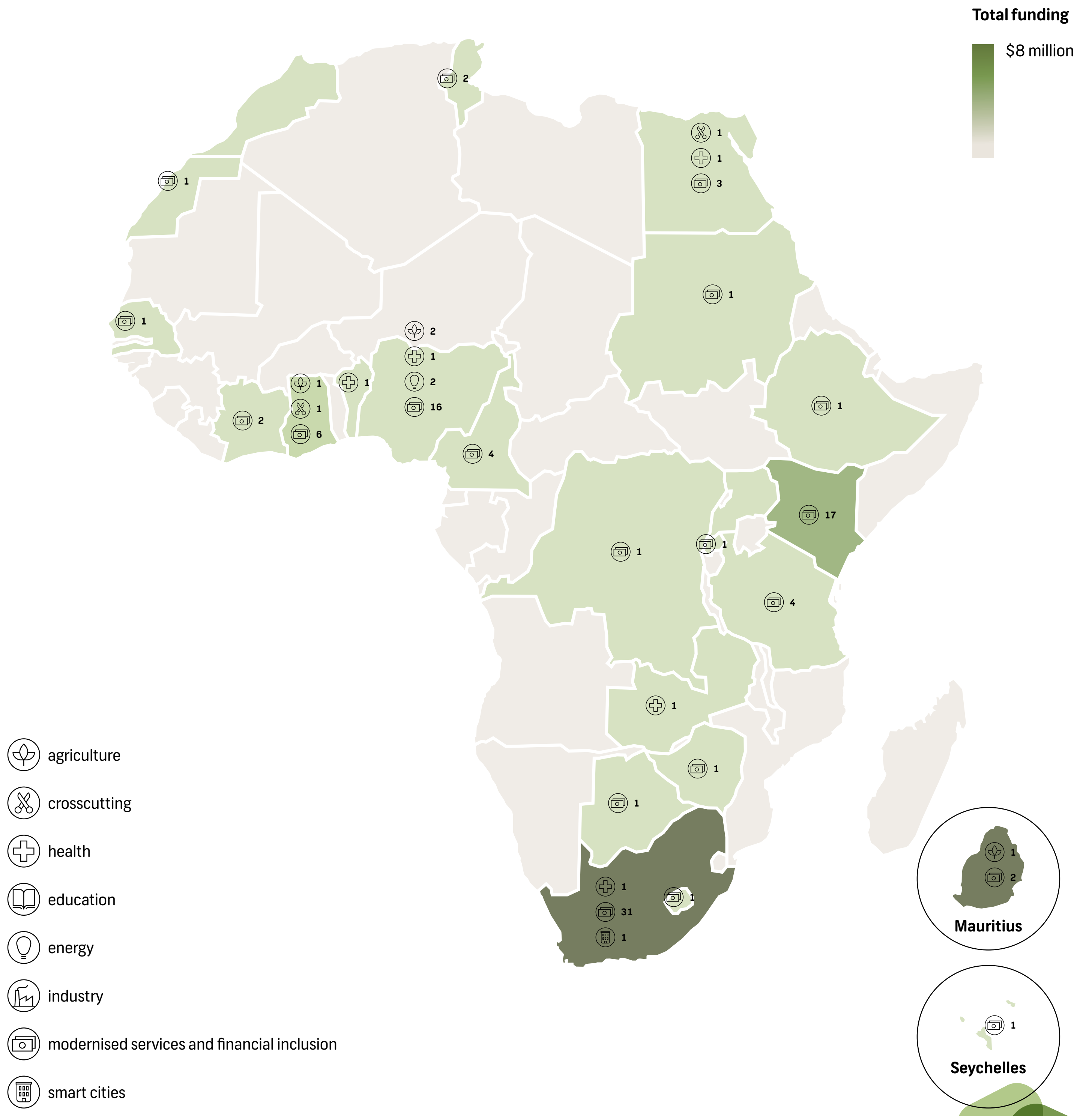
figure 33

state of blockchain startups in Africa by sector



ADAPTED FROM
Technopolis Group (2019), based on desk research and interviews[284]

b

box 08

blockchain is being used to track goods along the global supply chain: fair trade coffee from Uganda

Coffee is one of the most important cash crops in Uganda. The Uganda Coffee Development Authority (UCDA) estimates that approximately 500,000 households depend on coffee production. Due to the nature of limited processing capacities in Uganda, the vast majority of its coffee exports must be in the form of raw beans. This makes it difficult for the end buyer to ascertain where the beans originated from[289]. There is a global trend to incorporate fair trade principles in coffee supply chains. Some estimate that the growth of fair trade products results in a 24.5% increase in coffee sales. Blockchain can facilitate the verification of fair trade supply chains[290].

Carico Café Connoisseur, a Ugandan firm, has started using Blockchain to trace the origin of coffee beans. The firm claims that coffee bean purchasers are ready to pay a higher price if they are able to trace the origin of the coffee through Blockchain. Using Blockchain as a tool for origin verification and traceability offers several advantages, such as immutability of records, transparency and data security. Using Blockchain, Ugandan farmers will be able to digitally integrate an immutable certification. Consumers can verify the authenticity of the certification by scanning a QR (Quick Response) code with their smartphone[291]. They will also have access to transparent data regarding where and when the beans were grown and what quality was assigned to the beans throughout the process. Using blockchain puts an immutable time stamp on each and every step that the shipment makes, such as regulatory inspections, distribution warehouses and cross-sea shipments. This procedure empowers local coffee suppliers to charge more and pay the local farmers higher wages (Pepi, 2019). Carico Café Connoisseur has already completed its first pilot shipment, containing many tonnes of the Ugandan coffee brand Bugisu Blue. The shipment successfully made its way to South Africa in December 2018[292].

SOURCE Technopolis Group (2019), Uganda case study

start-up has signed an agreement for a pilot project with the Kaduna State Power Supply Company (KAPSCO) to deploy its P2P energy trading platform to the city of Kaduna in the north of the country. The project will connect 66 commercial and residential buildings in the Atiku Abukakar house cluster in a local smart grid infrastructure[297]. Another Nigerian start-up, OneWattSolar, is seeking to help people pay for the energy that they consume using Blockchain without the need to own the solar infrastructure that provides the power[298]. With this payment method, users are charged for their exact energy usage. Currently, about 6,400 households are on the company's waiting list. Also, OneWattSolar plans to expand in the near future. In 2025, the start-up hopes to access one million households without adequate power supply and provide solar energy through distributed technology[299].

In terms of agriculture and land use, Blockchain offers considerable potential for overcoming the challenges of remoteness and the multiplicity of small independent farms. Blockchain-based land registries can enable smallholders to securely keep and track land registration and mortgages, including digital authentication. This is particularly important in a setting with many small independent farms. In 2018, Ghana's government signed a memorandum of understanding with IBM for the use of IBM's Blockchain capabilities in the field of land registries[300]. As a result of that, Blockchain technology-based registers were allowed to verify ownership, thus making it possible to sell land or use it as a credit guarantee given that banks will know that one piece of land is not used multiple times. Similar initiatives are going ahead in Rwanda[301] and Kenya[302]. In addition, to validate land assets there are also more innovative uses in agriculture, such as the use of Blockchain tokens as a digital wallet for crop storage. A similar example is the use of Blockchain to validate the storing of crops, which is highlighted in box 9.

5.5.5 What needs to be done to take advantage of Blockchain in Africa?

Generally speaking, the adoption of most technological innovations is dependent on essential infrastructure, specialist personnel and appropriate governance (see figure 34). For Blockchain, the larger the P2P network, the better Blockchain solutions operate due to increased computing power. This means that there must be stable access to electricity, suitably-fast broadband, a motivated community of users (nodes) and the political will to adapt regulation and the sophistication to develop suitable governance models. Besides infrastructure issues such as the electricity required to power Blockchain solutions and the digital infrastructure, there are also some technology-specific challenges.

Regulatory changes and governance frameworks

In many countries, current regulations do not allow for decentralised solutions, most prominently in the energy sector, with the majority set up for centralised or hierarchical systems[303]. Regulatory approval has a considerable impact on the success or failure of implementing distributed infrastructure[304]. Central authorities in many countries around the world have been slow to address Blockchain technology issues, particularly in the context of cryptocurrencies. Indeed, many central authorities have taken an active position against citizens and businesses holding and trading in cryptocurrencies. This is changing. The US, EU and other western economies are updating legislation and taking policy positions on Blockchain, enabling further development. This is also the case in some African countries, such as South Africa.

As Blockchain's most well-known application, cryptocurrencies are viewed with scepticism by many national governments and authorities in Africa. In most cases, authorities have warned citizens and businesses against the use of virtual currencies[305]. South Africa is one of the main exceptions to this. South Africa's regulators in the FinTech and banking industries have offered a positive response in terms of finding the most effective and appropriate way to regulate cryptocurrencies in South Africa and the South African Reserve Bank (SARB) seems to recognise that there may soon be little difference between domestic and international payments using cryptocurrencies. Another example is Cameroon, where less stringent legislation provides an environment that is conducive to testing 4IR ideas and concepts such as Blockchain-based systems[306]. Another example regarding cryptocurrency regulation issues is that the Blockchain

b

box 09

blockchain in agriculture: crop storage in Nigeria

Binkabi is a Blockchain-enabled agriculture trading platform developed in cooperation with Sterling Bank, one of Nigeria's biggest banks. The platform will allow farmers to deposit their crops in a warehouse where they are currently often forced to sell it right away after harvest. In return for their deposited crops, farmers will receive a tokenised asset receipt that is stored on Blockchain. They can then use this token as an asset to borrow money against, allowing them to invest in their farms and to sell at the optimal time in terms of crop price rather than immediately after harvest as the loans they can receive thanks to the token allow them to wait for optimal prices.

Described as the 'Uber for grain' project model, the technology is leveraged to make agriculture commodity trading fairer and more profitable. Due to the challenges involved in supplying agriculture produce from the farm to the market, which leads to the wastage of agricultural produce, the platform provides a direct link between farmers and consumers, which eliminates the middlemen. Thus, the model is required for the purpose of confirming that sellers have the goods to sell and the buyer has the money to pay. It contributes to solving storage issues, enabling the farmers to get a fair share for their produce, gives them access to understand more new technologies and provides them with access to finance to carry out more production activities.

The platform tokenises agricultural commodities using Blockchain technology to boost agriculture trading and this contributes to eliminating inefficient paper-based processes which slow down trading and result in food wastage. Anyone can trade in agriculture commodities using Binkabi tokens. The more commodities are traded, the more discounts are earned. Farmers obtain instant rewards as their goods are sold through an online wallet which is decentralised.

SOURCE Technopolis Group (2019), Nigeria case study

f

figure 34

SWOT analysis for large scale adoption of blockchain in Africa

strengths	**weaknesses**
a number of existing focused initiatives in the Blockchain area	lack of appropriate legislation and/or regulation barring adoption
solutions can sometimes use existing hardware and infrastructure in Africa	lack of awareness of some applications of Blockchain among policy makers
existing software can be bought as a package from international companies or is sometimes freeware, which lowers technology adoption costs	uneven access to key infrastructure
high motivation across the continent to explore Blockchain-based solutions	few existing proven applications despite considerable interest in the topic
a young and entrepreneurially-minded workforce	
prior success stories of big leaps in technology	

opportunities	**threats (or challenges for increased uptake)**
streamline the current intermediation of services through Blockchain technology	blockchain has some energy intensive implications in some cases, such as in cryptocurrency mining, which can crowd out areas where energy is needed more
improving transparency in the public sector and creating more trustworthy electoral systems through the use of Blockchain in elections	cryptocurrencies are used to fund illegal activities
weak identity system in many African countries means that there is the potential to leap directly to Blockchain-based digital identity solutions since there is no legacy infrastructure	
cross-border trade using a trusted, transparent supply chain, which can also improve the value of African goods internationally	
automatic contract enforcement can reduce delays in payments	
blockchain-based asset registries can significantly lower the costs of capital due to increased security for lenders	
connect components of the financial trade system, providing a common framework for commerce management	

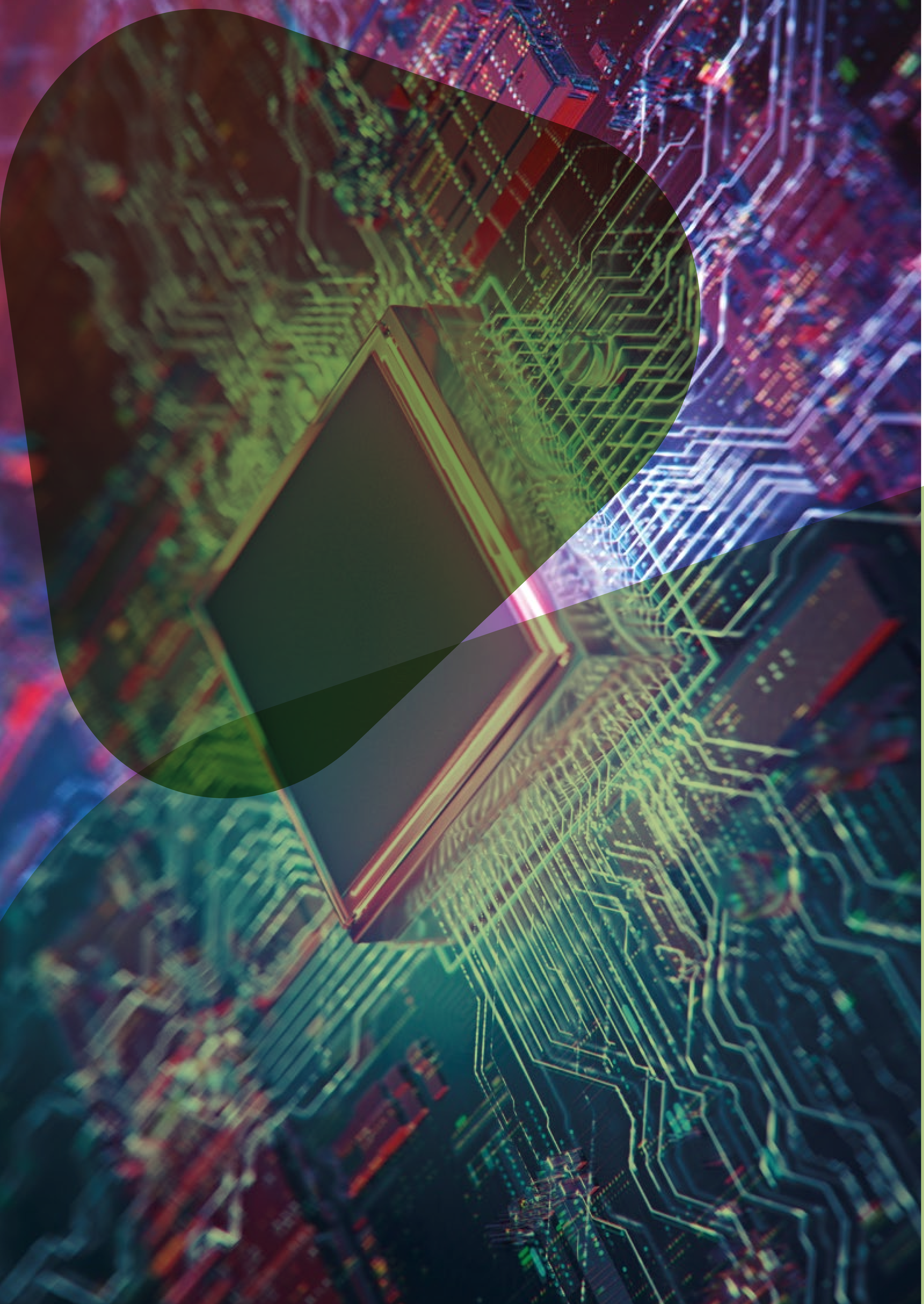
community in Nigeria argues that the country is missing an opportunity to attract major investments in the sector despite holding a third of the global Bitcoin reserves. As a result, the country's parliament recently carried out an inquiry to figure out the pros and cons of crypto-based payments[307]. The issue of Blockchain governance is significant and challenging at the same time. Despite its transformative potential across many areas, the risks and benefits of the application of Blockchain must be carefully weighed up and appropriate governance put in place to pursue a positive path of development here. Serious consideration of governance models must be undertaken although, due to the breadth of potential applications, it is most sensible to do this on a case-by-case basis[308]. New regulating agencies will have to be created or the existing regulators for energy, digital and financial issues will have to broaden their scope to address issues related to Blockchain regulation and governance. Moreover, the publicly run Blockchains will have to operate fully transparent Blockchain models to encourage the participation of private businesses and citizens.

Hardware and digital infrastructure for Blockchain

Blockchain runs on a distributed, P2P network of nodes (computers) that combine to authorise transactions or modifications to data. This means that ICT infrastructure is the second essential enabler of adopting the technology. While it is simple to establish a network node on a standard desktop computer, processing power is a premium requirement, and this means that not all hardware can be re-purposed. In principle, the availability of suitable hardware should be adequate in many cases, although there are cases where acquiring equipment can be difficult. The nodes must communicate with one another in order to process data modifications and transactions and so stable internet connectivity is essential. It is unclear whether existing mobile data infrastructure in Africa is suitable for broad-scale adoption and maintenance of Blockchains. The technologies that underpin Blockchain are established and proven. It is possible to set up Blockchain nodes via publicly-available Linux packages with little computing power. As such, there is – in principle – a relatively low barrier to using these technologies although it is important to ensure sufficient expertise in the set-up and maintenance of Blockchains, especially for new applications (i.e. establishing, rather than simply joining established mining pools). Nevertheless, for example for cryptocurrencies, high processing powers are required. In addition to this, the cost of ever-expanding indefinite time storage requirements needs to be considered.

Skills and human resources

Due to its decentralised nature and the relative ease with which a Blockchain node can be established, it is possible that individuals of all types can participate in P2P networks with a working knowledge of Linux. This is what underpins the growing pool of computing resource seen on the Bitcoin Blockchain. However, this is only one part of the equation. Developing a particular Blockchain solution on a 'professional' scale requires special expertise. However, this does not mean that a corporate solution is required. There are already many incubators and accelerators in Africa that are hosting Blockchain start-ups and helping them to grow. For example, the Cameroon Blockchain Business Council (CBBC) brings together businesses, entrepreneurs and business leaders to advance Blockchain and DLT, with a (long-term) view to facilitating cross-border trade based on cryptocurrencies. This application of Blockchain is currently not well understood, with authorities needing time to develop regulatory frameworks. A similar initiative is the Blockchain Lab in Nigeria, which was established to accelerate decentralised innovation across Africa. The lab offers training courses, consulting for companies and incubation for start-ups.



6
emerging technologies and market applications in Africa

6.1 MARKET APPLICATIONS IN AGRICULTURE

In 2017, Africa spent $64.5 billion on food imports and may spend even more in subsequent years (AfDB, 2019), potentially reaching $110 billion by 2025 (Shaban, 2017). This is unsustainable and unaffordable. Despite this, Africa has 65% of the world's remaining uncultivated arable land, an abundance of fresh water and about 300 days of sunshine each year. More than 60% of Africa's working population is engaged in agriculture and the soil across most of the continent is rich and fertile.

Africa is also the continent whose population has the highest growth rate. It is projected to double by 2050, from 1.2 billion to more than 2 billion people. But feeding a growing population will require a threefold increase in African agriculture production by 2050 (Dupoux & Zrikem, 2016).

Africa is missing an opportunity to be self-sustaining and to even export food. To seize these opportunities, African agriculture needs to be modernised. Emerging technologies can contribute to the fundamental transformation of agriculture in Africa.

The following sections (i) present the agricultural sector and its challenges in Africa, (ii) explore how 4IR technologies can transform agriculture in Africa, (iii) show current African agricultural use cases of 4IR technologies and (iv) discuss the challenges which limit the take-up of 4IR technologies and recommend actions to unlock the potential of emerging technologies in agriculture in Africa.

6.1.1 Presentation of agriculture and challenges for the sector

Agriculture plays a crucial role in the African economy and the daily lives of the majority of Africans. It accounts for some 60% of jobs across the continent. Despite its central role, on average, the agricultural sector accounts for only 16.5% of African GDP (AfDB, 2019). Nearly all producers are family farmers who live in rural areas. Agriculture provides 40% of export earnings for Sub-Saharan African countries with many countries like Côte d'Ivoire, Kenya, Ghana, Ethiopia, Malawi particularly dependent (UNCTAD, 2016).

Africa is a net food importer (Rakotoarisoa, 2011) and depends on the rest of the world to feed its population. Rice, a staple of many populations across Africa, is the most imported food product across the continent. According to the 2013 report of the Food and Agriculture Organization (FAO), these imports represent almost $700 million annually. African consumers spend 80% of their revenue on food (Salem, 2018) and are exposed to fluctuations in the cost of imported crops. Rising imports show the need to transform agriculture as a business, particularly by indicating the scale of demand that currently exists and if a vibrant private agribusiness sector in Africa can be stimulated to service it. These food imports represent a diverse set of markets, both in key primary commodities as well as processed goods and agro-industries, worth more than $100 billion in revenue per annum (AfDB, 2019). Even though African subsistence agriculture production is not enough to feed the population, there are exceptions where agricultural products are exported: cocoa in Côte d'Ivoire, coffee in Ethiopia, cashew nuts in Senegal, cotton in Mali etc.

The African agricultural sector is currently facing a number of problems.

One obstacle to the development of agriculture in Africa is **low productivity**. African agriculture performs poorly in terms of productivity, coming in five to six times below the global average (FAO, 2017). For example, Africa's cereal yield is only 41% of the international average. The low productivity of African agriculture has a high human and economic cost. High rates of poverty prevail, especially in agricultural zones such as the sub-humid Guinea Savannah and the semi-arid Sahel regions where more than half of the population live on less than $1.25 per day. 256 million people are under-nourished in Africa. Low productivity also damages the competitiveness of African agriculture. If nothing is done, the number of extremely poor people is expected to rise from 420 million in 2015 to 550 million by 2025 (AfDB, 2019).

Small family farmers are at the centre of agricultural production in Africa and are often living in extreme poverty. As a result, they have **limited financial and technical capacity**. In addition, the sector is lacking a young workforce, which is instead migrating to urban areas. As a result, the average age of African farmers is between 50 to 55 years old (Rabobank Foundation).

Security of land tenure and good governance remain major challenges across the continent. Most African countries have basic land tenure laws that are incomplete and poorly enforced, deterring private investment. Although women are the primary farmers of agricultural land in most African communities, their access to land is, on average, less than half that of men.

In addition, Africa is currently forgoing the potential value added from its agriculture. For example, Africa produces about 69.2% of the world's cocoa beans by weight but receives only 2% of the revenue of global sales of chocolate (AfDB, 2019). The farmers are far from transforming cocoa into processed goods locally. Larger private sector investments are focused mainly on crops with high export potential, not those processed in Africa.

Climate change is also increasingly making the need for transformation more urgent. Africa is already disproportionately affected by the impact of climate change because of agriculture's overwhelming dependence on the weather. African farmlands and pastures are being degraded and this is causing yields to decline. It is estimated that an increase in temperatures of 2°C will cause farm yields to decline by up to 20% across Africa. If no adaptation takes place, corn production, which is one of the main African crops, could decrease by 40% by 2050 (Ehui, 2018).

More recently, 4IR technologies have started to transform agriculture and the lives of smallhold farmers, offering them real-time access to market information and hassle-free direct access to subsidised inputs through efforts such as the e-wallet system. The following section will show how 4IR technologies can boost the transformation of agriculture in Africa.

6.1.2 How can emerging technologies transform agriculture in Africa?

Africa's agriculture needs to be transformed into a business-oriented and commercially viable sector that guarantees the continent's food self-sufficiency and puts an end to food insecurity and malnutrition (AfDB, 2019).

According to AfDB's agricultural strategy 'Feed Africa', achieving agricultural transformation in Africa requires (AfDB, 2019) the following actions to be taken:

- Increase large scale productivity;
- Boost value addition;
- Increase investments in hard and soft infrastructure;
- Expand agriculture financing;
- Enhance agribusiness environment (policy reforms in land tenure, financial sector deepening, regional integration and trade etc.);
- Increase inclusivity, sustainability and nutrition;
- Coordinate partnerships to drive transformation.

4IR technologies have the potential to address the above top-level targets, notably by having a positive impact on the productivity and profitability of the sector and the creation of new locally based added value.

Potential applications in agriculture are more significant with IoT, Big Data, Artificial Intelligence, drones and Blockchain. Additive Manufacturing offers fewer potential applications.

Internet of Things (IoT), Big Data and Artificial Intelligence

Use cases of IoT, Big Data and Artificial Intelligence (AI) applications on farms already exist. The global AI market in agriculture is forecast to be worth $2.6 billion by 2025, up from $518 million in 2017 (GHD & AgThentic, 2018).

IoT, Big Data and Artificial Intelligence are set to transform farming by allowing smart and precise agriculture[309], which yields more productivity and profitability.

IoT devices collect data that can help farmers efficiently manage their farms. Field sensors connected to the IoT can record information regarding soil moisture and nutrient levels, leading to improvements in water usage from efficient irrigation systems, determine custom fertiliser blends based on soil profiles and determine the optimal time to plant and harvest. In greenhouses, IoT sensors can eliminate the need for manual monitoring as the completely controlled environment can be adjusted to change temperature, humidity, light levels and carry out automatic irrigation.

IoT applications can also be used to monitor the health, reproductive cycle and location of livestock. In the dairy industry for example, wearable sensors can be used to detect disease signals that are otherwise invisible to farmers while sensors can also measure milk fat, protein, somatic cell counts, progesterone and antibiotics at every milking (Shoup, 2017). By continuously collecting data on the animal, farmers can determine which cows are able to produce more milk and consequently take steps to improve diets that improve productivity.

IoT device installations in the agricultural world will increase from $30 million in 2015 to $75 million in 2020, for a compound annual growth rate of 20%. The US currently leads the world in the use of the IoT in agriculture[310]. Efficiencies gained from the IoT increase over time as farms become more connected and sensors can be applied to monitor more variables. With more IoT devices, the average farm is expected to generate an average 4.1 million data points per day in 2050, up from 190,000 in 2014 (Meola, 2016).

Likewise, Big Data and Artificial Intelligence (AI) can help farmers gain access to complex information that can inform farming decisions. The integration of multiple sources of data such as long-range climate forecasting, data collected through IoT on farms, mapping technology, historical industry data – past yields, market data, current consumption data – supply chain logistics, prices, distributions, volumes, social media data – trends, events, political and social movements or benchmarks with other farms further enhances the effectiveness of AI. AI increases the value of collected data by analysing and converting it into information to support farm management decision-making. It can be applied at a range of magnitudes from converting data collected on individual animals and plants to the level of an entire farm level by presenting information for crop planning and monitoring.

Big Data and AI can be applied in a wide range of settings. Examples of applications include precision farming, reduction of farm operating costs and development of new plants and seeds.

Machine learning software that can track yields, control equipment, monitor field conditions and manage inputs with precision allows for smarter and more customised interactions, which are creating opportunities for better decision-making on farms. Big Data and AI have the potential to help farmers manage their livestock efficiently with minimum supervision. New trials are being conducted where the technology can examine animals individually to determine their condition and suitability for market, while in dairying, AI is already in use in automated milking units that can analyse the milk quality and flag abnormalities (GHD & AgThentic, 2018).

Big Data and AI offer agriculture improved allocation and reduction of costs via targeted allocation of inputs such as fertiliser and chemical application.

Important developments in biological information collection and analysis have accelerated plant genomics. Research in laboratory settings is producing data that can be analysed to develop new hybrid seeds that perform across different environments.

Blockchain in agriculture

In agriculture, Blockchain can improve traceability, increase producers' earnings and secure contracts and transactions. Blockchain also has the potential to create financial incentives for ecologically and economically beneficial production practices.

In the case of introducing increased transparency into agricultural supply chains, a Blockchain can assist in providing an immutable record (traceability) from the provenance to the retail store of a product. End consumers increasingly want to understand where their food comes from and how it was produced and transported. Blockchain can provide participants all along the supply chain with data on provenance, production practices, transaction details and product quality and safety and verified regulatory and financial compliance. Supply chain provenance, in addition to transparency, provides two key benefits: reducing food fraud and enabling food safety. For example, Italian pasta and pesto sauce manufacturer Barilla has teamed up with IBM to tackle transparency and traceability in its pesto production cycle. IBM's Food Trust, built on IBM's Blockchain platform, helps Walmart track food products along its supply chain (FAO & ITU, E-Agriculture in Action: Blockchain for agriculture. Opportunities and challenges, 2019). In the context of emerging markets, where food fraud and safety are particularly important, these properties are interesting.

Moreover, Blockchain can help increase the earnings of producers in agriculture by providing better monitoring of their inventory and simplifying their food value chain, resulting in greater income for the farmers. Post-harvest losses are particularly damaging to farmers in Africa: they reduce their earnings and are harmful for food security. Total food losses in Sub-Saharan Africa are estimated to come to $4 billion per year, an amount which can feed 48 million people. Losses on cereals are estimated to be high and account for about 25% of the total crop harvested. These losses can be even greater in perishable products and account for up to 50% of harvested fruits, vegetables and root crops (Aulakh & Regmi, 2013). In order to prevent post-harvest losses, farmers must be proactive in monitoring their crop storage techniques, ensuring that CO_2 concentration remains at an acceptable level to prevent mould growth and infestation. Blockchain in conjunction with Internet of Things (IoT) devices, such as sensors and scanners, can help monitor a farm inventory. Sensors can detect the potential for losses three to five weeks earlier than traditional temperature monitoring techniques do. Utilising a decentralised ledger on a Blockchain will provide more seamless communication between the players in terms of what needs to be done, whether that means harvesting crops, making storage-related adjustments, ordering new equipment or otherwise. In addition, the process of sending a crop from the farm to the market usually depends on a third party for coordinating the goods delivery. These middle actors capture margin. With Blockchain, commodity buyers can interact directly and securely with the supplier. Producers (farmers and companies) therefore receive a larger share.

A Blockchain by design is cryptographically secure and can help secure contracts and transactions (smart contracts) namely in land registration and agricultural insurance.

In land registrations, Blockchain-based implementations could provide an incorruptible ledger of land records. Especially in the case of the remote and most deprived areas, if this is linked effectively to sovereign ID/digital ID, then the safekeeping of land records even in times of natural disasters or wars would not be an issue. The United Nations Development Programme (UNDP) in India is working with partners to make land registry more reliable. At a high level, this project will capture and permanently record each transaction throughout the sale of a property. The Swedish government's land ownership authority, Lantmäteriet, has piloted land registry and property transaction on Blockchain. They believe that this provides a safe and secure way to have digital originals and that it could reduce government expenses by hundreds of millions of dollars.

Low-cost agricultural insurance schemes are increasingly viewed as mechanisms for providing social protection to the increasing numbers of people affected by floods or droughts and in helping to lessen the impacts of such events on them. However, despite the multiple benefits, the rate of adoption of insurance products by the rural poor still remains relatively low. The mechanisms that are in place to validate claims and to effect payouts are still time consuming and this is one of the reasons for index-based insurance not being chosen as the first risk mitigation strategy by smallholder farmers. Index insurance based on smart contracts based on Blockchain can automate and greatly simplify the process, thereby facilitating instant pay-outs to the insured in the case of adverse weather incidents. Automatic data feeds provide continuous and reliable hyperlocal data to the contract, thereby eliminating the need for an on-site claim assessment by the surveyor (FAO & ITU, E-Agriculture in Action: Blockchain for agriculture. Opportunities and challenges, 2019).

Finally, Blockchain has the potential to allow consumers to assign value to differentiated production practices (e.g. certifications; resource efficiencies; welfare standards). Price premiums may incentivise the development of supply chain infrastructure that supports differentiated production (i.e. as opposed to conventional commodity-based supply chains), for example different crops or production systems. Primary producers would then have more options, as well as an enhanced ability to communicate their production choices to end consumers and receive a premium back (GHD & AgThentic, 2018).

Drones

The agricultural drone market is expected to grow from a projected $1.2 billion in 2019 to $4.8 billion by 2024[311]. Key factors driving the growth of the market for agricultural drones are pressure on the global food supply due to the growing world population and the increase in venture funding for the development of agriculture drones. North America is expected to hold the largest share of the market in agriculture drones during the forecast period. This growth is attributed to the exemption from the Federal Aviation Administration (FAA) under the 'part 107 rule', which is leading to a high rate of adoption of drones in agriculture. This is attracting more investment from venture capitalists in the agriculture drones' market.

Through instant data gathering and processing, drones offer various applications in agriculture in the following ways, which are currently being used by farmers globally: soil and field analyses, crop spraying, irrigation, crop health assessment and livestock monitoring.

Drones have the ability to produce precise maps for soil analysis in pre-planting and further analysis for irrigation application, fertiliser and chemical requirements. Using the Normalised Difference Vegetation Index (NDVI), a mapping method that identifies whether an area contains live green vegetation, data from drones can be applied to gridded management maps, where information can be used within variable rate systems for sowing, spraying and other management operations.

With automated distance-measuring equipment, drones can scan the ground and spray the correct amount of chemicals with increased efficiency and reduced environmental impact. This targeted spraying of chemicals is a key benefit of drones as it reduces input costs and provides positive environmental outcomes such as a reduction in chemical and artificial fertiliser use.

Drones with hyperspectral, multispectral and thermal sensors can be used to inspect fields for moisture deficiencies and to calculate vegetation index / heat signatures. This information can then be used by farmers to make more efficient adjustments to irrigation operations that focus on specific areas that are moisture deficient.

Drones can be used to provide high resolution imagery to show detailed crop development and reveal crop health and spot bacterial or fungal infection on trees. By scanning a crop using both visible and near-infrared light, drone-carried devices can identify which plants reflect different amounts of green light and Near InfraRed light. This information can produce multispectral images that track changes in plants and indicate their health. Farmers can therefore monitor crops for disease and, in the case of damaging weather events, document losses more efficiently for insurance claims. Drones can also be used to monitor livestock remotely and potentially improve profits via timely monitoring, negating the need for physical inspections. Drone operators can check in on livestock to monitor injuries, birthing or to ensure none are missing.

Additive Manufacturing

While agricultural engineers currently use Additive Manufacturing (AM) to rapidly develop low cost prototypes, the agriculture industry is not currently one of the main sectors using or driving the development of AM globally (GHD & AgThentic, 2018).

In agriculture, AM has the potential to change equipment supply chains by enabling on-site printing of parts. AM can reduce the cost and time required to design and manufacture equipment needed in agriculture by farmers. The prototyping capabilities enabled by AM create opportunities for advancements in agricultural research (e.g. 3D soil modelling). AM may be especially applicable for protected cropping, vertical farming and other forms of indoor farming as it may enable the cost-effective printing of small, precise parts.

6.1.3 Current use cases of emerging technologies in agriculture in Africa

While still in their infancy, African initiatives using 4IR technologies are flourishing in the agriculture sector. The most common applications in Africa are based on Artificial Intelligence (AI), Big Data and IoT and drones while Blockchain technologies are still at a very early stage.

The present study identified 86 African companies located in 17 countries: Cameroon, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Kenya, Malawi, Mauritius, Morocco, Nigeria, Rwanda, Somalia, South Africa, Tanzania, Tunisia, Uganda and Zambia. Figure 35 illustrates trends in market applications and investments. The map is only used for the purpose of illustrating trends in agriculture and is not intended to give an exhaustive overview of current emerging technologies applications and investments in start-ups across the continent.

As shown by Crunchbase, Nigerian start-ups attracted the most funding ($13,567,172) while Egyptian ones the least ($15,000); in between, companies were funded in Mauritius ($8,640,000), South Africa ($4,751,167), Kenya ($1,586,031), Morocco ($1,000,000) and Ghana ($50,000). It should be noted that investigations did not show funding in countries other than the ones noted on the map.

In some of the countries where we carried out in-depth research, there is growing awareness about the potential of AI, Big Data and IoT for improving agriculture. Some interesting use cases are presented in the following sections. Boxes 10, 11 and 12 highlight three of them.

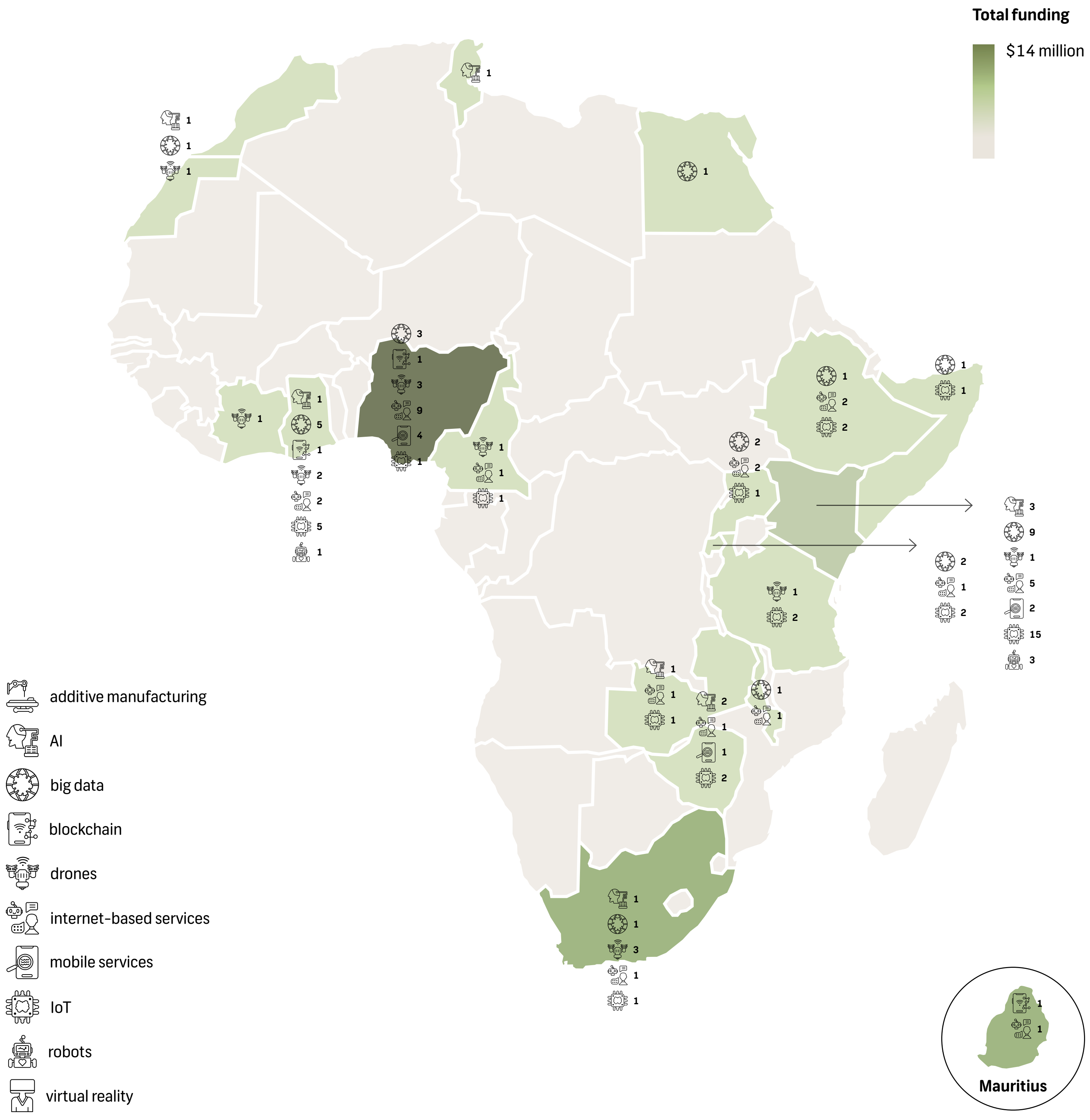
In Morocco, the company OCP (phosphate producer and transformer, fertiliser) has entered into a public-private partnership with the University Mohammed VI Polytechnic (UM6P) to create a new venture called Agri Edge. See Box 10 for more details. The Moroccan company, Visio-Green Africa, a subsidiary of the French company Visio-Green, launched Morocco's first, complete IoT system in 2018. The goal is to have a smart irrigation system, to give farmers the ability to manage their fields remotely in a very simple way and to collect or stock various types of data to manage yields more efficiently. The first project was launched together with the Moroccan Association of Producers and Exporters of Fruit and Vegetables.

In Nigeria, Plantheus is a plant off-line diagnostic application that requires no internet access to run diagnostic analyses on the condition of plants. The AI algorithm that will be used in the application will be adept enough to learn about new crop diseases. Another Nigerian start-up is Hello Tractor, which offers technology for smarter, better maintained and more profitable tractors using an AI solution from IBM. The company sells its own brand of tractors and uses AI to automate complex decisions for the purchaser of the tractor and the bank issuing credit. It assists the farmer in selecting the best tractor for his or her needs while simultaneously providing the bank with information that will inform their loan decision. The tractors include sensors that are used to monitor their condition (IoT) subsequent to their purchase. See Box 11 for more details. MTN, one of Africa's biggest telecoms providers, has already trialled an IoT-based Animal Identification Management System. This uses affordable RFID chips that are attached to individual farm animals, mostly cows. The chips provide real-time information on the location of the animals to the farmer, allowing them to manage their livestock more efficiently. Automatic alerts occur if a cow breaks out of a designated area. In the future, this solution could also be expanded to trigger an alert if a cow enters areas that it should not, such as planted farmland. Similarly, Vetsark analyses Big Data to protect crops and livestock from pests and diseases. Using real-time data on diseases and pests, Vetsark can report diseases and file clinical cases, cutting inventory losses and gaining business insights. The start-up uses machine learning for disease prediction. To date, the start-up has been used to save $50,000 worth of livestock

f

figure 35

4IR market applications and investment in startups: trends in agriculture in Africa



ADAPTED FROM
Technopolis Group (2019) based on CrunchBase and web mining

and helped vaccinate 120,000 cattle. The entrepreneurs are in discussions with the country's federal government to deploy the system across the country. Nigeria-based Zenvus seeks to improve decision-making for farmers by providing insights into crop status based on data collected from sensors and other means (IoT). The data is stored in the cloud and can be accessed by the farmer irrespective of their location. This allows farmers to use fertilisers and irrigation more precisely, increasing farming efficiency.

In Cameroon, the start-up AllGreen is developing intelligent modules to identify diseases in plants. It is capable of analysing and diagnosing crop diseases in real time and with precision, as well as notifying the owners of good practices to be adopted to combat disease. AllGreen technology is incorporated on drones deployed at various plantations.

In Uganda, Jaguza is a start-up that has developed a mobile app using Big Data analytics in combination with drones and AI to improve online and offline livestock identification, record keeping and monitoring. The platform also sends automatic notifications each time an animal moves out of range and this information is stored on a cloud server. See Box 12 for more details. MUIIS (Market-led, User-owned ICT4Ag-enabled Information Service) offers accurate satellite weather information, agricultural advice, trend analysis for soil, water evapotranspiration records, insurance data and market information for farmers. Tips and instructions are sent to mobile devices and can be as specific as 'spread fertiliser between 5pm and 7pm' or 'winds expected at 3pm.' Farmers have reported that this type of intervention has helped increase crop yields and contributed to improving food security.

In Kenya, several start-ups use AI for precision farming: Vital Signs analyses pixel values and colour from satellite imagery data to estimate rainfall and drought patterns. Arifu provides curated access to information via SMS to help farmers determine, for example, what fertiliser matches their specific needs. FarmDrive offers credit to farmers in need of supplies (e.g. fertilisers) by relying on data such as the size of land, location and crops to determine the risk and corresponding interest rates.

In the area of agriculture, the take-up of drones is significant and there are many examples from across the continent that illustrate different use cases. In many cases, drones are also linked with other 4IR technologies, namely IoT, Big Data and Artificial Intelligence.

Morocco, for instance, is home to several applications of 4IR technologies in agriculture involving the deployment of drones in combination with Big Data analytics, IoT and Artificial Intelligence. French start-up Airinov expanded to Morocco with an exclusive partnership with Etafat, a Moroccan company specialising in topography. Together, they are using drones with sophisticated sensors to identify and monitor vegetation. It transmits this data to Airinov, which is responsible for transforming it into agronomic advice via certified algorithms, optimising inputs and improving yields through the optimal use of fertilisers. Insurance company MAMDA initiated a pilot project for claim assessments on parcels using drones in 2017. The objective of this pilot is to identify agricultural areas affected by climate events and to have an overview of plots for damage assessment and compensation to farmers in considerably shorter time frames. Images captured by drones are analysed by a dedicated application and can determine the vegetative state of crops and an estimate of yield. Thus, the data collected will enable farmers to improve the yields of their farms and optimise investments in terms of inputs (advice on dosing, fertilisation, identification of treatment areas). All advice and information are transmitted via smartphone to farmers with the goal of reducing the time that it takes for them to receive compensation.

In Uganda, drones are used in the Technical Centre for Agricultural and Rural Co-operation CTA's Eyes in the Sky project at the Igara Tea Factory. The drones assist smallholder farmers in the provision of a crop inventory (crop count and yield estimations) and management advice. This helps farmers calculate yields and their seed and fertiliser needs. Over 4,000 digitalised profiles of smallholder farmers were created. These profiles map the farms' location, size and productivity. Based on the data gathered by drones, farmers can apply for credit since the collected information can serve as collateral.

b

box 10

Agri Edge

In Morocco, the company OCP (phosphate producer and transformer, fertiliser) has entered into a public-private partnership with the University Mohammed VI Polytechnic (UM6P) to create a new venture called Agri Edge. The business unit was created by OCP and incubated at UM6P.

Agri Edge is a platform related to agriculture precision. It analyses agricultural data to guide farmers in their decision-making. The platform offers farmers three services: fertilisation, precision irrigation and integrated pest management.

The Agri Edge team is composed of agronomists and experts in precision agriculture.

Agri Edge has developed an irrigation control system that reduces production costs for the farmer, optimises the amount of water used for irrigation and, on a large scale, reduces water stress on groundwater.

Sensors directly implanted in the selected plots make it possible to record key data, which are then transcribed on the application available on the customer's smartphone. The farmer therefore has access to real time information and can quickly make the right decisions with the support of the Agri Edge team's recommendations. These include, among other things: the place, time and duration of irrigation required.

A pilot test showed that the system put in place helps to save 15% of water. Agri Edge's objective is to reach 30% of water saving in the medium term.

Access to the service is free for small scale farmers while large scale farmers have to pay for the service. Having reached the theoretical development stage, this business unit also completed the testing phase for fertilisation and precision irrigation. Currently, the project is in the scaling up phase.

SOURCE Technopolis Group (2019), Morocco country case

Furthermore, Nigerian Orbital Solutions uses Big Data from digital farmer profiles using the geospatial platform Agroexchange and drone technology to provide small scale farmers with technology driven advisory services. The ultimate goal is to facilitate aggregation and reduce post-harvest losses for smallholder farmers by using geospatial data and farmer profiles to provide information about the optimal location for farming production and processing. The Lagos-based start-up Track Your Build uses drones to collect data on vegetation, plant counting and yield prediction, plant health, height and field performance, nitrogen content and many other data streams in order to maximise field productivity while reducing environmental impact. In Cameroon, the start-up Will & Brothers is working on an Artificial Intelligence (AI) system called Cyclops, which will enable drones to detect people and identify different types of animals.

There are a few Blockchain initiatives developing or transforming agriculture in Africa.

In Uganda, Blockchain enables smallholders to keep and track land registration and mortgages, including digital authentication, securely. This is particularly important in a setting with many small independent farms. Another example is the use of hand-held soil scanners on individual farms for soil diagnosis. Commentators have suggested that this could be undertaken through intermediation cooperatives that own the field equipment, combined with wireless transmission of results.

Rwanda and Nigeria are two other countries that are digitalising their land registry, the latter to modernise the mortgage system in Nigeria to create a one stop shop for land transactions and secure mortgages. Also, in Nigeria, Binkabi is a Blockchain-enabled agriculture trading platform that allows farmers to deposit crops in warehouses and to be issued with a tokenised asset receipt. This gives them the option of more flexible trading times and to borrow against their receipts.

So far, not many examples of Additive Manufacturing applications have been found in agriculture across Africa. An example of a recent project where AM is being piloted is the 3D4AgDev project that is funded by the Bill and Melinda Gates Foundation, GIZ, and supported by the University of Galloway. The project uses 3D printing to provide women smallholder farmers with the ability to develop their own labour-saving agricultural tools that are tailor-made for their culture, soils and cropping systems (Naudé, 2017). The tools can provide routes out of poverty by improving the labour productivity of smallholders' agricultural systems. Tools may save labour, lead to higher yields and incomes, reduction of child labour and more time for other activities. The project enables user-led innovation where end users are involved in the research and design of an innovative product or process. The use of 3D printers enables rapid prototyping of their ideas. Female smallholders that lack formal education can design agricultural hand tools and household food processing equipment that meets their own needs. Plastic prototypes can be copied by local tool manufacturers, developing their own modifications to ensure that the agricultural tools are suited to the purchasing power and needs of smallholder farmers. The project is run by a research team that consists of an interdisciplinary group from the University of Galway. Participating organisations are the International Centre for Tropical Agriculture (CIAT), CRS, Concern Worldwide and MakerBot.

6.1.4 Challenges, recommendations and prospects

In this section, we will discuss the challenges posed by the adoption of 4IR technologies in African agriculture from the perspective of consumers and farmers. We will also present the key limitations for large scale adoption of 4IR technologies and recommend actions that could unlock the full potential of 4IR technologies. The challenges, recommendations and prospects are based on our analysis of information that we collected from stakeholders during field visits and interviews.

Blockchain

From the consumers' perspective, while there is broad awareness of Blockchain in association with cryptocurrencies, there is little popular understanding of Blockchain use in agriculture.

b

box 11

Hello Tractor

There were less than 25,000 tractors in Nigeria in 2007, according to the World Bank. To fill this gap and accelerate the country's agricultural transformation through mechanisation, a Nigerian entrepreneur has created Hello Tractor, a start-up that sells smart tractors. Thanks to a geolocation system, their owners can rent them to farmers who need them.

Hello Tractor designed a small tractor with a GPS antenna, which can be located in real time. The idea is to connect the owners of this type of tractor with farmers who need it. To order a tractor, farmers send an SMS to the company, which then takes care of finding the nearest machine owner. An application has also been designed to facilitate transactions.

For the moment, the tractors are assembled in Nigeria with parts coming from China. The tractors cost on average $4,000 and appear to be expensive, especially for farmers who mostly do not have access to finance.

In order to circumvent this obstacle, Hello Tractor has formed partnerships with banks to offer loans at reduced rates. The purchase price of the tractor can also be reimbursed by the profits made from renting the machine.

Hello Tractor also partnered with USAID on a $2 million project to modernise Nigerian agriculture. This support allowed Hello Tractor to sell at least 300 tractors in the country and has had an impact on thousands of farmers. Its platform uses an AI solution from IBM which automates complex decisions for tractor owners related to the choice of tractor and for banks providing credit for the purchase of tractors to decide on who to provide with a loan.

The company is exploring the idea of extending its activities to other African countries, namely Senegal and Kenya.

SOURCE Technopolis Group (2019), Nigeria country case

b

box 12
Jaguza

Jaguza developed a livestock app which is an artificial intelligence and computer vision system (IOT), mobile (android, Windows, IOS) as well as SMS, USSD and web-enabled system (both online and offline platform) that aims to improve livestock production in Uganda and across the continent. It has a number of available modules from which a farmer can choose the module that suits his/her needs best (Self Service App).

Jaguza focuses on developing and deploying mobile and offline best farming practice to increase access to animal health information for smallholder farmers in rural communities. It developed a unique algorithm which combines data crowdsourcing and machine learning with predictive analytics to forecast diseases early enough to help rural farmers improve their productivity. Jaguza continuously collects animal health information from farmers and health workers and correlates it with external data sources including laboratory data, historical data and early warning signals. Predictive analytics are then applied to accurately predict diseases before they break out in communities.

Jaguza is pioneering market-based approaches to bring low cost livestock services to smallholder farmers. The app sends farmers low-cost, easy to understand voice alerts and reminders about actions needed to look after their crops as well as actionable information and advice to help deal with disease outbreaks. In addition, Jaguza allows farmers to pay using their existing mobile credit. The Jaguza app is currently operational in over 40 communities in 62 Ugandan local farms in Uganda, where it provides accurate animal health data, outbreak alerts and educational content to over 8,300 unique users every month.

SOURCE Technopolis Group (2019), Uganda country case

The same observation applies to farmers: there is confusion and scepticism around Blockchain amongst producers as it is often associated with cryptocurrencies. As this confusion dissipates, scepticism may persist around the adoption of Blockchain unless clear benefits to producers are incorporated and communicated from the beginning (e.g. efficiency gains, financial premiums). If the initial attempts to implement Blockchain are solely focused on ensuring government compliance and meeting regulatory requirements, there may be push back from producers. In addition, it will be critical that the cost to implement these new systems is distributed amongst the stakeholders and not placed entirely on producers, especially if they are not gaining value immediately.

Key limitations to the widespread use of commercial Blockchain applications in agriculture include availability of quality data and regulations.

IoT, Big Data and Artificial Intelligence
Farmers will only adopt the technology if it is cost effective and produces real value such as efficiency, yield improvements or other operational savings. The cost of implementation and ongoing service is a major limitation for farmers, particularly when there is no immediate value received, which, for IoT, can take several years of accumulating data.

The first key barriers to adoption concern capabilities. Many farmers lack the skills to operate and troubleshoot electronics and digital systems. In rural areas, there is a general lack of awareness regarding digital technologies and further knowledge is required to understand how to implement, effectively use and maintain the technologies. Rural areas may lack the technological expertise needed to service the IoT. African farmers will need specific practical training and support and the applications should be adapted in order to be easy to operate.

The second key barrier to adoption is security and data management. Farmers may be concerned about data privacy and be afraid that their information falls into the wrong hands. The benefits of the IoT are also accelerated when data is exchanged between different providers along the value chain. The IoT industry therefore needs to consider industry-wide data standards, protocols and overarching regulation to remain competitive in agriculture. The quality and veracity of data is a central theme in the adoption of AI. Unfortunately, it is difficult to find structured, high quality data as records are being kept in different formats and are unable, at present, to unlock any value.

Regulations surrounding intellectual property rights is an issue as potential disputes between farmers and service providers may arise regarding the ownership of information. Ownership rights vary depending on how data is being collected and who is performing collection. For example, ownership and use of data generated using ground-based equipment owned by the farmer will be controlled by the farmer, except in the case of machinery operating data, which the equipment manufactures may reserve ownership rights over.

Another barrier is connectivity and interoperability. Rural connectivity in Africa is a major limitation in the deployment of IoT devices and major improvements in wired and wireless solutions are needed for the technology to be beneficial. For IoT sensors, the issue of connectivity is more nuanced as networks are needed to work over long ranges while also consuming low amounts power. Many current use cases are point solutions rather than interoperable platforms which allow data sharing and more valuable usage.

Governance will be needed around the use of AI and Big Data, for example regarding liability for accidents with autonomous equipment. Farm insurance policies will eventually need to evolve to cover this aspect of new farming practices.

Another key aspect is usability of those technologies, which can appear complex. If farmers do not understand the use cases, they will not use the technology. Application developers and service providers must be particularly aware of that.

Drones
The popularity of drone usage for precision agriculture is slowly growing in Africa thanks to the communication about current use cases and service provider start-ups. However, barriers to adoption remain. The same concerns about ease of use, security and capabilities mentioned above still apply.

The cost of operating drones in agriculture is still expensive and may not be affordable to small farmers unless services are jointly funded and pooled for use by all partners. Furthermore, drone technology is not effective if unable to transfer information quickly and this can be a problem in remote areas due to limited connectivity infrastructure.

Finally, the area that drones can currently cover is limited by the battery life of the drone and regulatory requirements around how far they can fly.

In conclusion, apart from crosscutting actions such as infrastructure and connectivity, key recommendations which can help unlock the potential of emerging technologies in agriculture in Africa are:

- Raise the awareness of consumers and farmers about the potential benefits of emerging technologies according to their specific needs;
- Ensure that market applications and services to farmers are user friendly and easy to implement;
- Provide specific practical training and support to farmers on how to use the technologies;
- Organise value chains for technology to be cost competitive for small farmers;
- Take proper regulation on emerging technologies, which include, among other things, the following: data privacy and security, intellectual property rights on data collected, liability for accidents with autonomous equipment and responsibility for AI-powered decisions;
- Ensure the availability of quality data concerning weather, agriculture market data and agronomic data by upgrading national statistical systems.

6.2 MARKET APPLICATIONS IN ENERGY

6.2.1 Presentation of energy and challenges for the sector

A dynamic energy sector is crucial to achieving the AfDB's goals linked to its priority 'Light Up and Power Africa', which aims for a boost in electricity generated (by 162 gigawatts by 2025), and significant increases in on-grid (an additional 130 million) and off-grid (an additional 75 million) power connections. As things stand, access to energy is a major challenge to socioeconomic development on the continent, with more than 640 million Africans lacking access[312]. Due to rapid population growth, Africa is the only region in the world in which the total number of people without electricity is increasing. Africa's total installed grid-based capacity of roughly 158 gigawatts in 2012[313] is less than that of Germany[314]. As a result, many Africans still cook with wood and open fires, which may lead to as many as 900,000 premature deaths *per annum*[315]. However, this is already an improvement on 2000, with energy generation increasing by 65% between then and 2012[316]. As of 2014, Africa's energy generation has been mainly accounted for by fossil fuels (coal: 56%, oil: 9%, gas: 9%) – much of which is imported, with hydropower making up 22% and other renewables a mere 1% (nuclear accounts for 3%)[317]. Given that, in Africa, more than $17 billion a year is spent on fuels such as kerosene and firewood to power generators, in particular to charge phones in the absence of access to an electrical grid, there is a big opportunity in Africa for renewable energy solutions (notably solar and wind power) and better electricity infrastructure. These energy sources are not only emission-free, thus contributing to climate change mitigation, but also have the advantage that they can be deployed off-grid in rural areas, reducing the need for expensive transmission infrastructure.

Capitalising on this potential will be crucial for Africa's socioeconomic development but is afflicted by a set of challenges. Firstly, there is a lack of infrastructure to generate and transmit electricity to customers, both through the electricity grid and through off-grid solutions. Secondly, the energy market across Africa is highly fragmented. This also translates into regional variances in terms of electricity generation and consumption, with northern and southern Africa performing better than the rest of the continent[318]. The electricity sector also struggles with low capacity utilisation, inefficient grid operations and high transmission and distribution losses[319].

It is thus of paramount importance that Africa's energy sector is modernised by increasing electricity generation from renewables, deploying infrastructure throughout the continent to transmit energy through both large-scale and mini grids and making use of technology to increase energy efficiency and monitor supply and demand.

There are some positive developments: In South Africa, renewable energy has taken off; the price of wind power is now competitive with coal. Ethiopia, Kenya, Morocco and Rwanda are also attracting large investments in renewable energy. In South Africa, companies use sensors and ICT to immediately react to changes in the energy quality, such as voltage imbalances, to avoid damage to their equipment. There are also more and more examples of companies "defecting" from the grid and installing their own photovoltaic panels (PV) or biomass powered micro-grids. Some companies, e.g. in the pulp and paper sector, which produce energy as a by-product of their production processes, i.e. in the form of heat, aim to become energy suppliers to the grid themselves. Both developments need smart technologies to steer the complex underlying processes efficiently[320].

6.2.2 How can emerging technologies transform energy in Africa?

According to the AfDB's energy strategy 'Light Up & Power Africa', modernising the energy sector requires:

- Setting up an enabling policy environment;
- Transforming utility companies for success;
- Dramatically increasing the number of bankable energy projects;
- Increasing the funding pool to deliver new projects;
- Supporting Bottom of the Pyramid energy access programmes, particularly for women;
- Accelerating major regional projects to drive integration and;
- Rolling out waves of country-wide energy 'transformations'.

4IR technologies can play an important role in helping to reach these goals. Utility companies can be modernised with the help of sensors and smart meters that use sensors to allow remote monitoring of electricity consumption and other IoT technology, off-grid, bottom-up energy programmes can benefit from innovative pay-as-you-go schemes linked to IoT-enabled devices. The IoT allows us to track material and energy flows to achieve new efficiencies along product value chains. AI can be used for predictive infrastructure maintenance. Predictive user behaviour that relies on machine learning algorithms can potentially balance consumer demand and utility supply. For example, where power batteries often have difficulties powering homes through the night, AI software can learn the energy needs of a home and adjust the power output in such a way that electricity usage is reduced, for example by dimming lights and TV screens and slowing a fan's motor. Blockchain technology can help increase the number of bankable energy projects whilst drones may facilitate grid maintenance, to name a few examples. The potential for Additive Manufacturing to modernise the energy sector is more limited by comparison.

In an Africa whose energy sector has been transformed by 4IR technology, renewable sources of energy would be fully integrated with energy storage systems and the energy supply at the household level would be managed by AI-enabled algorithms. Blockchain-enabled networks are designed for secure peer-to-peer transactions combined with incorruptible contracts between multiple parties. Individual households can manage their own supply and demand to incorporate self-generated energy. A house equipped with a simple windmill and a roof made up of photovoltaic tiles could sell surplus power to a neighbour in need. They could also buy from another house to meet a shortfall. 4IR-enabled micro-grids would bring affordable energy to communities that have never enjoyed a reliable electricity supply.

Internet of Things (IoT), Big Data and Artificial Intelligence

Our field research suggests that the current take-up of 4IR in the African energy sector is only at a nascent stage. In terms of the number of actual use cases, IoT appears to be the most common technology used out of the ones within the scope of the study, often in combination with solar power. Big Data and AI are also relevant technologies. Use cases from different African countries show that smart metering and decentralised grids using solar power are already a reality on the continent. In Uganda, IoT-enabled pay-as-you-go schemes make energy more affordable to citizens. Big Data is used in Nigeria to identify cost-effective ways to install distributed power with micro-grids.

Overall, the number of AI applications in the energy sector in Africa appears to be scarce. Rather than disrupting the energy sector, AI has not yet been put into widespread use due to a lack of stable power supplies. Stability in the power supply needs to be in place before entrepreneurs and businesses in Africa can develop local AI technologies. African decision-makers can find inspiration as to the potential of IoT, Big Data and AI for modernising the energy sector in other parts of the world.

In Australia, for instance, intelligent monitors detect when an individual pole is in trouble. They then report the fault and call out a repair crew. They can also communicate with other poles to redirect the supply and preserve the grid's integrity. Smart metering is already a relatively common application to measure consumption levels and to communicate this with users and energy providers to manage energy more efficiently. Domestic energy usage can be optimised by the automation and promotion of sustainable practices such as running applications during off-peak times. This is facilitated by IoT-type technologies such as smart meters providing real-time and two-way communication with the user and automatic collection of meter readings and other data.

In Korea, the government decided to launch an "era of safe and clean energy" in order to respond to the demand from consumers for energy sources that do not pollute the environment and public health[321]. Consequently, the focus of energy policy has shifted to more renewable energy and liquid natural gas (LNG) for which the government aims to use core 4IR technologies such as AI, IoT and Big Data. In addition, the Korean government is investing in clean energy. Part of this plan is the use of technologies such as AI, the Internet of Things and Big Data to deliver smart energy systems. For example, a platform to enable the use of Big Data in the power sector is under development, which will allow consumers to monitor their power use and electricity bills, encouraging electricity savings. If the platform is successful, it will also be applied to the gas and heat energy sector.

In India, which faces problems in its energy sector similar in nature if not in magnitude to those in Africa, companies are using IoT to make energy production and consumption more efficient: Gram Power is an example of an Indian-based company providing services such as energy consumption monitoring, adapting energy consumption to the time of day when energy is cheaper, and alerts to avoid fires, short circuits and fines due to overload. The company also provides services for distribution networks such as a digital map and solutions for customer communication. Zenatix provides energy saving solutions to large commercial consumers of electricity by using advanced machine-learning based models. The company collects data via remote monitoring, which enables automated and intelligent control of assets along with predictive and preventive maintenance. Machinepulse provides solutions to optimise the performance of utility and rooftop solar PV plants, including data acquisition hardware, cloud-based monitoring software and advanced analytics.

Blockchain in energy

Blockchain-empowered networks and platforms can be used to create a trustworthy environment for financial and other transactions. Smart contracts and peer-to-peer payment schemes can use Blockchain to create markets for energy generation and consumption in decentralised (micro-)grids, allowing for precise charging for electricity consumption and verified peer-to-peer electricity trading[322]. Some use cases of Blockchain in energy could already be identified in Africa. This is particularly important in an African context, where the lack of transmission infrastructure combined with rapid population growth, including in vast rural areas, means that building a completely centralised energy infrastructure would simply take too much time.

Furthermore, Blockchain may support automated payments, electrical vehicle charging and sharing and transferable renewable energy credits (RECS).

Internationally, several initiatives aim to accelerate the adaptation of Blockchain technology across the energy sector, such as the Energy Web Foundation[323]. Other small companies focusing on P2P energy trading include LO_3 Energy[324], Power Ledger[325] and PowerPeers[326].

One interesting use case that could also be introduced in Africa (it is already used in Asia and Latin America) concerns Solarcoin, a Blockchain solution for managing an off-grid solar power generation network. It is a solution that builds a community of producers and consumers and allows community members to know how much energy they produce and how much they consume. This allows all users to know exactly how much they should pay according to real consumption. This solution could be adopted even in remote villages where the government seeks to develop alternative sources of energy.

Drones

The use of drone technology does not appear to be widespread in Africa and is mostly focused on the oil industry.

Drone-based solutions for the energy sector can also help to make better use of existing infrastructure. Companies from Estonia to India are working on drone inspections of power lines.

Additive Manufacturing

This study could only identify one concrete use case of Additive Manufacturing (AM) in the African energy sector. In principle, there is some potential for AM to improve energy efficiency: according to one estimate, it could cut global energy demand by 27% by 2050 (The Economist Intelligence Unit, 2018). This means that AM deployment in Africa could relieve pressure on regional electricity generation.

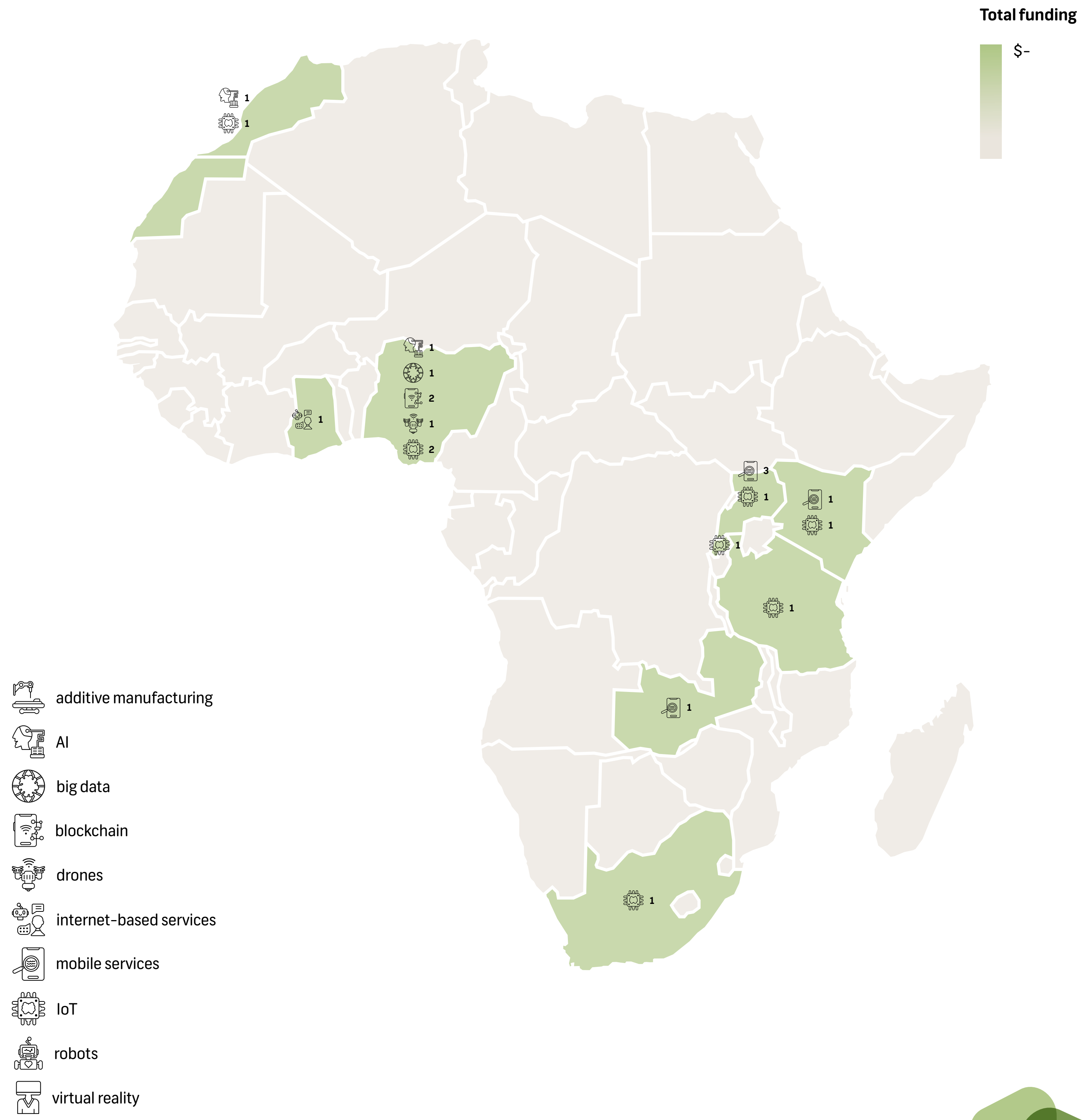
AM could also potentially be used to produce spare parts for critical energy infrastructure, to print batteries, complex parts of turbine blades and may also be used for parts that otherwise need to be shipped to remote and inaccessible environments (e.g. off-shore wind turbines). In the future, such applications may develop, e.g. for the production of fully-functioning small wind turbines or the blades of larger wind turbines – the latter is one of the options mentioned for the five metre tall 3D printer at the Nelson Mandela Metropolitan University in South Africa (NMMU, 2017).

Conversely, uninterrupted energy supply is needed for 3D printing processes to work, so without a certain reliability of power, AM is unlikely to take off in Africa.

f

figure 36

the fourth industrial revolution: african companies in the energy sector



ADAPTED FROM
Technopolis Group (2019) based on CrunchBase and web mining

6.2.3 Current use cases of emerging technologies in energy in Africa

This study identified 21 African companies developing applications in the energy sector located in nine countries. Figure 36 illustrates trends in market applications and investments. The map is only used for the purpose of illustrating trends and is not intended to give an exhaustive overview of current applications in energy and investments in start-ups across the continent.

Nigerian start-up Anergy provides solar energy and offers IoT-enabled remote monitoring and predictive maintenance services through its tracking software[327]. Another Nigerian start-up, Upnepa.ng, has developed an IoT-powered platform providing real time information and history of electricity supply in selected communities and homes across Nigeria[328].

Also, in Nigeria, General Electric and the Massachusetts Institute of Technology (MIT) are implementing a World Bank-sponsored project to put the Reference Electrification Model (REM) into practice. REM is a geospatial package that utilises Big Data to identify cost-effective ways to install distributed power with micro-grids. It creates unique power plans specific to a location. It can pick the least expensive energy source, such as solar power where there is enough sunshine or hydropower near a reliable water source. It can even create a detailed project plan, down to how many wires need to run to which buildings — information vital to effective project budgeting and planning. It uses population data, existing grid information, natural resource surveys, satellite-sourced topography data and other variables to optimise the cost and benefit of either extending an existing electrical grid or constructing a micro-grid[329].

The Earth Institute implemented a World Bank-supported programme in Nigeria using Big Data analytics as input for piloting geospatial least-cost planning for universal electricity access by 2030, developed as part of the ESMAP funded World Bank Nigeria Electricity Access Project (NEAP). The data set covers the service area for the Kano Electricity Distribution Company (KEDCO) Nigeria.

b

box 13

UMEME's smart energy solutions: Deployment of automated meter reading (AMR) technology for large power users

Uganda's retail power distributor Umeme Power Company is reported to have invested $24 million in automated meter-reading technology. Industrial and commercial customers (0.55% of UMEME customers) account for over 70% of UMEME's sales and revenue. If the losses from large power users are tackled efficiently, UMEME will be able to connect more households to the grid.

In 2011, UMEME started with AMR pilots for 1,000 industrial customers. The meters were remotely collecting data related to billing and consumption that was sent to a central server where it was processed and analysed. The pilot indicated that the industrial users breached and tampered with meters installed by UMEME. Starting in 2014, more than 3,700 large power user meters have now been retrofitted with AMR technology.

The installation of smart meters has several benefits, such as:

- Over 45 gigawatt hours were saved and $6 million of savings were achieved for the electricity sector;
- The billing cycle has been reduced from 14 days to 6 days. This enables customers to receive bills earlier and pay on time;
- Available information regarding customer installations helps with the improvement of customer service, such as early detection of outages and meter faults;

SOURCE Technopolis Group (2019), Uganda country case

The start-up UR power, incubated under Active Spaces in Cameroon, is also developing a solution to provide rechargeable solar batteries for households. Their solution integrates Virtual Reality (VR) in the company website so that clients can easily understand their installations in different home types; plus, the device has built-in smart sensors and uses AI to easily collect data and analyse the functioning of the devices[330].

Another example of an African company that tries to deliver smart solar power is Azuri Technologies Ltd., which has already brought their solution to 150,000 people, focusing on East Africa and Nigeria. The company uses a lease-to-own model, where customers pay a monthly, weekly or as they go fee that is cheaper than paying for kerosene, the 'traditional' energy source for many African citizens[331]. Azuri takes advantage of machine learning technology to install home solar devices that learn a customer's typical power-usage pattern and adapt energy output to manage the system according to the customers' needs. The system also monitors weather conditions and ensures that electricity stays on on cloudy days[332].

In Cameroon, ENEO has started with pilot projects to test the applicability of about 500 smart meters in Douala in Cameroon in 2017, which are linked to a Metering Management System (MMS)[333] and also incorporate elements of Big Data and AI. ENEO has also launched its prepaid card electricity meters, which function with an AMR (Automated Meter Reading) technology, measuring the consumption of electricity in a precise manner and in real time. ENEO is currently planning to install 20,000 prepaid meters and 40,000 smart meters in 2019[334]. See Box 13 for a further example of AMR in Uganda.

Mobile IoT connections are used in Uganda to enable the functioning of pay-as-you-go (PAYG) solutions for clean energy and water systems as well as for the transport and logistics sector with vehicle tracking and fleet management solutions. As of the end of 2018, there were approximately half a million cellular IoT connections in Uganda, which makes it the seventh largest cellular IoT market in Sub-Saharan Africa.

In Morocco, the government funds several collaborative research and demonstration projects, involving national universities and research centres with the participation of their foreign counterparts. The SECRETS (Sustainable Energy Clusters Realised Through Smart Grids) project led to the establishment of a state-of-the-art smart grid laboratory at the National School of Applied Sciences of Ibn Tofail University in Kenitra. This laboratory will be used for capacity building and the development of new models for transmission, management and distribution of electrical energy that can be implemented on a large scale.

Also, in Morocco, Smart Grid Tahala is an autonomous distribution network using solar energy and a two-way communication system allowing residents from a remote rural area to benefit from water and electricity at no cost and without cuts. A solar field has been distributed over the rooftops of various facilities and several smart meters gather data and transmit it over the General Packet Radio Service (GPRS) network to the control platform, for optimised and adapted management of this network. This project is not only interesting through its use of a decentralised network for the intelligent and digital distribution of solar energy; it also had a social impact. Smart Grid Tahala has enabled 1,500 inhabitants to benefit from free energy and has promoted the schooling of children and the empowerment of women. Smart Grid Tahala has also enabled the development of local agriculture, with surplus photovoltaic energy being used to pump water.

The Moroccan company Elum Energy deploys AI software to manage renewable energy distribution. The Moroccan government supports these entrepreneurs and looks for opportunities for future exports to other African countries[335].

OneWattSolar, based in Nigeria, is a start-up that allows individuals to pay for the energy that they consume using Blockchain-based services without the need to own the solar infrastructure that provides the power[336]. Currently, about 6,400 households are on the company's waiting list. In 2025, the start-up hopes to access one million households without adequate power supply and provide solar energy through distributed technology[337].

Nigeria Solar Bankers launched a full-scale smart grid project using its Blockchain-enabled P2P energy trading platform in Nigeria. The start-up has signed an agreement for a pilot project with the Kaduna State Power Supply Company (KAPSCO) to deploy its P2P energy trading platform to the city of Kaduna in the north of the country. The project will connect 66 commercial and residential buildings in the Atiku Abukakar house cluster in a local smart grid infrastructure[338].

- Beatdrone, based in Nigeria, is a drone service provider primarily operating in the oil and gas industries. It provides detailed optical imagery to assist with site inspections, pipeline management and real time security surveillance[339];
- Oando Plc, a Nigerian oil company, has been issued the first national Remotely Piloted Aircraft/Drones (RPAS) certificate. This will allow the company to deploy drones in its area of operations for environmental observation and the monitoring and surveillance of its facilities;
- Great Lakes Energy deploys additive manufacturing in to packaging and storage solutions for its solar products[340]. This process allows the company to deliver customer-tailored solar systems safely, to all parts of Rwanda[341].

6.2.4 Challenges, recommendations and prospects

In this section, we will discuss the challenges posed by the adoption of 4IR technologies in energy applications in Africa. We will also detail the existing limitations for the large-scale adoption of 4IR technologies and recommend actions to overcome them. The challenges, recommendations and prospects are based on our analysis of information that we collected from stakeholders during field visits and interviews.

IoT, Big Data and Artificial Intelligence

Consumer needs have been the focus of many of the recent IoT-enabled solutions. Novel payment schemes and smart metering reduce energy consumption for consumers while off-grid solutions can increase people's independence and thus improve their economic autonomy. Access to electricity enabled by 4IR technologies has the potential to transform rural communities, making them advocates for additional 4IR developments.

The management and storage of this data is expected to lead to a rise in energy consumption within new data centres. Developing countries will need to manage where data centres are placed to ensure optimal energy efficiency[342]. In fact, the expected increased demand on energy resources will require energy investments as well[343].

There are numerous reasons why the IoT, Big Data and AI have not yet experienced greater take-up. The cost of deployment of these technologies is still prohibitive for many, even if innovation has reduced the cost somewhat. African companies have not uniformly been prepared to develop new 4IR derived business models, leaving some regions and sectors lagging behind. Moreover, some rural citizens in particular may be hesitant to permit the installation of devices that they do not own and may fear entering into dependent relationships with providers. Raising awareness within business and social communities, demonstrating the associated benefits of 4IR technologies and training users on the use of these technologies will overcome many of the obstacles inhibiting the energy sector. As an intermediate step, successful solutions from countries such as Nigeria or Uganda should be replicated across the continent to demonstrate viability and benefits.

Overall, there is a medium term prospect for IoT/Big Data/AI to transform Africa's energy sector.

Blockchain

For many potential users, Blockchain-based systems have clear benefits. They make it possible for households to sell excess energy generated by, for example, roof-mounted solar panels. The peer-to-peer nature of the technology means that such a transfer can take place directly between households with a high degree of autonomy[344] rather than relying on selling energy surpluses back to existing energy utilities. Not only does this ensure market pricing but it also supports the real time trading of green energy, creating more efficiency in the balancing of supply and demand and supporting the integration of renewable energy into the grid.

Blockchain is also attractive from a consumer's point of view as it allows for decentralised trading, creating a trustworthy environment where no single trader can monopolise production and consumption. This is key in an African context where many stakeholders mistrust the public sector in running centralised distribution networks that rely on customer data.

A major limitation of Blockchain's use in the African energy sector and more widely is the fact that Blockchain technology requires immense amounts of energy due to the computing and server capacity needed to store the information held on Blockchains. A 2018 study into energy consumption by the Bitcoin Blockchain found that the network could consume 67 terrawatt hours of power annually[345], which is almost equal to the annual electricity consumption of Ireland. This could present significant challenges for the broad-based adoption of Blockchain on the African continent, which is known to have an inadequate power supply. A lack of access to power and high energy costs in local markets mean that fast-increasing demand often outstrips the public infrastructure at peak times[346]. The key question determining the viability of Blockchain solutions in energy in Africa, then, is whether there will be a net energy gain, i.e. do the benefits in terms of increased energy efficiency and deployment outweigh the cost of increased energy consumption caused by the very same technology? The fact that Blockchain can facilitate, in particular, the use of renewable, as opposed to fossil fuel-based, energy, is encouraging in this regard since the potential of renewable energy in Africa is virtually limitless.

Overall, the potential for Blockchain in energy in Africa is medium.

Drones

At present, drones in energy are mainly of interest to big energy companies that can afford to deploy them rather than being of interest in agricultural use cases that are attractive to small, rural communities. Overall, there is a medium prospect for drones in energy in Africa.

Additive Manufacturing

The prospects for Additive Manufacturing (AM) in energy in Africa are difficult to ascertain at this point given the dearth of concrete use cases. It appears to have limited potential.

In conclusion, apart from crosscutting actions such as infrastructure and connectivity, key recommendations which can help unlock the potential of emerging technologies in energy in Africa are:

- Raise awareness and educate about the benefits of smart meters, pay-as-you-go schemes and decentralised grids;
- Make sure that products are user friendly and easily installed/repaired;
- Ensure that roll-out of renewable energy, in particular solar, works in tandem with the use of 4IR in energy so that the benefits in terms of energy efficiency and reliability gains outweigh the cost of increased energy demand;
- Focus on demonstration projects of integrated IoT/Big Data/AI solutions, building on existing African use cases from countries such as Uganda or Nigeria;
- Consider the prospect of Blockchain-empowered systems to speed up the roll-out of affordable energy.

6.3 MARKET APPLICATIONS IN INDUSTRY

Africa's industrial development has lagged behind that of other developing regions. Growth prospects in Africa are bright, with a consumer market of over 200 million and increasing consumer spending, with more and more Africans moving to middle-level incomes (McKinsey & Company, 2010). Nevertheless, Africa's annual industrial activity generates just $700 GDP per capita, compared to $2,500 in Latin America and $3,400 in Asia. Exports from Africa consist mainly of low-technology manufactured products and unprocessed natural resources (AfDB, 2019). There is considerable variation across the continent, with some countries and industries forging ahead both in terms of economic returns and the number of jobs created. The population of Africa continues to grow, with a projected population of over two billion people in 2050.

The low economic growth and favourable demographics provide an opportunity for African countries to pick up the pace. Current technological developments can facilitate the acceleration of industrialisation.

The following sections (i) present the industrial sector and its challenges in Africa, (ii) explore how 4IR technologies can transform industry in Africa, (iii) show current use cases of 4IR technologies in industry in Africa and (iv) discuss the challenges which limit the take-up of 4IR technologies and recommend actions to unlock the potential of emerging technologies in industry in Africa.

6.3.1 Presentation of industry and challenges for the sector

Industry plays a vital role in development. It increases the value created in an economy by generating activity further along value chains (from raw materials to finished products) and boosts productivity by introducing new technologies and techniques. Industrialisation can improve the balance of trade by creating goods for export and creating local competition for imports (AfDB, 2019).

Despite the potential of African nations and promising trajectories, most African countries have limited industrial development. While other countries in developing regions are starting to plateau, Africa still contains a wealth of favourable factors (e.g. the availability of low-cost labour and the abundance of natural resources) for further industrialisation.

There are some recurrent issues when it comes to Africa's industrial sector.

There is a lack of skills within Africa's workforce, with only two thirds of 15 to 24 year olds having completed primary education and less than one in five students continuing beyond primary school. Companies have difficulty locating sufficiently qualified workers and are forced to attract foreign workers or need to invest heavily in intensive training courses (Signé, 2018).

Infrastructure also continues to be an obstacle. Despite investments, gaps in energy infrastructure still result in frequent power outages in many African countries. Electricity can cost up to three times more in Africa than in comparable developing regions, with industry having to rely on expensive backup generators as a primary energy source, affecting their profit margins. Weak transportation networks also hinder manufacturers' ability to capitalise on regional economies of scale (Signé, 2018).

Thirdly, trade is hampered by port and tax bureaucracies, resulting in high direct and indirect costs of international trade in manufacturing. The bureaucratic infrastructure varies greatly between countries. It takes about 10 days to export a container from Morocco while exporting a container from Zambia can take as many as 51 (Signé, 2018).

6.3.2 How can emerging technologies transform industry in Africa?

Africa's industry can be transformed into a more productive and efficient sector that capitalises on its potential. This will be needed to feed and clothe two billion people by 2030 and to make, process and export goods out of Africa, thereby boosting industrial and economic growth.

According to AfDB's Industrialisation Strategy for Africa 2016-2025, requirements for fast-track industrialisation in Africa are (AfDB, 2019):

- Foster successful industrial polices;
- Attract and channel funding into infrastructure and industry projects;
- Grow liquid and effective capital markets;
- Promote and drive enterprise development;
- Promote strategic partnerships in Africa;
- Develop efficient industry clusters across the continent.

4IR technologies have the potential to support the above top-level targets, notably by having a positive impact on the productivity and profitability of the sector and the creation of new locally based added value.

Potential applications in industry are more important with IoT, Big Data, AI and Additive Manufacturing (AM). Drones and Blockchain offer fewer potential applications.

Internet of Things (IoT), Big Data and Artificial Intelligence (AI)

Use cases of IoT, Big Data and AI applications in industry already exist. The global AI in the manufacturing market alone is forecast to be worth over $17 billion by 2025, up from $1 billion in 2018 (Markets and Markets, 2019).

IoT, Big Data and AI will dramatically improve processes, enhancing productivity and ultimately improving business results.

The IoT is a rapidly growing network of objects that are connected via the internet. In particular, the Industrial Internet of Things (IIoT) can be used to acquire and access far greater amounts of data at far greater speeds and far more efficiently than before. The IIoT is expected to bring immense benefit to industry, which needs to find better ways to streamline processes and use large quantities of data. Newly availably operational data can be used for predictive maintenance and remote asset management that can reduce equipment failures and unexpected downtime. Furthermore, it can be used to improve worker productivity, safety and working conditions. For example, the IIoT can minimise workers' exposure to noise, chemicals and other hazardous gases, especially in traditional heavy industries (WEF, 2015).

Big Data generally refers to data sets that are impractical to analyse with traditional database tools due to their size, variety of data inputs and the speed at which new data is created. Part of what makes the concept of Big Data so compelling to industry is the promise of solutions to problems that were previously impossible to address. The use of Big Data and analytics tools to improve business results has already had a large impact on business by creating new business models in the internet economy. Big Data makes it possible to work in a variety of areas, including recommendation engines, sentiment analysis, fraud detection, marketing campaigns and consumer analysis, etc.

AI is expected to make major changes to industry as well. AI refers to a system's ability to interpret data, learn from the data and subsequently improve the system's actions for future iterations. It is expected that businesses adopting AI will gain a competitive edge that will be hard to match through other means. Artificial Intelligence will improve prediction, planning and decision-making. It also has the potential to reduce the time spent in decision-making and improve the quality of decisions. In this way, it will enable businesses to improve performance and internal processes.

Likewise, the automation of business processes through the above-mentioned technologies is expected to result in large productivity gains, increasing labour productivity by up to 40% (Accenture, 2019). Processes that are currently performed by humans can be automated, allowing finite human resources to focus their activity elsewhere. Automation will also augment other processes by providing more information for human decision-making.

Additive Manufacturing

In industry, Additive Manufacturing (AM) has the potential to disrupt the established forms of design and manufacturing by localising and democratising production. Over time, printing a single item may be as cheap as having a dedicated factory producing thousands of items, overturning traditional views on economies of scale (Pierrakakis, 2015).

AM changes production processes and equipment use. AM is able to produce products for nearly any conceivable industry (Van Barneveld & Jansson, 2017). This flexibility in producing products from a single machine is different from more traditional manufacturing methods, where individual machines are optimised to produce individual products. This could result in more general purpose production facilities instead of the more specialised factories that we currently see in the manufacturing industry (Van Barneveld & Jansson, 2017).

AM also removes technological barriers, giving more freedom to product developers and innovators. As processes are more similar, the complexity of production is now shifting towards the designing and modelling of products and the associated coding. IT and industrial engineering personnel will be more important than before, as will ICT and creative skills. More complex products, mainly in form, can be produced at low cost, which could revolutionise products (Van Barneveld & Jansson, 2017). New functionality can be added to products, as this is now less limited by the production process – changing products as well (Van Barneveld & Jansson, 2017). Rapid prototyping through 3D printing can also speed up the development of innovative products and designs.

AM has the capacity to contribute to improvements in resource and energy efficient manufacturing. By contrast with subtractive manufacturing, AM processes add material, nearly eliminating leftover or waste material (Van Barneveld & Jansson, 2017). The ability to design and test more variants will lead to more efficient and lightweight designs. By creating lighter products through AM, the stress on resource consumption in the manufacturing sectors can be reduced.

Additionally, the possibility to produce products on demand is expected to lead to less production of non-essential products, lowering consumption overall (Pierrakakis, 2015). Transportation of products could also be reduced if AM products are produced more locally – closer to customers.

One of the most significant advantages that AM has to offer to emerging countries is to lower the barrier to entry into manufacturing for small businesses. Companies and individuals can produce a wide range of products with only a 3D printer, a computer, some software and some production materials. Small, one-man production shops are (in principle) easily set up with only a small investment and no costs for tooling or employees. These companies can slowly start to scale up their business. As the number of clients or sales volume grows, the production can be expanded with additional AM capacity or other production methods – such as more traditional injection moulding. In this way, small businesses can grow into larger businesses – once they are successful – with only small start-up costs. This could be a way to foster private sector development in emerging countries. (UNIDO, 2017)

Furthermore, AM has the potential to bypass traditional industrial development in emerging countries. Traditional industry requires greater capital investment in equipment, infrastructure and personnel than is needed for AM. An AM business can be started with limited upfront costs, lowering the barrier to access industrial development. The dependency on foreign goods is minimal in AM production as only raw production materials are needed. Products can be designed to fit the local context in terms of conditions, culture and fashion. Local production reduces transport costs and lowers product prices. However, compared to traditional industry, the number of jobs associated with such AM businesses will fall due to the automated and efficient production of goods with AM (Ramalingam, Hernandez, Martin, & Faith, 2016).

Blockchain

Blockchain is a technology that is relevant to industry in particular when transactions need to take place. The decentralised database structure it provides, using state of the art cryptography, should increase trust and efficiency (Marr, 2018).

Economic exchanges require trust and every type of economic exchange outside face-to-face transactions requires the intervention of a trusted third party. Blockchain technology offers the potential to replace trust in institutions, such as commercial and central banks, with trust in a new, fully decentralised system (BIS, 2018). As almost any type of information can be digitalised and placed on a Blockchain, it has potential to transform the way in which people and organisations handle identity, transaction and debt information (Mainelli & Smith, 2015). Blockchain offers a globally available, verifiable and tamper-proof source of data that provides anyone with the ability to provide robust and trusted third party services (Mainelli & Smith, 2015).

Blockchain proponents argue that it will expand opportunities for exchange and collaboration by reducing reliance on intermediaries and the frictions associated with them (Pisa & Juden, 2017). The technology could facilitate cross-border payments (Spatz, 2018) or supply chain and trade finance via cryptocurrencies such as Bitcoin or Ethereum (Ganne, 2018), and has a potential role in facilitating faster and cheaper international payments (Pisa & Juden, 2017). This may also apply to crowdfunding and charitable donations (Champion de Crespigny, et al., 2016).

Based on these aspects, commentators speculate on use cases in the banking and trade finance sectors, including development of an interbank system for improved speed and traceability of transactions.

There are benefits to individuals and small businesses too. Blockchain technology also has the potential to put an end to delays in payments, which are among the main causes of business failures. This stems from both improved transaction speed but also the use of smart contracts that would automatically release payment upon fulfilment of a given task by the service provider.

Examples of industrial sectors where Blockchain can be applied are the automotive industry, the retail and the financial sector. In the automotive sector, transactions need to take place across the value chain with parts suppliers and manufacturers, customers and safety regulators. Blockchain helps to build efficiency and transparency in this system. In other sectors, Blockchain can help address supply chain challenges, ensuring that information is efficiently and transparently available, that data transfer is simplified and that networks are integrated.

Blockchain technology is expected to increase customers' trust in the financial sector where transactions can be made more secure and fraud and crime could be reduced. The same holds true for the retail sector, where supply chain visibility can be enhanced, allowing customers to receive real-time information on their delivery, meanwhile ensuring delivery is on-time and as efficient as possible.

Drones

Drones are pilotless aircrafts that can be used to gather information on an environment and can relay it back to the controller. Drones are expected to have a profound economic impact in multiple domains. In particular, drones are expected to address future mobility needs by replacing services on the ground, by rail, by water and in the air (Schechtner, et al., 2018). The level of integration between drones and manned counterparts still remains to be seen but at least some degree of integration is to be expected. Within the private sector, there seems to be a particular interest in the use of drones for the purposes of carrying cargo (Sandvik, 2015).

While drones will not remove the need to build roads for the transport of heavy goods and people, they do offer the opportunity to design transport infrastructure in new ways and to reduce the need for 'last mile' road connectivity. Possible areas of application include drone-based delivery and logistics, eVTOL (electrical vertical take-off and landing) taxis as well as personal transport (WEF, 2018). It must be noted, however, that these applications are in the early stages of development and may not be of immediate relevance to developing economies.

Apart from the above, drones can be used to inspect infrastructure, for example to inspect power lines, power plants, wind turbines, oil platforms, bridges, dams, storm damage and more. Drones can operate in complex circumstances and enter challenging terrains and environments where more conventional aircraft may not be able to reach or are too expensive to operate. This can save significant human resources, taking minutes by drone instead of hours in person. Companies have been experimenting with drone inspection across all types of hard infrastructure (Walker, 2019).

Furthermore, drones can be used for land registration through aerial mapping and security as they are capable of providing real-time detailed views from above, enabling enhanced situational awareness as well as faster and informed decision-making on the ground.

6.3.3 Current use cases of emerging technologies in industry in Africa

While still in their early stages, we have identified 29 promising African initiatives using 4IR technologies in industry, located in nine countries: Egypt, Ghana, Kenya, Morocco, Nigeria, Rwanda, Senegal, South Africa and Tunisia. Figure 37 illustrates trends in market applications and investments. The map is only used for the purpose of illustrating trends and is not intended to give an

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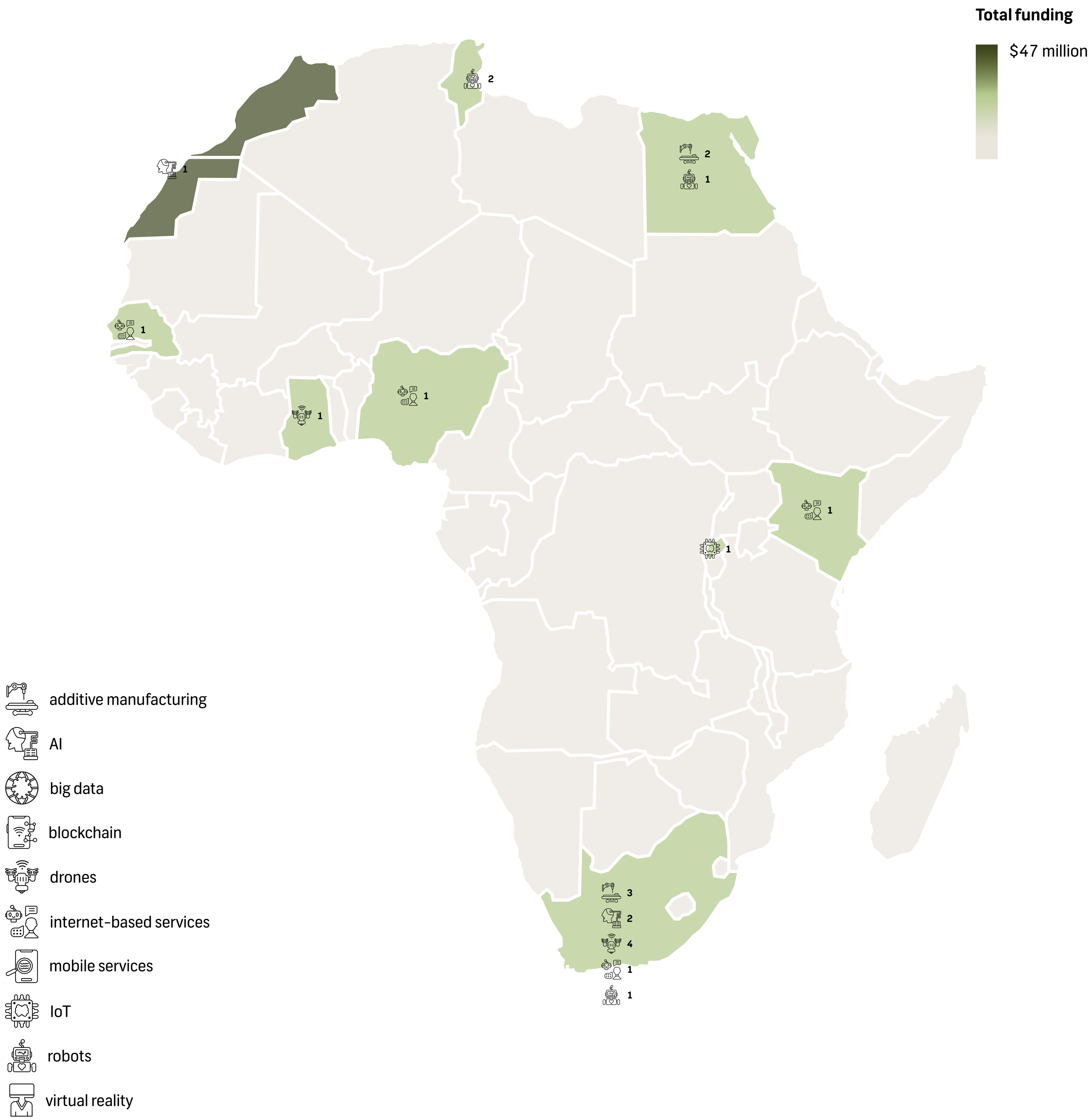
figure 37

the fourth industrial revolution: african companies in industry



ADAPTED FROM
Technopolis Group (2019) based on CrunchBase and web mining

exhaustive overview of current applications in industry and investments in start-ups across the continent.

According to Crunchbase, Moroccan start-ups attracted the most funding ($46,821,742) while Egyptian ones attracted the least ($200,000). It should be noted that investigations conducted did not show funding in countries other than the ones noted on the map.

The most prevalent applications in Africa are based on Artificial Intelligence (AI), Big Data and IoT and Additive Manufacturing while Blockchain technologies and drones are underutilised.

According to our in-depth research, there is growing awareness about the potential of AM, AI, Big Data and IoT for upgrading industry. Some interesting use cases are presented in the following sections.

The take-up of Additive Manufacturing (AM) is significant in industry and there are many examples from across the continent that illustrate different use cases.

In Morocco, the automotive and aeronautics sectors have been utilising additive manufacturing as a form of rapid prototyping. Dassault Systèmes, for example, has a 3DS Learning Lab for educational research. The lab conducts educational research to improve engineering education at various academic levels. The learning solutions developed within the lab have a focus on additive manufacturing, including 3D design and animations, a 3D printing Massive Open Online Course (MOOC) or the creation of a 3D-printed robot.

In South Africa, the awareness and potential of AM technologies is high, in particular among manufacturers. The technology is being used in rapid prototyping and testing. The cost of printers and materials remains the limiting factor as far as more widespread adoption of AM is concerned. It is expected that investments in and use of AM by manufacturers will increase when the technology becomes more affordable (Deloitte, 2016).

Examples of use cases in South Africa include an entrepreneur that is printing appliances (e.g. lawn mower, vacuum cleaner and shoes) and the firm Rapid 3D becoming a leading supplier of AM components (Naudé, 2017). Hans Fouche has his own company called Fouche 3D, which prints with several large-scale 3D printers he developed himself, including the Cheetah 3D printer. The large printer enables him to print objects of one cubic meter in size. The large size of these printers allows for the manufacture of a lawnmower, vacuum cleaner and even an acoustic guitar.

The Kenyan start-up AB3D has established a 3D printing facility in Nairobi, offering low-cost access to 3D printers manufactured from recycled materials and eWaste, open-source designs, materials and workshops (Banga & te Velde, 2018a).

Initiatives using IoT, Big Data and AI are at a preliminary stage, but the number of initiatives in industry is increasing. In Morocco, a few AI applications have been introduced in industry and the financial sector. Applications include supply chain management, traffic management, video surveillance and telemetry (Choukrallah, 2016). Experts generally agree that there is potential for IoT applications in industry in Morocco due to the presence of large multinationals capable of providing key technologies such as IBM in Big Data and Orange in IoT (La Tribune Afrique, 2017; La Nouvelle Tribune Tech, 2018; CIOmag, 2019).

Similarly, Cameroon has start-ups such as SiQueries, a Software as a Service (SaaS) data analysis and visualisation start-up providing massively scalable data warehousing services, which seem promising.

Nigeria is yet to implement large-scale IoT projects but, when faced with perennial counterfeiting problems, the National Agency for Food and Drugs Administration and Control (NAFDAC) resorted to product verification initiatives using Radio Frequency Identification (RFID). The technology, developed in collaboration with Verification Technology Limited (VTL), uses tags equipped with RFID to ensure that legitimate drugs are tracked throughout their

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box 14

Thales

The Thales Group for aeronautics has opened a 3D printing site for aeronautical and spatial components where it is building 3D-printed parts for communication satellites.

Thales will eventually invest between 15 to 20 million euros. The site currently has two laser machines, with up to a dozen expected in the future. Other AM techniques are expected to be used at the site in the future. It employs ten engineers, who have been trained for almost a year in Europe.

Thales has also established links with the International University of Rabat. It hosts three PhD students, including one from the INSA Euro-Mediterranean Fez, a school with an additive manufacturing laboratory.

Thales hopes to be able to make larger and increasingly complex parts in the future and is working on ways to expand the range of materials that can be used with 3D printing technology.

SOURCE Technopolis Group (2019), Morocco country case

supply chains, tracing them all the way from manufacturer to consumer.

There are few concrete Blockchain initiatives in industry. Although Blockchain was ranked highly as a technology with relevance to manufacturing during the development of country case studies, there are few obvious and concrete examples.

In Nigeria, Interswitch is examining Blockchain-based solutions for supply chain finance. Several financial and transportation companies in Morocco are considering the incorporation of Blockchain into their processes. These include Wafacash, Saham Assurances, several banks and large public groups such as Tangier Med Port (Amoussou, 2018). The Moroccan Professional Association of Shipping Agents, Ship Dealers and Charter Brokers (APRAM) believe that Blockchain may save up to 20% of the costs associated with international shipping (Handaoui, 2018).

Like Blockchain, the amount of drone-based applications in Africa in the context of industrialisation appears to be somewhat limited. Cameroon provides a compelling case for African drone manufacture. Two associated start-ups launched in Douala in 2015, Will & Brothers and Drone Africa, together with other domestic start-ups, have started offering Cameroon-made drones to farmers. These drones are more cost-efficient than imported drones as customers avoid paying for transport costs, customs fees and for the importation of spare parts. Building the drones in Africa also reduces the manufacturing costs, making the drones more competitive across the African drone market. Although the drones are made in Cameroon, some of the parts still need to be imported.

6.3.4 Challenges, recommendations and prospects

In this section, we will discuss the challenges posed by the adoption of 4IR technologies in industry in Africa from the perspectives of consumers and industry (producers). We will also outline the key limitations that are preventing widespread adoption of 4IR technologies and recommend actions that could mitigate them. The challenges, recommendations and prospects are based on our analysis of information that we collected from stakeholders during field visits and interviews.

Additive Manufacturing

Awareness of 3D printing in Africa is relatively high. There are several examples of AM in Africa and there are over 500 3D printers in Africa that are associated with one of the largest 3D printing networks in the world. This existing experience with AM can be used to further expand the uptake of AM.

The right business environment is needed to encourage the creation and growth of new industries. AM businesses, innovative ecosystems and technological hubs require financial support. These hubs can foster new start-ups and support business growth by providing manufacturing equipment and training.

A lack of expertise in 3D printing tends to limit the development of this technology in Africa. A challenge is to reskill people in current manufacturing jobs and to provide the right digital skills to others on the labour markets – e.g. related to 3D modelling.

Furthermore, the success of 3D printing in Africa will depend on support infrastructure and capabilities such as reliable electricity and fast and reliable access to the internet (Naudé, 2017). The technology may require adjustment to account for local conditions as they are usually created assuming the availability of steady power supplies, transport and commercial infrastructure and favourable weather conditions (Ramalingam, Hernandez, Martin, & Faith, 2016).

IoT, Big Data and Artificial Intelligence

Overall, the adoption of IoT, Big Data and AI in Africa is relatively low at present. There are, however, specific countries where there are relatively high levels of activity. One of the key challenges standing in the way of large-scale IoT adoption are limits in network capacity. There is a general lack of dedicated data centres and connections that are capable of collecting, storing, transmitting and receiving large volumes of data. It is important to invest in good digital infrastructure both when it comes to the expected rise in energy consumption and the necessary internet connectivity.

Furthermore, there are additional challenges associated with the use of Big Data that include the uneven coverage, accessibility and usage (of data) across regions and population segments in Africa. There is often a mismatch between supply and demand, with data often unavailable at the time and place it is needed most (UNECA, 2016).

Finally, there is a challenge in terms of human capital, where technically knowledgeable personnel are required to implement IoT, Big Data and AI. This will be challenging for developing countries due to the comparative lack of related research centres (Miazi, Erasmus, Razzaque, Zennaro, & Bagula, 2016). Training and education therefore need to take place at all levels to both develop intellectual capacity in this area and inform the public of the potential benefits.

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box 15

Kudi.ai & Lara.ng

In Nigeria, Kudi.ai uses Artificial Intelligence to facilitate financial transactions and payments on chat platforms like Facebook Messenger, Slack and Telegram (Kudi, 2019).

The start-up has developed a chatbot which allows users to make payments and send money to friends and family in Nigeria through messages. It uses Artificial Intelligence to understand user requests, drive conversations, understand their spending habits and prevent fraud.

The chatbot can be used to transfer money, facilitate cash withdrawals, pay TV subscriptions, electricity bills, data subscriptions and airtime.

The start-up is working with banks and telecommunication companies in an effort to trial working on a larger scale.

Lara.ng is another Whatsapp-styled chatbot that offers turn-by-turn directions and fare estimates for transportation within Lagos. It uses Artificial Intelligence to offer conversational-style directions for public transport, tricycles and other transportation modes in Lagos (Lara, 2019).

The first version of the platform was launched in 2014 and followed up by Lara.ng in 2017. The app offers public transit directions complete with price estimates – with an option to share with others or use a rideshare service. A user only needs to type a query like 'From Obalende, Lagos to Ajah Bus Stop' and Lara will provide step-by-step directions and price estimates.

Apart from this, the app can be used by the company to gather information on how often a user uses a particular route, how much they spend on average and what are their most visited places. This allows the team to gain unique insights, improving their recommendations for other consumers.

Currently, Lara has around 100,000 users, of which 12,000 are monthly active users.

The most challenging aspect for the company has been hiring new staff. It has been very difficult for the start-up to find good people that fulfil their requirements. They have noticed a lack of capable technology talent in the Nigerian labour market (Okunola, 2018).

SOURCE Technopolis Group (2019), Nigeria country case

Blockchain

While there is broad awareness of Blockchain in association with cryptocurrencies, there are few examples of Blockchain being used in industry. The existing use cases are exploratory or in the very early stages of development. On both the consumer and producer side there is an issue of trust in the technology's applications, with central authorities in African countries often warning citizens and businesses against trading or holding cryptocurrencies. This will require awareness-raising about the uses and benefits of Blockchain.

Similar to the technologies mentioned above, access to electricity, sufficient computing power and stable internet connectivity are all basic requirements for the adoption of Blockchain technologies. While there is an acknowledged high potential for renewable energies across Africa – and Blockchain itself may offer a solution to uneven energy distribution – these sources should be more developed and sustainable to support the implementation of Blockchain.

In terms of human resources, the presence of start-ups and Blockchain-focused incubators and accelerators proves that expertise exists and could be leveraged. Investment in more accelerators – perhaps on a regional scale – would help to grow this capacity. Funding to help scale accelerator graduates would also be a worthwhile investment.

Furthermore, developing appropriate governance models for Blockchain applications is required on a case-by-case basis, also encompassing the context within which Blockchain technology is being developed.

Drones

Despite promising trends, the drone service industry is still in its infancy in Africa. There appears to be a general lack of awareness about drones and their applications. This is an important precondition, together with user acceptance, to the proliferation of drones. The take-up of drones will partly depend on the citizenry understanding the advantages and disadvantages of increased drone usage (Schechtner, et al., 2018). Industry use of drones will also depend on the amount of emphasis placed on the different areas in which drones can have potential benefits.

Challenges for industry might arise due to limited battery life and the government regulation of drones. Some tentative regulatory responses can already be observed in Africa. There are countries at both extremes, with some banning the use of drones and others having no regulation at all. Many fall in between, some with dedicated drone regulations and others falling under existing aviation rules. For industry, it is important that there is clarity and stability to ensure that a market exists.

Furthermore, for industry it is essential that the sensitive data gathered by the drones is safe and protected against cybersecurity risks and 'dronejacking' (Schechtner, et al., 2018).

Finally, despite the fact that drones are in principle relatively easy to use, relevant human capital is still a necessity. A workforce interacting with these technologies must be trained so that they have the necessary skills to plan flight itineraries and pilot UAVs but also to use data analysis software and GIS.

In conclusion, apart from crosscutting actions such as infrastructure and connectivity, key recommendations which can help unlock the potential of emerging technologies in industry in Africa are:

- Raising the awareness of consumers and producers about the potential benefits of emerging technologies according to their specific needs;
- The provision of financial support for technology hubs, research centres and accelerators that foster start-ups and enable business growth;
- Provide training and support for smaller businesses that need people with specific skills for these technologies, including the reskilling of current workers;
- Take proper regulation measures on emerging technologies. This includes, amongst other things, the following: data privacy and security, governance models for Blockchain and AI applications and clarity on drone regulation.

6.4 MARKET APPLICATIONS IN EDUCATION

Africa's population consists of a high percentage of young people and there is an urgent need to provide good quality education. Africa has the largest and youngest population on earth, with more than 200 million of its 1.2 billion people aged between 15 and 24.

However, despite this pool of latent talent and potential, Africa's workforce is growing at a faster pace than the jobs that are available in both the public and private sector. In certain cases, the education provided is not sufficiently linked to industrial needs, both now and in the future. In sum, Africa is currently not benefiting fully from the demographic dividend it should be generating from the energy and skills of its young population.

With this challenge in mind, it is imperative to invest in education, particularly in STEM (science, technology, engineering and mathematics) and language skills to ensure competitiveness in the future digital global economy.

The 4IR might hold the solution needed to address this particular challenge. The emerging technologies of 4IR can be used to improve the quality of education. Conversely, reorienting the content of education can better prepare Africa's youth for the emerging technologies of tomorrow.

The following sections (i) present the education sector and its challenges in Africa, (ii) explore how 4IR technologies can transform education in Africa, (iii) show current use cases of 4IR technologies in education in Africa and (iv) discuss the challenges which limit the take-up of 4IR technologies and recommend actions to unlock the potential of emerging technologies in education in Africa.

6.4.1 Presentation of education and challenges for the sector

Africa's population is overwhelmingly young. With 200 million people aged between 15 and 24 (the youth bracket), Africa has the youngest population in the world. The current trend points towards this figure doubling by 2045[347].

The story of Africa's worrisome youth unemployment is often told alongside the story of the continent's fast economic growth. While six of the 10 fastest-growing economies in the world are located within Sub-Saharan Africa, the unemployment rate for the region is 6%. The problem is that, in most African countries, youth unemployment occurs at a rate more than twice that for adults. Youth account for 60% of all African unemployed. In north Africa, the youth unemployment rate is 30% and it is even worse in Botswana, the Republic of the Congo, Senegal, South Africa and several other countries.
Young women feel the sting of unemployment even more sharply. In most countries in Sub-Saharan Africa and all of those in north Africa, it is easier for young men to get jobs than it is for women, even if they have equivalent skills and experience.

Despite a pool of latent talent and potential, Africa's workforce is growing at a faster pace than the jobs that are being made available both in the private and public sector. In South Africa, for example, unemployment is at a record high, with two out of every three young people out of work. In order to remedy this situation, some African countries are participating more actively in international outsourcing platforms such as Upwork. In 2013, for example, the Nigerian government launched a 'Microwork for Jobs initiative'.

With these increasing global job opportunities, it is imperative to invest in education, particularly in STEM (science, technology, engineering and mathematics) and language skills to ensure competitiveness in the future digital global economy. Indeed, in some countries, such as South Africa, there is at present little alignment of the education system with the current needs of industry, let alone those of Industry 4.0. There is an oversupply of graduates in the humanities and social sciences and a critical undersupply of artisans and technicians, scientists and engineers, an ongoing skills gap which weakens the manufacturing and advanced industries. In other countries such as Uganda, the completion rate of elementary school is 53% and this remains a challenge, whilst the quality of the educational system itself needs to be improved given that the majority of Ugandan students lack basic literacy and numeracy skills.

As African economies and labour markets become more driven by services and are less dependent on commodities, it is clear that countries must foster digital skills as part of a process of transitioning their populations away from low-skill and low-paid jobs to high-skill and high-paid jobs.

6.4.2 How can emerging technologies transform education in Africa?

Emerging 4IR technologies will undoubtedly be part of the solution to address the challenges posed by disruptions across traditional sectors and industries. From enterprise to grassroots levels, there is a unique opportunity to combine the growth in the ICT sector with the growth in population across the continent. The need to foster digital skills is an essential ingredient for success as African countries move towards services-driven economies. Teaching young people to be agile and adaptive will go a long way towards equipping them with the skills needed to thrive in a digital world.

Upskilling not only existing workers but also new workers entering the job pool will become increasingly important. To attract and entice young talent, digital firms need to embed understanding such as in relation to software, algorithms, entrepreneurship, game theory, design and communication skills into the way they operate and train employees. Certainly, proponents view Africa's young and tech-savvy population as willing adopters of technological solutions to urban problems.

Data engineers and scientists, machine learning and deep-learning engineers, AI analysts, Blockchain miners and traders, cloud native experts, DevOps, Big Data and IoT skills are critical in this era of digital revolution.

Whilst education can be used to better train and prepare Africa's youth for emerging technologies, 4IR technologies can also be employed inversely to improve education, access to education and training for digital skills.

The potential applications of modern 4IR technologies are most apparent within the domains of IoT, Big Data and AI. Selected applications also exist within Additive Manufacturing. With regard to drones and Blockchain technologies, examples of their use within education is not apparent. It is, however, through education that African youth will become trained to become adept at using these technologies.

Internet of Things (IoT), Big Data and Artificial Intelligence

The IoT has the potential to improve the quality of education and access to education. The large scale diffusion of mobile communications technology has transformed educational practices, with easier access to educational resources inside and outside schools. For example, the arrival of low-cost, low-consumption smartphones and tablets allows ICT in education to gradually move out of the school environment and to be more accessible whenever and wherever a student chooses. There has been a shift from a tool-based approach to one that is centred on content and use. These mobile tools, particularly tablets, offer major opportunities to tackle the problem of a lack of books and textbooks. The distribution of e-readers to 600,000 children in nine African countries has had a considerable impact in terms of reading and pupils' results in educational tests. The option to send text messages containing short lessons, multiple choice tests or audio recordings has also been shown to have an important effect on teachers. This is also true of MOOCs (massive open online courses) adapted to African countries' needs and capacities.

The cross-fertilisation of teaching models and tools has broadened the potential of information and communication technology in education. Some technologies, perceived as outdated, are undergoing a partial revival thanks to the combination of media that can be used in any single project. For example, radio and television programmes are inexpensive and attract a considerable audience. Combined with the internet and mobile phones, they provide promising educational results.

For Artificial Intelligence, there is the potential for machine learning to be used to anticipate job market demand, automate teachers' routine tasks and to personalise learning. AI can also be used to fill skills shortages within the labour market, that is, by carrying out tasks for which the local workforce lacks the appropriate skills.

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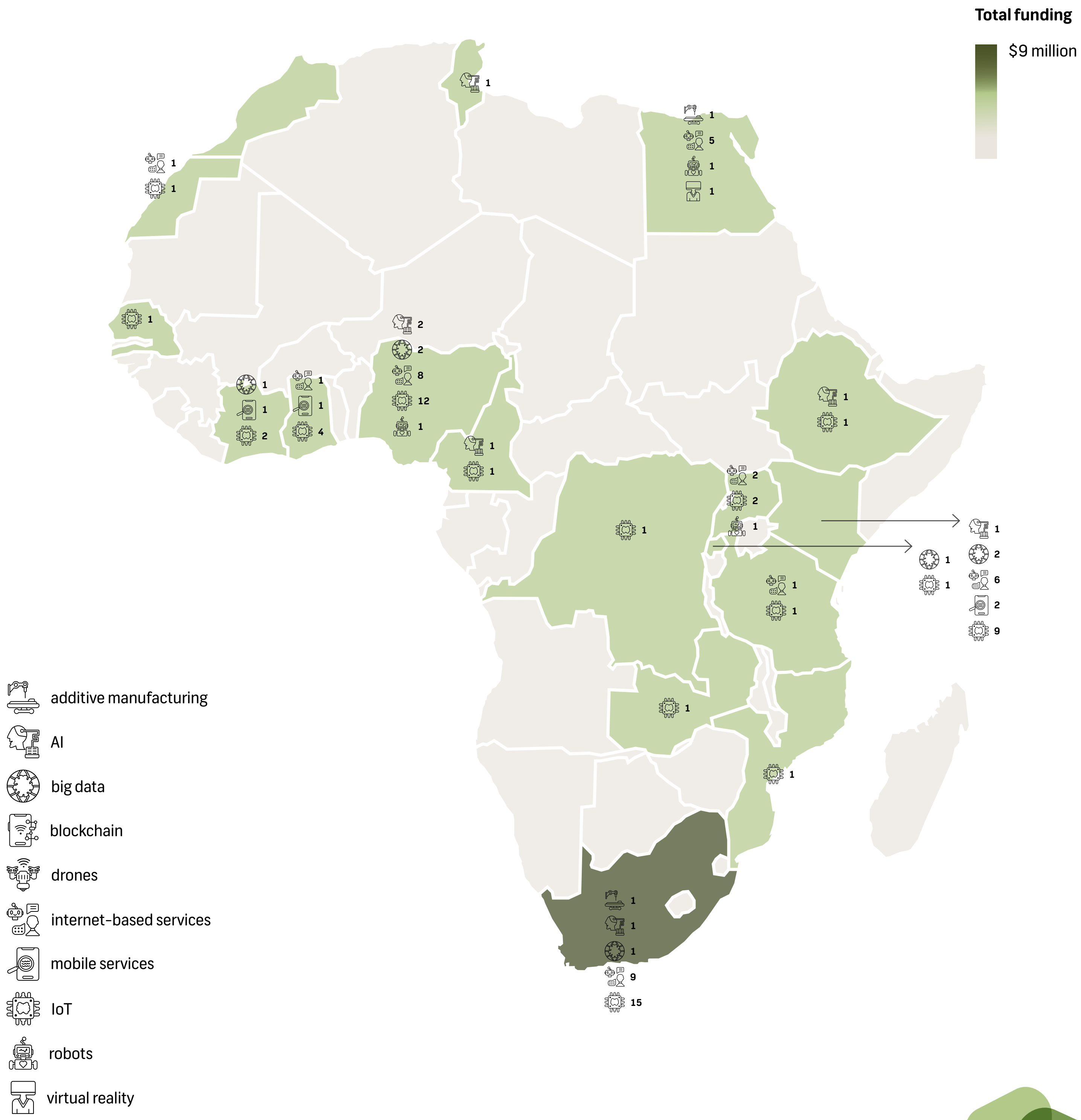
figure 38

the fourth industrial revolution: Africa companies in education



ADAPTED FROM
Technopolis Group (2019) based on CrunchBase and web mining

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box 16

E-higher education vision of Cameroon

In the education sector, in 2015 the government of Cameroon established a strategy for higher education based on governance and quality assurance, professionalisation and provision of more funding and digitalisation of higher education. Based on this, the e-higher education vision programme was established with plans to enhance e-learning, e-administration and the construction and equipment of nine digital centres in each of the state universities and in one inter-state university; plus, 500,000 laptops have been distributed to university students (32GB SSD with 2GB RAM) since then, with the objective being to connect the laptops to a cloud service and interconnect the universities with common services.

This project can be a good use case for the development of cloud services, but again the quality of laptops is quite weak for exploitation by the students. This is one of the few cases where there has been dedicated funding for a digitalisation strategy inCameroon (up to XAF 75 billion). A key lesson for other countries is that, ideally, the infrastructure should first be set up for such services to flourish and local content should be developed and encouraged to boost the IT industry before distributing laptops.

As already mentioned earlier in this report, education is key in the take-up of the 4IR, but this e-vision does not currently specifically mention the teaching of 4IR technologies nor are there dedicated efforts to raise the awareness of tertiary education students about these technologies (apart from general awareness-raising about ICT which have seemingly been identified). If this project comes to fruition as planned, then it will be a very good use case for the dissemination of cloud technologies nationwide.

SOURCE echnopolis Group (2019), Cameroon country case

It is also important to invest in human capital and expand provision of training and education in areas such as machine learning and data analytics for AI solutions to be adopted across Africa. Currently, there is limited AI education in Africa and there is a shortage of AI experts. In order to reap the rewards of the widespread use of AI technology, countries need to ensure that they have education and skills systems in place to make society ready to work with these technologies and to take full advantage of this technology for socioeconomic development.

Additive Manufacturing

There are some examples of the use of Additive Manufacturing (AM) within education. These mainly consist of cases where higher education institutions use 3D printing laboratories to teach and train young people to use these technologies.

6.4.3 Current use cases of emerging technologies in education in Africa

While still nascent, African initiatives using 4IR technologies are steadily becoming more apparent in education.

The desk research and interviews identified 100 African 4IR companies in education, located in 17 countries. The IoT is the most common technology used. Figure 38 illustrates trends in market applications and investments. The map is only used for the purpose of illustrating trends and is not intended to give an exhaustive overview of current applications in education and investments in start-ups across the continent.

According to CrunchBase, South Africa has gathered the most funding ($8,758,330) while Rwanda was the least funded ($5,000). It should be noted that investigations conducted did not show funding in countries other than the ones noted on the map.

In particular, the most common existing applications of emerging technologies are based on Artificial Intelligence (AI), Big Data and IoT. Some applications of additive manufacturing have been identified.

Internet of Things (IoT), Big Data and Artificial Intelligence

In certain African countries, efforts have been made to improve the quality of and access to educational platforms and courses for training on IoT, Big Data and Artificial Intelligence.

In Nigeria, for example, the South African telecoms provider MTN supports the initiative called Data Science Nigeria, which provides training and education on data science and analytics. The courses cover, inter alia, Big Data, machine learning and AI applications drawing on locally relevant solutions with a high impact on the economy, for example in the healthcare sector. The initiative is implemented in partnership with Nigerian universities to benefit students. The initiative also contributes to regional integration by inviting students from other African countries to participate, such as in bootcamps presenting best practices as to how to apply 4IR technologies. The ultimate goal is to build an ecosystem around AI research and innovation in Nigeria in support of applications related to the United Nation's Sustainable Development Goals. Elsewhere, in late 2018, Google opened an AI research centre in Accra, Ghana[348]. Furthermore, Google and Facebook sponsored a Masters of Machine Intelligence degree programme for students hosted by the African Institute of Mathematical Sciences in Kigali, Rwanda. The involvement of Africans in the development of AI can help to prevent algorithmic biases and discrimination in AI products[349].

The IoT has also been employed to improve the quality and access to education in Africa, such as described in Box 16.

Additive Manufacturing

Certain African countries have also started working with Additive Manufacturing and integrating it within education. In Morocco, for example, a 3DS Learning Lab was established by Dassault Système and ESSTI Rabat. The lab focuses on educational research that is performed together by higher education institutions and companies. Elsewhere, in Cameroon, Songhai Labs wants to create the first 3D printing technology space in francophone Africa dedicated to the local production of medical equipment for rural clinics. The project is also designed on a circular model of zero waste and will incorporate a strong educational component.

6.4.4 Challenges, recommendations and prospects

In this section, we will discuss the challenges posed by the adoption of 4IR technologies in education in Africa. We will also present the key limitations standing in the way of the widespread adoption of 4IR technologies and recommend actions for unlocking the potential of using 4IR technologies. The challenges, recommendations and prospects are based on our analysis of information that we collected from stakeholders during field visits and interviews.

Internet of Things (IoT), Big Data and Artificial Intelligence

The most promising emerging technologies for education in African are the IoT, Big Data and AI solutions as a means to improve the quality and access to education for African youth.

The main barrier to these technologies is connectivity and interoperability. Rural connectivity in Africa is a major limitation standing in the way of the deployment of IoT devices. Major improvements in wired and wireless solutions are needed for the technology to be beneficial. For IoT sensors, the issue of connectivity is more nuanced as networks are needed to work over long ranges while also consuming low power. Many current use cases are point solutions rather than interoperable platforms which allow data sharing and more valuable usage.

Additive Manufacturing

In Africa, Additive Manufacturing (AM) is still at an extremely embryonic stage of development concerning its use within education. The success of 3D printing in Africa will largely depend on supporting infrastructure and capabilities such as reliable electricity and fast and reliable access to the internet.

6.5 MARKET APPLICATIONS IN HEALTHCARE

Over the past 50 years, African countries have made considerable headway in improving the health outcomes of their populations. Nevertheless, and despite these advances, significant underlying challenges, which come in the form of endemic poverty, epidemic diseases and food insecurity, continue to burden healthcare delivery.

The traditional communicable diseases of HIV/AIDS, malaria and tuberculosis remain the main drivers of mortality. At the same time, chronic conditions such as cardiovascular diseases, diabetes and cancer – associated with a growing middle-class lifestyle – are also emerging as major killers on the continent. This is creating a double-disease burden which African health systems are ill-equipped to handle.

African healthcare systems are underfunded, overstretched and overstaffed, rendering the challenge of addressing this double-disease burden a monumental challenge. These systems must be modernised in order to ensure adequate healthcare delivery. In this respect, emerging technologies can contribute to deeply transforming and improving healthcare delivery in Africa.

The following sections (i) present the healthcare sector and its challenges in Africa, (ii) explore how 4IR technologies can transform healthcare in Africa, (iii) show current use cases of 4IR technologies in healthcare in Africa and (iv) discuss the challenges which limit the take-up of 4IR technologies and recommend actions to unlock the potential of emerging technologies in healthcare in Africa.

6.5.1 Presentation of healthcare and challenges for the sector

Despite steady improvements in recent decades, African countries continue to be burdened by negative health indicators, particularly within Sub-Saharan Africa and compared to global averages. Healthcare delivery remains suboptimal insofar as health systems lack the proper human and financial resources to cope adequately with health issues.

Africa remains the global region with the lowest average life expectancy and the highest adult mortality rates. Furthermore, Africa is the only global region to have witnessed a rise in mortality between 1990 and 2008, from 371 deaths per 1,000 people to 392 deaths[350]. HIV/AIDS continues to devastate the region, particularly Sub-Saharan Africa, which hosts 13% of the world's population but 66% of the people with HIV/AIDS[351]. More than 90% of the estimated 300-500 million malaria cases that occur worldwide every year are African, mainly in children under five years of age[352]. Complications during pregnancy and childbirth are one of the leading causes of death for women of childbearing age in Africa. Of the 20 countries with the highest maternal mortality rates worldwide, 19 are in Africa and the region has the highest neonatal death rate in the world.

Then there is the strain on African health systems imposed by the high burden of life-threatening communicable diseases coupled with increasing rates of noncommunicable diseases such as hypertension and coronary heart disease. Basic sanitation needs remain unmet for many: only 58% of people living in Sub-Saharan Africa have access to safe water supplies[353]. Noncommunicable diseases, such as hypertension, heart disease and diabetes are on the rise and injuries remain among the top causes of death in the region.

Concomitantly, the provision and supply of healthcare services in Africa remains suboptimal. On average, there are only nine hospital beds per 10,000 people in Africa compared to the world average of 27[354]. There are also severe inequalities in healthcare delivery, where the richer a person is, the more likely they are to receive qualified professional healthcare. Disparities in service provision between rural and urban areas is also a challenge which, in addition to poor road infrastructure, ageing power infrastructure and prevailing poverty levels, means that patients often do not have access to healthcare services on time. In sum, many African health systems are full of structural weaknesses, including in terms of funding, the low level of use of technology, human resources, research and development and access to primary healthcare centres in remote areas.

6.5.2 How can emerging technologies transform healthcare in Africa?

African healthcare must be modernised in order to improve its delivery and populations' access to healthcare services. Improvements at this level will in turn have a favourable impact in terms of steady improvements in healthcare outcomes.

Emerging technologies will play an important role in the future of African health systems. The adoption of 4IR technologies can assist African health systems in overcoming existing obstacles in terms of infrastructure, transportation and affordability in order to provide improved healthcare services.

The potential applications of modern 4IR technologies are most apparent within the domains of the IoT, Big Data and Artificial Intelligence. Certain applications have also been identified using drones, Blockchain and

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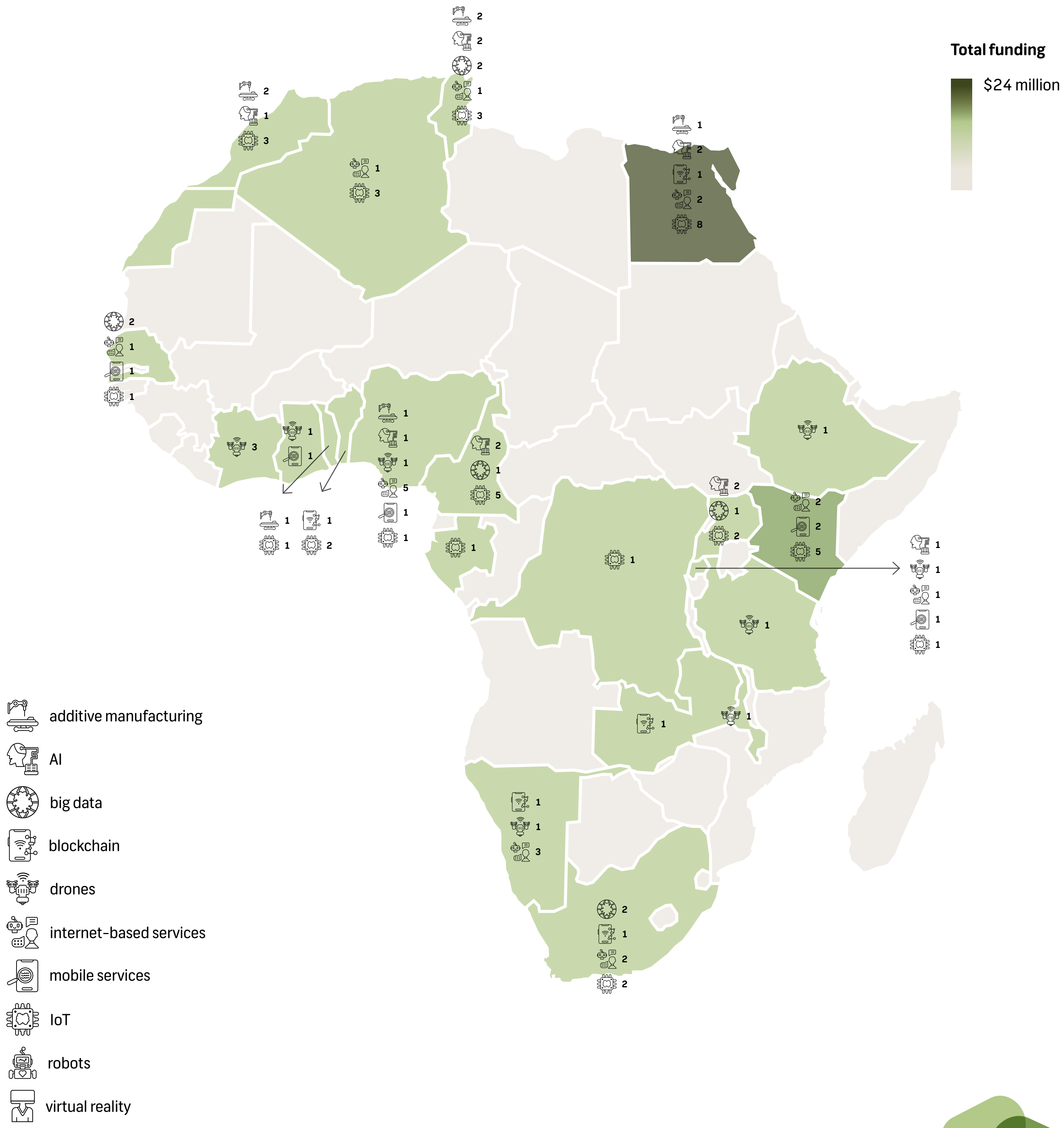
figure 39

the fourth industrial revolution: African companies in health



ADAPTED FROM
Technopolis Group (2019) based on CrunchBase and web mining

Additive Manufacturing although these applications are less evident.

Internet of Things (IoT), Big Data and Artificial Intelligence

IoT technologies are likely to have a large and positive impact on African healthcare delivery. For example, hand-held devices can be used to detect if a pharmaceutical product is genuine. Video therapy and remote diagnosis and care can also be enabled by technology, such as by using image recognition to render certain diagnostics automatic.

AI and Big Data have been becoming steadily more prevalent in healthcare systems, helping to analyse large amounts of data to improve efficiency in both care and access to medical supplies. In particular, AI is starting to be used for surgery, diagnosing diseases, early identification of potential pandemics, imaging diagnostics and remote therapy. AI has also been used to detect health conditions as well as to educate and communicate with patients via mobile phones. In Africa, where healthcare facilities are often under-resourced and understaffed, AI is beginning to be adopted to fill these gaps.

AI can help to create better tailored, higher quality and more accessible healthcare solutions, thereby improving public health outcomes. By making use of digital health records, AI can help to render healthcare delivery more efficient and more responsive to citizens' needs.

Harnessing technology and creating effective e-Health and m-Health services will be one of the means of increasing access to healthcare across the continent. Ensuring e-Health tools will help to overcome the triple challenges of inadequate access, finance and human resources by delivering high quality healthcare services to all citizens, even to those located in remote areas. e-Health can also contribute to greater transparency and accountability in health services by promoting evidence-based practice and error reduction, diagnostic accuracy and treatment. e-Health will also empower users, enabling better self-care and decision-making. It can also be promoted to delegate tasks as appropriate, thereby helping to address skills shortages. Finally, e-Health has the potential to increase cost-efficiency by streamlining the process, reducing waiting times and improving data accuracy.

b

box 17

use case of AI in healthcare in Nigeria

Annually, 245,000 Nigerians die from tuberculosis (TB). It is considered one of the most major infectious diseases across developing countries by the World Health Organization[357]. TB is curable but there has been an increase in the number of drug-resistant cases of TB, which points to a lack of adherence to treatment by patients.

The NIMCURE project is being implemented by the Lagos-based Co-Creation Hub in conjunction with the Nigerian Institute of Medical Research. The project aims to leverage AI to improve surveillance and detection of outbreaks of tuberculosis (TB) around the country and to improve adherence to TB treatment.

This is achieved by building a system that continuously collects, analyses and interprets health data in order to predict and plan for outbreaks and epidemics earlier in their course. The system consists of a digital public health intelligence platform. AI is used to recognise patterns in the data collected (disease case reports) and identify and report on any anomalies and patterns indicative of possible outbreaks early on to healthcare organisations, facilities and the public. The system also draws on a wider range of data to identify anomalies, including healthcare product purchases, absences from work or school, presenting symptoms to a healthcare provider or presenting laboratory test results.

In addition, NIMCURE promotes adherence to TB treatment using a digital care tool helping patients and caregivers to better manage the treatment process remotely and on the go. This draws on video-observed therapy.

NIMCURE was carried out as a pilot project between April 2018 and March 2019.

SOURCE Technopolis Group (2019), Nigeria country case

Blockchain in healthcare

The use of Blockchain in digitalising and sharing medical records is one of the identified applications of the technology for the healthcare sector. As things stand, patients and healthcare providers would not trust a central entity to hold such a database but rather would favour a decentralised, anonymous database which requires a Blockchain solution. This could in turn create the basis for Big Data and AI solutions to improve healthcare provision and diagnostics in the country.

Another area where Blockchain technology could improve healthcare services is in payments by insurance companies. Many hospitals in Africa currently experience delays in payment by insurance companies, where the payments from these companies covering the costs of services provided for a patient can sometimes be delayed by years. This makes it difficult for hospitals to be able to operate properly. A governance system using smart contracts and Blockchain whereby payments are made automatically no later than three months after service delivery could address this problem and help hospitals budget more efficiently.

Drones

Medical drones are steadily changing the way that emergency healthcare is provided in Africa. Indeed, drones have arisen as a good solution to resolve the difficulties and inaccessibility of certain rural areas in terms of the delivery of emergency medical supplies. Under this system, a healthcare worker messages or calls the central base, after which a drone is loaded, programmed and launched. On arrival, the drone circles down to an altitude of 20ft and releases its payload by disposable parachute, after which the drone automatically returns to base. At present, medical drones are particularly present in Rwanda and Tanzania, in the form of Zipline, a Californian company.

Additive Manufacturing

In the healthcare sector, the possibility to print on demand is beneficial when there is a lack of availability of medical supplies. In countries that are affected by conflicts, low-cost modular prosthetics that fit patients' needs are promising, for example for children with missing limbs that require frequent replacements and refits because they are still growing. Indeed, 3D printing can play a role in healthcare by reducing the costs for prosthetics and samples. Additive Manufacturing (AM) can also play a role in the production of medical equipment and in the testing of diseases.

6.5.3 Current use cases of emerging technologies in healthcare in Africa

While still nascent, African initiatives using 4IR technologies are steadily becoming more apparent in the healthcare sector.

Desk research and interviews identified 87 African 4IR companies in health, located in 21 countries. IoT is the most common technology used. Figure 39 illustrates trends in market applications and investments. The map is only used for the purpose of illustrating trends and is not intended to give an exhaustive overview of current applications in healthcare and investments in start-ups across the continent.

According to Crunchbase, Egypt has gathered the most funding ($23,535,880) while Nigeria has gathered the least ($100,000). It is to be noted that investigations conducted did not show funding in countries other than the ones noted on the map.

In particular, the most common existing applications of emerging technologies are based on Artificial Intelligence (AI), Big Data and IoT. Some applications of Additive Manufacturing (AM) and drones have been identified while Blockchain technologies remain at an early stage. A selection of interesting use cases are presented in the following section.

AI and Big Data have been becoming steadily more prevalent in African healthcare systems. In Cameroon, the Bonassama District Hospital in Douala has been integrating SOPHiA since 2017, AI developed by the multinational Sophia Genetics, into the clinical workflow to advance patients' care. By using this AI solution, the hospital now forms part of a larger network of 260 hospitals in 46 countries that share clinical insights using Big Data analytics across patient cases, feeding a knowledge base of biomedical findings to accelerate diagnostics and care[355]. This allows the hospital to rapidly analyse genomic data and decide on the most effective care. Another example of AI and machine learning for the healthcare sector comes from Songhai Labs. The Yaoundé-based start-up is working on a project in partnership with the WHO in Cameroon

b

box 18

use cases of IoT at Makerere University in healthcare

In 2011, Makerere University students developed WinSenga, which is a foetal heart rate monitor using a smartphone. WinSenga is a handheld device that can scan a pregnant woman's womb and report foetal weight, position, breathing patterns, gestational age and heart rate. The information is transmitted to a smartphone and onto the mobile app, which plays the part of the nurse's ear and recommends a course of action. Analysis and recommendations are uploaded to the cloud and can be accessed by a doctor anywhere to track progress at any time[363].

Elsewhere, the mobile application Matibabu was also developed by Makerere University students to perform a non-invasive malaria test. This test is able to diagnose malaria patients without a prick on their skin and shows them where the available treatment centre is located. It uses smartphone technology accompanied with a custom-made hardware to test for the presence of plasmodium in human blood[364].

SOURCE Technopolis Group (2019), Uganda case study

and a UCLA start-up from California. Within this project, HSPC polyclinic in Kumba, a private hospital in south west Cameroon, was provided with a digital application which helps it to compile data on patients for epidemiological surveillance via Artificial Intelligence[356].

In Kenya, Sophie Bot is a free chatbot that relies on AI to process and reply to questions on sexual and reproductive health. According to a stakeholder consulted for this study, the advantage of the app is that it allows patients to receive a diagnosis and potentially remote therapy more easily and freely than if they have to travel to the nearest doctor. Similarly to the Kenyan example, in South Africa, citizens in regions without primary healthcare facilities are often reliant on the services of mobile clinics. Numberboost is a company working to develop a system to allow citizens to locate nearby mobile healthcare clinics — a service that could help improve citizen access to healthcare.

IoT solutions are also becoming more evident across the continent. In Uganda, fast take-up in mobile technology has enabled innovations around m-Health tools. For example, the ICT4MPOWER project implemented by the Ministry of Health, Uganda Communications Commission and the Ministry of ICT aimed at developing an electronic health record and referral system, a unique client ID system as well as strategic delivery of eLearning and tele-consultation[358]. Elsewhere, an Electronic Medical Record (EMR) system was implemented to improve access to antiretroviral treatment at the Reach out Mbuya HIV/AIDs clinic. This has reduced the number of missed appointments and improved clinic efficiency. Mama Ope is a biomedical smart jacket that measures body temperature, heart rate and lung condition. The technology is similar to a stethoscope. It stretches across the whole chest and the side of a patient's body. It surveys specific points on the lungs for symptoms of pneumonia, characterised by a swelling of the lungs caused by infection. The jacket is connected to a mobile phone app via Bluetooth which sends, records and analyses the medical data, ready for a healthcare professional to make an informed diagnosis[359].

Another Ugandan example is Text to Change, which, together with the AIDS Information Centre and Celtel mobile network, piloted an SMS mobile phone-based platform to scale up HIV/AIDs awareness and encourage participants to access HIV counselling and testing[360]. In 2016, the Ugandan Ministry of Health introduced an electronic medical records system to track patient histories across both public and private health facilities nationwide. The main aim was to ensure that the individual's medical information could be shared digitally and securely across health centres and departments whilst protecting the privacy of patient data at the same time[361]. The Ministry of Health has also implemented mTrac (Mobile Tracking) as a RapidSMS-based health management information tool designed to strengthen health systems in Uganda using a basic mobile phone. The goal was to speed up response time and accountability while reporting on disease surveillance and medicine tracking in all 5,000 health facilities in Uganda, which has been achieved to a great extent[362].

In Nigeria, MTN Nigeria is already working on bringing the IoT to healthcare. Wearable sensors that communicate an individual's health status may in the future replace some medical check-ups but this requires robust health management systems that are not yet in place in the country. Insurance companies may also be interested in tracking customers' health status and intervening to protect their health. Elsewhere, Gricd is an IoT start-up that provides an affordable and portable cold chain device for efficient storage of vaccines, blood and other health/agricultural products (also to be potentially used in the oil/gas sector, in and around abattoirs, and for fast moving consumer goods like refreshment beverages). The solution improves 'last mile' delivery using a smart, IoT-enabled cold chain box sending real-time data to customers. For instance, in case a vaccine to be transported has been tampered with, it can be located en route before it is delivered to patients. The data collected includes temperature in the box (automatically issuing an alarm when the temperature exceeds predefined levels), location and battery duration.

Elsewhere, Treplabs is a Nigerian start-up installing sensors at blood drip pumps that can prevent clinical and surgical errors by monitoring infusion treatment. The device they develop can prevent backflow of blood during drip treatment by monitoring flow rates and volumes administered and automating the drip treatment process. Medical staff can check the flow rate via a mobile app and web dashboard. The device sends automated text messages to staff once the fluid left drops below 5%.

Many IoT solutions are also emerging within the healthcare sector in Cameroon. ICT-based tools such as GiftedMom[365] and Happy Mothers[366] are apps which allow mothers and pregnant women in Cameroon to access medical advice in rural communities. In a similar vein, Himore Medical has designed a wireless solution called CardioPad that enables the monitoring of cardiovascular diseases (CVDs). While the majority of CVD specialists practise in Yaoundé, 80% of the country's population lives in rural areas. CardioPad provides improved access to CVD healthcare for patients living in remote areas. It is a touchscreen tablet that includes a set of four wireless electrodes and a sensor that attaches to the patient's chest. This generates a signal, which is then transmitted via Bluetooth to the tablet. A digested electrocardiogram (ECG) of the patient's heart function is then transmitted through a mobile network to a second CardioPad device situated in a city hospital, where a registered cardiologist can make a diagnosis.

In terms of 3D Printing, Songhai Labs in Cameroon wants to create the first 3D printing tech space in francophone Africa dedicated to locally producing medical equipment for rural clinics. The project is also designed to be based on a circular model of zero waste and will incorporate a strong educational component. Cameroon also possesses an industrial 3D printer, which is one of the biggest in western and central Africa. It is hosted within the premises of the National Advanced School of Engineering (ENSP) and has produced many 3D samples for mannequins and organs to be used by hospitals. This project was funded by the Israeli government.

In Zambia, molecular biology and chemistry labs are 3D-printed for use for testing malaria in a project of the Vanderbilt-Zambia Network for Innovation in Global Health Technologies. Elsewhere, in Uganda, 3D printers have been introduced to print prosthetic limbs for amputees.

6.5.4 Challenges, recommendations and prospects

In this section, we will discuss the challenges posed by the adoption of 4IR technologies in healthcare in Africa from the perspective of consumers and patients. We will also present the key limitations for the widespread adoption of 4IR technologies and recommend actions for unlocking the potential of using 4IR technologies. The challenges, recommendations and prospects are based on our analysis of information that we collected from stakeholders during field visits and interviews.

Blockchain

From the consumer side, while there is broad awareness of Blockchain in association with cryptocurrencies, there is little popular understanding of Blockchain use in healthcare. Key limitations to the widespread dissemination of commercial Blockchain applications in healthcare include availability of quality data and regulations. In addition, any major application of Blockchain technology within healthcare would realistically require a government buy-in in order to take off.

IoT, Big Data and Artificial Intelligence

The most promising emerging technologies in African health systems are the IoT, Big Data and AI solutions, including e-Health and m-Health applications as a means to improve primary healthcare delivery and public health for African citizens.

The growth of the ICT industry in Africa and increases in mobile phone penetration have helped African populations, especially rural and underserved communities, in gaining greater access to e-Health and m-Health applications. This has had a positive impact, especially in the areas of disease control and prevention through disease surveillance.

However, most e-Health and m-Health applications are at the proof-of-concept stage, used within a small context and lack scalability. Most of these are donor funded and operated in silos. Moreover, e-Health implementations in Africa lack prior planning stages such as strategy and need readiness assessment.

Another barrier is connectivity & interoperability. Rural connectivity in Africa is a major limitation standing in the way of the deployment of IoT devices. Major improvements in wired and wireless solutions are needed for the technology to be beneficial. For IoT sensors, the issue of connectivity is more nuanced as networks are needed to work over long ranges whilst also consuming low power. Many current use cases are point solutions rather than interoperable platforms which allow data sharing and more valuable usage.

Another key aspect is usability of those technologies which can appear complex. If farmers do not understand the use cases, they will not use the technology. Application developers and service providers must be particularly careful about that.

Drones

The popularity of the use of medical drones for the delivery of emergency health products, mostly blood and vaccines, is slowly growing in Africa thanks to communication on current use cases and the presence of predominantly Californian-based start-ups on the continent. However, barriers to adoption remain.

In particular, the size of area that medical drones can currently cover is limited by the battery life of the drone and regulatory requirements around how far they can fly. This means that medical drones are currently most used in smaller countries such as Rwanda, where they have to cover smaller areas, rather than larger ones such as Cameroon, where accessibility to rural areas remains an issue. National regulations on drones that African countries are gradually adopting should cover a large area.

Additive Manufacturing

The market entry barriers for new technologies in healthcare products such as Additive Manufacturing (AM) are particularly high as this is a more highly regulated market in a largely public sector. It must be noted that the take-up of new technologies by the health sector faces several challenges, of which a lack of financing is the most urgent. The healthcare sector in most countries is experiencing a lack of funding, which also has an impact on the capacity for this sector to pay for 4IR technologies. Furthermore, in the case of Cameroon for example, there tends to be a predominance of short-term lending and a high level of non-performing loans. Loans tend to be predominantly attributed to larger private companies rather than to SMEs.

6.6 MARKET APPLICATIONS IN SMART CITIES

Africa is undergoing impressive urban growth. The continent, which was alongside Asia as one of the least urbanised in the world in 2014, is now experiencing fast urbanisation rates. Indeed, Africa is envisioned to reach a population of 2.4 billion within the coming decades, favouring cities over rural areas[367]. By 2030, it is expected that six of the world's 41 megacities will be African, namely: Cairo, Lagos, Kinshasa, Johannesburg, Luanda and Dar es Salaam.

The urbanisation process undoubtedly has the power to transform the global economy. However, it also comes with a set of challenges such as the need for mobility and access to urban services, access to clean water and sanitation, public health and safety issues as well as policy-related matters. The urbanisation process can therefore spur development only if initiatives are adopted to cope with the structural challenges that urbanisation generates and efforts are pursued to create inclusive, safe and sustainable cities as outlined by the UN Sustainable Development Goals.

Within this context, smart cities are presented by policy makers as the solution to rapid urbanisation growth. Within this process, emerging technologies will make an important contribution towards the transformation of African metropolises into smart cities.

The following sections (i) present the role of smart cities and their challenges in Africa, (ii) explore how 4IR technologies can transform and promote smart cities in Africa, (iii) show current use cases of 4IR technologies in smart cities in Africa and (iv) discuss the challenges which limit the take-up of 4IR technologies and recommend actions to unlock the potential of emerging technologies in smart cities in Africa.

6.6.1 Presentation of smart cities and challenges for the sector

An extraordinary period of urbanisation is underway in Africa where, after thousands of years, the vast majority of people will leave the countryside and pour into urban areas in search of work. The profile of Africa's cities will be permanently altered and, in the process, radically challenge policy makers to improve infrastructure and public services, leveraging these forces for sustainable and inclusive growth.

Within this demographic challenge, smart cities have emerged as an optimal solution. A smart city is a digital ecosystem that enhances a city's liveability, workability and sustainability. Technology and connectivity play a central role in the infrastructure of smart cities. As a solution, smart cities address issues of urbanisation, economic development and the technological needs of its inhabitants and visitors. They offer a place to live, learn and work; a space to develop business and entrepreneurial activity in the digital arena while also providing healthcare: a crucial issue in Africa. Equally crucial, smart cities are built on sustainable energy infrastructure. A smart city encompasses everything from public spaces with free Wi-Fi to solar-powered street lights and, as in Addis Ababa, automated lift car parks that reduce the space needed for cars.

Smart cities will be a crucial means by which Africa may avoid a demographic, political and human disaster in the coming decades.

Indeed, there are a set of factors that make African cities the ideal candidates for the adoption of smart city technologies. For example, as some African countries currently lack steady telecommunication cable installations, African cities can install the newest available ICT technology, removing the costs associated with removing or upgrading existing ICT infrastructure. Importantly, the continent's booming young population is also an advantage, as young people are more likely to adopt emerging and smart city technologies.

The stakes are certainly high. For example, while 60% of the Moroccan population is urban, this proportion will reach 70% by 2050. By this time, Casablanca, the largest city in Morocco, will have five million inhabitants. The challenge for cities such as this is to ensure quality of life for the urban population. It encompasses meeting the challenges posed by a significant growth in population, rapid urban development as well as limited natural and financial resources.

6.6.2 How can emerging technologies transform smart cities in Africa?

Due to the geographical, historical and cultural variations across Africa, there is no one-size-fits-all model for any African city to become a smart city. Each country is at a different phase of development and there are varying levels of political and economic stability. That being said, emerging technologies will play an important role in each version of African smart cities.

The potential applications of modern 4IR technologies within smart cities are most apparent within the domains of the IoT, Big Data and AI. Although Blockchain technologies were highly ranked as a relevant technology for smart cities, there are few obvious and concrete examples of their application in this context. Similarly, there have been few concrete examples of the use of drones and Additive Manufacturing.

Internet of Things (IoT), Big Data and Artificial Intelligence

The adoption of IoT is a priority for smart cities and forms the basis for a range of 'smart' initiatives, including farms, factories, energy grids and smart cities.

Big Data and AI are also fundamental to the development of smart cities. Examples of smart city solutions include the automation of patrolling, surveillance and other dangerous tasks and the improvement of crime forecasting models using Big Data. Real-time updates on traffic information and the intelligent control of traffic flows will also help minimise traffic congestion and car accidents.

Another set of emerging technologies concerns the energy domain in the form of smart meter systems. These systems use sensors that allow remote monitoring of electricity consumption and are related to smart city initiatives, which can be piloted in urban environments that have the main enabling factors for IoT and Big Data deployment (i.e. physical and virtual infrastructure and human capital).

6.6.3 Current use cases of emerging technologies in smart cities in Africa

At present, there is little doubt that north African cities such as Cairo, Tunis, Algiers and Casablanca are ahead of the game, yet they are not the only cities to conduct experiments in smart city technology. Accra, Lagos, Abidjan and Nairobi are enclaves that are agglomerating urban and peri-urban areas, which are attracting investors. Johannesburg and Kigali are also benefitting from the emergence of a dynamic and connected middle class.

The IoT, Big Data and AI are by far the emerging technologies with the highest number of current applications in African smart cities.

In Morocco, several smart city projects have been established. Aware of the importance of open data in modernising its public and urban space, Morocco has developed several data-sharing initiatives, strengthening the links between citizens, associations, companies and public actors. These include the Casablanca Smart City (e-Medina), the eco-city of Zenata and the green city of Benguerir. The city of Casablanca will rely on the capabilities of IoT and Big Data technologies. The goal is to optimise the acquisition and processing of information to improve the activities of the city administration and better inform citizens of Casablanca. e-Medina, a cluster organisation set-up in 2015, is the implementing body of this project. Its mission is to create and develop a smart city ecosystem to develop transformative initiatives using digital technologies. The cluster supports and helps to finance smart city projects for the city of Casablanca. Furthermore, data platforms like the one developed by the start-up Cityzenith make it possible to compile, process and visualise urban data. The company has developed a city visualisation platform in 5D, adding to the classic 3D the dimensions of time and data. Transformation into a smart city also involves developing a network of information at the city level through the collection and analysis of Big Data from users via sensors and applications. The city of Casablanca already initiated the establishment of such a network in January 2016 by inaugurating an intelligent and optimised CCTV system, including 760 cameras connected by 220 kilometres of optical fibre.

In Nigeria, there are several initiatives to build smart cities, for instance in Lagos, Kaduna and Abuja. In 2016, the city of Lagos started its Smart Cities Initiative with the support of the city of Dubai. The overall aims of this project include job creation and carbon neutrality for the city. The initiative is aimed at leveraging ICT and increasing connectivity to improve urban life, drawing on the IoT, Big Data and AI. The first steps towards implementation included the installation of free Wi-Fi infrastructure to facilitate the connectivity and data flow needed for smart city solutions and training of State government staff to align them with the vision for a smart city. Key areas of focus for the technology will be to improve waste collection and traffic management. Other related activities include government

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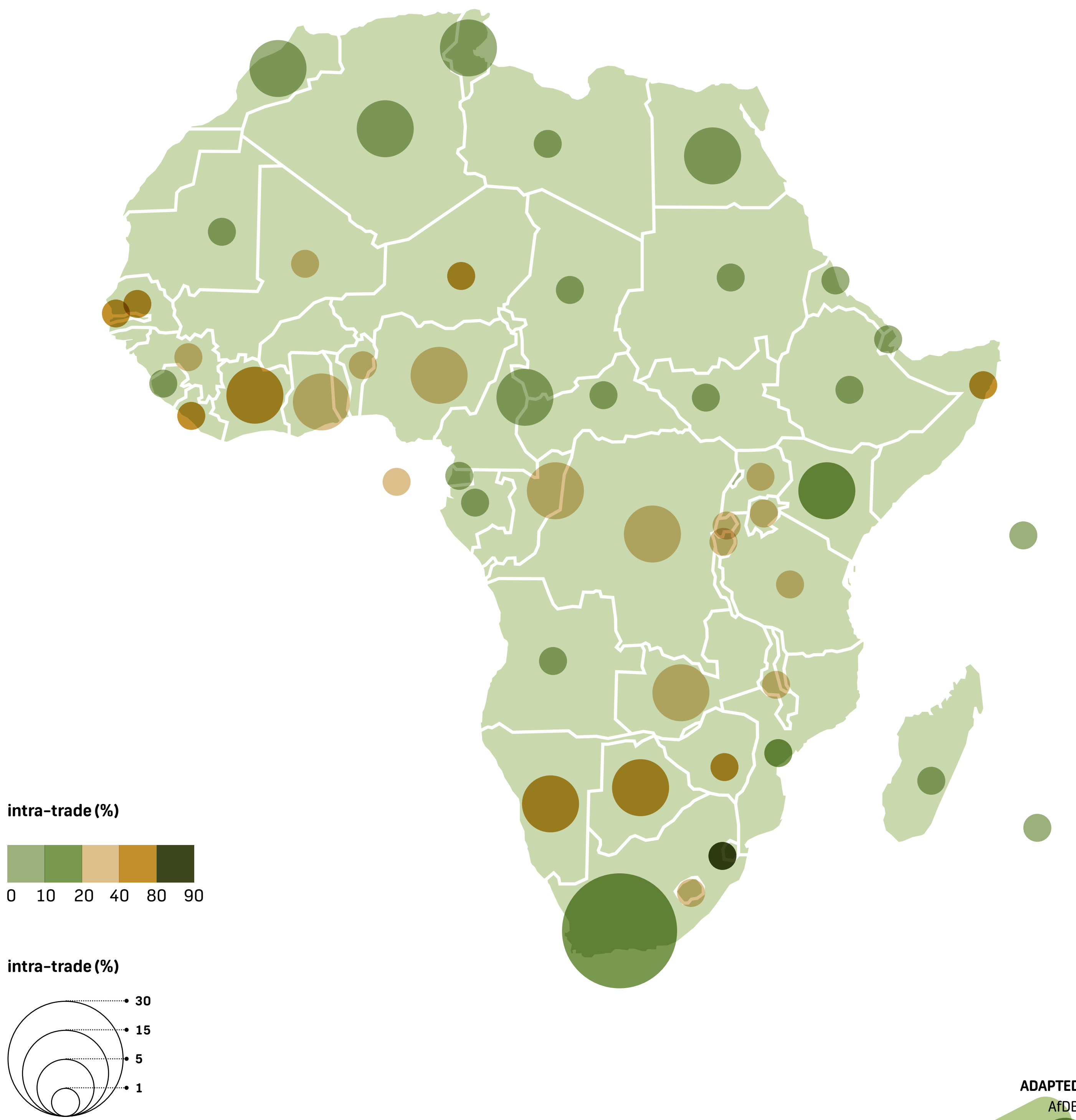
figure 40

intra-African trade



ADAPTED FROM
AfDB, 2019

support for private smart city initiatives such as Eko Atlantic City close to Lagos. Inspired by the Lagos example, the country's federal government is now working on a national policy on smart cities.

6.6.4 Challenges, recommendations and prospects

Governance is paramount to the success of smart cities projects. For example, the transformation of Casablanca into a smart city is slowed down by the lack of clear governance. In fact, while the e-Medina cluster is related to and is involved in numerous projects, it does not act as a decision-maker. The lack of a clear decision-maker, with effective governance, will be a hindrance to the development of the Casablanca Smart City.

Despite all the efforts undertaken for the development of smart cities in Nigeria, a lack of financial means still poses considerable challenges to the full realisation of these smart cities.

For the AfDB, potential projects in this domain range from supporting one or two smart city initiatives through to the provision of metrics and indicators and the financing of infrastructure.

6.7 MARKET APPLICATIONS IN REGIONAL INTEGRATION

Regional integration is a powerful driver of social and economic development. It creates the potential for high-value manufacturing, knowledge transfer, productivity growth and job creation. Regional economic integration in Africa took a major step forward with the adoption of the agreement establishing the African Continental Free Trade Area (AfCFTA).

However, despite some landmark achievements, intra-Africa trade remains low. Significant barriers to trade remain, such as the high cost of trading across borders. There have been notable efforts to improve infrastructure connectivity and create conducive policy environments for business. Regional economic communities continue to promote integration, but progress is needed in many areas (AfDB, 2019).

The following sections will (i) present the state of regional integration in Africa and its challenges in Africa, (ii) explore how 4IR technologies can accelerate regional integration in Africa, (iii) show current use cases of 4IR technologies in regional integration in Africa and (iv) discuss the challenges which limit the take-up of 4IR technologies and recommend actions to unlock the potential of emerging technologies in regional integration in Africa.

6.7.1 The state of and challenges of regional integration in Africa

African regional economic integration was given a boost with the adoption of the agreement establishing the African Continental Free Trade Area (AfCFTA) in March 2018 and the launch of the operational phase in July 2019. On the continental level, the AfCFTA will be one of the largest free trade areas since the formation of the World Trade Organization, given Africa's current population of 1.2 billion people, which is expected to grow to 2.5 billion by 2050. It will be governed by five operational instruments, i.e. the rules of origin; the online negotiating forum; the monitoring and elimination of non-tariff barriers; a digital payments system and the African Trade Observatory (AU, 2019).

By committing countries to removing tariffs on 90% of goods, liberalising tariffs on services and addressing other non-tariff barriers, AfCFTA is expected to significantly increase the value of intra-Africa trade and investment.

This remarkable progress must not hide the obstacles that persist in integrating Africa. In fact, as shown in Figure 40, intra-African trade remains limited at 14.4% of total trade, with a decline in low-income countries from 22.6% in 2015 to 20.4% in 2018. By comparison, interregional trade in Asia accounts for 59% of total trade. This disparity can be explained by the lack of quality infrastructure and a large number of non-tariff barriers (AfDB, 2019).

As a result of the current limitations, the cost of trading across borders remains high, although it fell slightly in 2017 (AfDB, 2019).

On the positive side, there have been notable efforts to improve infrastructure connectivity across the continent and the cost of cross-border trading is expected to diminish thanks to the continuous investments in infrastructure and the AfCFTA.

There has also been a significant increase in cross-border investment in Africa. In Africa-to-Africa (A2) Investment: A First Look, the Bank reported that cross-border investments reached $12 billion in 2018, up from $2 billion in 2010. The State of African Cities Report 2018 identifies Johannesburg, Casablanca, Cairo, Lagos and Nairobi as amongst the most significant sources and recipients of intra-Africa investment.

On a regional level, regional economic communities (RECs) such as ECOWAS, WAEMU, ECCAS, EAC and SADC promote regional economic integration among their members and regional infrastructure development.

Africa has been making steady progress on freedom of movement of people and liberalising visa policies. Eleven of Africa's 54 countries have liberal visa policies — up from 10 in 2017. According to the Brookings Institution, more than 10 million Africans already travel across national borders every year. By 2030, consumer spending on tourism, hospitality and recreation in Africa is projected to reach $261.8 billion, almost double the amount spent in 2015. There are now 76 One-Stop Border Posts (OSBPs) across Africa with more in the pipeline. Before 2009, there were none. However, free movement of persons and goods is still a challenge, notably due to security threats (AfDB, 2019).

Regional integration also implies free movement of goods. In the case of a free trade zone, goods which justify community origins circulate freely and are exempt from customs duties. The role assigned to the rules of origin is to contribute to the construction and consolidation of the regional market by neutralising the negative effects of importing products from third countries that may compete with local products and disrupt markets. In some regional economic communities (RECs) such as ECOWAS and WAEMU, the community origin of a good is proven by a Certificate of Origin (CO), which is delivered by national authorities.

The challenge for some RECs is, on the one hand, to keep the rules of origin simple and transparent. For example, in WAEMU and ECOWAS, the value-added origin criterion is considered difficult to apply because, among other things, of the complexity of the international value chain and manufacturing processes (ECOWAS, 2016). On the other hand, the management of documents that confer the community origin remains manual (WAEMU, 2018). According to the AfDB, intra-Africa trade could grow by up to 15% if the bilateral tariffs that are applied today in Africa are eliminated and the rules of origin kept simple and transparent (AfDB, 2019).

In addition, fraud and counterfeiting are major threats for regional integration in Africa. African countries are particularly vulnerable to counterfeit goods because many commercial activities take place in unregulated markets, borders can be easily breached and resources for fighting counterfeiting are often inadequate. Thus, if counterfeit products penetrate a country within a REC, the other country members are equally exposed.

While data on counterfeiting focused on the African continent is not as readily available, recent research by the Confederation of Tanzania Industries estimates that over 50% of all goods (including food, drugs and construction materials) imported into Tanzania are fake (Nwuneli, 2018).

Counterfeiting reduces tax revenue and inhibits economic growth by allowing unfair competition with local producers and raising serious quality and even sanitary issues. For example, it is estimated that fake pharmaceuticals account for between 30% and 60% of the African market. Furthermore, the World Health Organization has estimated that some 100,000 people die in Africa every year because of counterfeit pharmaceuticals (Maguire & Ramara, 2018). The situation is also alarming in the food industry. Anecdotal evidence suggests that rates of counterfeit food could be between 10% and 50%, depending on the food category and the country (Nwuneli, 2018).

Most of the counterfeit goods in Africa come from the east, particularly China. However, counterfeit goods come from other countries as well and a significant number are even

f

figure 41

how blockchain can impact cross-border trade

ports and terminals

provide	information about the disposition of shipments within the boundaries of the port / terminal
benefit from	pre-built connections to shipping lines and other actors, end-to-end visibility across shipping corridors, and real-time access to more information to enrich port collaboration and improve terminal planning

ocean carriers

provide	information about the disposition of shipments across the ocean leg
benefit from	pre-built connections to customers and ports/terminals around the world and real-time access to end-to-end supply chain events

customs authorities

provide	information about the export and import clearance status for shipments into and out of the country
benefit from	more informed risk assessments, better information sharing, less manual paperwork and easier connections to national single window platforms

freight forwarders / third party logistics providers

provide	the transportation plan, inland transportation events, information on intermodal handoffs, and document fillings
benefit from	pre-built connections to the ecosystem, improved tools for customs clearance brokerage function, and real-time access to the end-to-end supply chain data to improve effectiveness of track-and-trace tools

intermodal transport

provide	information on the disposition of shipments carried on trucks, rail, barges, etc.
benefit from	improved planning and utilisation of assets (e.g. less queuing) given real-time access to end-to-end supply chain events for shipments

shippers

engage	with the solution as a consumer of the shipping information events and paperless trade capabilities
benefit from	a streamlined and improved supply chain allowing for greater predictability, early notification of issues, full transparency to validate fees and subcharges, and less safety stock inventory

ADAPTED FROM
IBM, 2018

manufactured on African soil (Maguire & Ramara, 2018). Regional integration can be further driven by advances in technology (AfDB, 2019). The following section will show how 4IR technologies can accelerate regional integration in Africa.

6.7.2 How can emerging technologies accelerate regional integration in Africa?

One of the reasons why trade within Africa is low is that most of the products needed by African countries are not produced in Africa and therefore need to be imported. By contrast, most of the products that Africa offers are raw materials destined for export. In Africa, most products that cross borders come from other continents or are destined for them (Afreximbank, 2018).

As developed in the previous sections, emerging technologies have the potential to transform all economic sectors (agriculture, industry, energy, mining and services) by increasing local production, allowing the local production of goods and services which were previously imported, facilitating customisation of products, developing regional value chains, creating innovative ways to respond to the needs of customers and the population and bringing producers closer to their markets. Therefore, one of the positive externalities of a better diffusion of emerging technologies in the sectors will be an increase in intra-African trade.

In addition, another positive externality will be a boost for cross-border investments. In fact, as previously stated, there is already an upward trend in intra-African investments. If successfully driven, the uptake of emerging technologies will favour the development of homegrown African multinationals benefiting from the business opportunities arising from emerging technologies. These African ventures will in turn play an important role in increasing cross-border investments.

On another note, emerging technologies can help solve some of the technical obstacles which make regional integration harder, namely the high costs of cross-border trading, fraud, counterfeiting and compliance with rules of origin. They can also help develop trade finance solutions which will further enhance regional integration.

Blockchain in regional integration

As previously discussed, the cost of trading across borders remains high in Africa. Time and the cost of clearing goods add to the costs due to the numerous pieces of documentation and procedures needed to obtain the certificate of origin, quality conformity and phytosanitary certificate, authorisation to import or export and to comply with customs regulations.

As in other sectors, Blockchain and smart contracts have the potential to have a positive impact on African cross-border trade (see figure 41). Applications driven by the digital ledger technology would help to reduce the huge volumes of paperwork and multiple bureaucratic interventions, which are considered necessary in pursuit of legitimate trade. Time and effort would be saved all along the supply chain by parties not having to reproduce the information and submit it manually to the authorities or trading partners.

Customs administrations and other border agencies can therefore improve their capacity for risk analysis and effectiveness by using Blockchain, which can ensure data integrity, traceability and transparency, make information on any shipment available in real time and allow data to be collected (Okazaki, 2018).

A producer can start a Blockchain recording the sale of goods to a distributor and then being augmented by every transformation (storage in a warehouse, consolidation with other goods, quality inspectors, packaging, shipment, clearance by customs in the export country etc.). The distributed ledger concept guarantees the integrity of the data stored in the Blockchain as the Blockchain is incremented and, therefore, when it is presented to the customs authorities of the importing country, they can rely on every piece of information having been generated by its originator. Blockchain can therefore contribute to reducing fraud and counterfeiting by giving a perfect traceability of goods exchanged across borders. In addition, opportunities for corruption or collusion (a common problem in many countries which significantly adds to the cost of trade) would be reduced as the data cannot be retroactively tampered with or altered along the way. Furthermore, customs would be able to see the necessary and accurate data (seller, buyer, price, quantity, carrier, finance, insurance etc.) that have been tied with the goods to be declared and also keep track of the location and status of such goods in real time.

Over time, Blockchain technology would create a vast repository of Big Data which can be used to analyse trade patterns and trends to enable increasingly sophisticated risk profiling, which would enhance the border authorities' risk management capacity.

In practical terms, Blockchain technology needs to be embedded into customs' practices through a common platform which would embrace trade-related commercial entities and thus would enable the sharing of information among them.

There are currently use cases of such applications of Blockchain in cross-border trade by customs administrations. For example, the Korean Customs Service (KCS) revealed its plan to exploit the potential of emerging technologies such as Blockchain and Big Data. KCS adopted Nexledger, a Blockchain platform developed by Samsung SDS, to establish a Blockchain-based export customs clearance system. This platform is capable of handling large quantities of transactions in real time and offers a smart contract function, which enhances security and convenience[368]. South Korea's Ministry of Science and ICT, in collaboration with the Korea Customs Service (KCS), is also building a Blockchain-based e-commerce goods customs clearance system. The main goal is to automate the existing system to reduce inefficiencies in clearing goods purchased online (directly) by people living overseas. The Blockchain-based system will help address many of the issues in the existing manual-driven process. It will allow real-time tracking of transactions and logistics and prevent tax evasion and document forgery. The solution will also help block the import of illegal items into the country[369].

The private sector has also begun to explore the impact of Blockchain on trade logistics. IBM has conducted two pilots using Blockchain within the context of trade logistics. One pilot was conducted with Maersk to track shipments of flowers from Kenya to Rotterdam. A second pilot was conducted with the Singapore Customs Administration, which incorporates customs in the supply chain. This suggests a real potential for integrating customs and border authorities with the supply chain to achieve significant benefits in terms of facilitation (Pugliatti & Gain, 2018). Blockchain also helps to develop more efficient trade finance solutions, often characterised by a high number of participants located in different places, a large volume of documents that need to be approved, countersigned by and delivered to various parties. Blockchain promises to reduce the time required for the completion of transactions and the associated costs, while increasing transparency between the participants and mitigating fraud risks (ReedSmith, 2019).

There has been a significant increase in banks' interest in the development and use of Blockchain technology in the context of trade finance operations. For example, Barclays and Wave, an innovative start-up company, executed a global trade transaction platform using distributed ledger technology. This platform, where trade documentation was processed with funds remitted via Swift, facilitated a letter of credit transaction in a very short time (ReedSmith, 2019).

Deutsche Bank, HSBC, KBC, Natixis, Rabobank, Société Générale and UniCredit have decided to cooperate to develop and commercialise a Digital Trade Chain consortium, the aim of which is to simplify trade finance for businesses[370]. The banks worked with IBM to assist with the development of the platform. The platform aims to fill financing gaps that hamper domestic and cross-border trade for small and medium-sized businesses (SMEs) by providing more transparent, simplified, efficient, secure and paperless trade financing services. The banks hope that, by conducting trade financing on a distributed ledger, transactions recorded on the ledger would promote accountability and also allow businesses easier access to their records and finances without the need to endure the more tedious and time-consuming traditional processes involved in authorising and clearing trade transactions.

Big Data, Artificial Intelligence and the IoT in regional integration

Given the growing numbers of commercial transactions and limited amount of available resources, it became impossible to inspect all the customs operations and identify all instances of fraud.

Big Data analytics and AI can help analysts derive powerful insights for risk profiling and management and therefore prevent customs fraud in Africa.

There are current use cases of platforms powering Big Data and AI, namely by customs services. Such platforms appear to be more efficient in fraud detection than traditional ones. For example, Brazil's customs fraud detection system, HARPIA, uses AI. This system was built through a partnership between Brazilian universities and the Brazilian Federal Revenue (Digiampietri et al., 2008).

The Korea Customs Service plans to establish a Big Data analysis centre to improve timeliness and accuracy in identifying illegal items. The agency will build a platform by combining data from all customs administration sources. The customs agency will also set up a customs clearance system powered by AI to improve screening and to examine high risk items. It will adopt AI-powered X-rays to prevent the entry of illegal items, including drugs, through deep learning technologies[371].

The IoT can help reduce the costs of logistics and therefore the cost of cross-border trade in Africa, especially when goods are transported by road. In the logistics domain, the IoT can enable companies to easily track driver activities, vehicle location and delivery status. Data collected by sensors can be analysed and help to ensure that more efficient route and delivery planning is done.

Self-driving vehicles, autonomous trucks and cranes can also be used in ports and optimise logistics costs. There have been testing applications, for example in Caofeidian and Yangshan in China and in Rotterdam[372].

Drones in regional integration

Drones can be very instrumental for development and regional security challenges across borders in Africa. Drones will certainly be an ideal solution for border surveillance, ensuring easy, faster and efficient means to collect data.

b

box 19

Kobo 360

Kobo360 is a technology company which is disrupting the $150 billion Africa logistics industry, which still mostly relies on telephones, opaque pricing and is full of expensive middlemen.

Kobo360 aggregates end-to-end haulage operations to help cargo owners, truck owners, drivers and cargo recipients achieve an efficient supply chain framework. With only a click of a button on their seamless mobile and web applications, cargo owners can simply request a truck of their choice and have their goods picked up and delivered to the required location through a robust, all-in-one logistics ecosystem.

Kobo360 uses Big Data, the IoT, machine learning and AI to reduce logistics frictions while empowering rural farmers to earn more by reducing farm wastage and helping manufacturers of all sizes to find new markets. Kobo enables unprecedented efficiency and cost reduction in the supply chain, providing 360-visibility while delivering products of all sizes safely, on time and in full.

Today, Kobo360 has moved 300 million kilogrammes of goods, supported 2,345 business and operates a total fleet of 10,879 vehicles.

Kobo360 was first launched in Nigeria and now has operations in Togo, Ghana and Kenya.

SOURCE Technopolis Group (2019), Nigeria country case

6.7.3 Current use cases of emerging technologies in regional integration in Africa

The use cases of emerging technologies to boost cross-border trade are still nascent in Africa. However, we identified interesting use cases in logistics, customs management and security. They are presented in the following sections. Box 19 and 20 highlight three of them. In Nigeria, Kobo 360 is a startup disrupting the logistics sector by using data from trucks, which is analysed using

b

box 20

Nigeria customs service

Nigeria Customs Service (NCS) operations are not automated and as such there are opportunities for corruption, which results in revenue losses. To remedy this issue, NCS has adopted the Oracle Blockchain Cloud Service.

Oracle Blockchain Cloud Service provides a platform which allows users to build their own networks and to quickly integrate with Oracle PaaS and third party applications that they already use, as well as other blockchain networks. It also enables users to deploy and run smart contracts and eliminates unnecessary processes.

The NCS intends to use Blockchain to document and track products manufactured locally, from the source of licensing and permits to distribution and points of sale.

The NCS is eyeing 50% growth in customs revenue due to the adoption of Blockchain technology.

SOURCE Technopolis Group (2019), Nigeria country case

BigData, the IoT and AI to reduce logistics frictions and to help manufacturers find new markets. The company provides effective monitoring solutions for logistics operators and explicitly aims to power trade and commerce across Africa.

The Nigerian Customs Service (NCS) is working on a cross-border trade platform project using smart contracts on Blockchain. This should facilitate intra-regional trade and allow traders to import products from neighbouring countries rather than faraway places.

Cameroon already uses drones for security purposes. The United States supported Cameroon with surveillance drones to support their fight against Boko Haram in 2015.

In South Africa, Transnet Port Terminals is moving to create an intelligent port terminal, fit for the future. Still in its infancy, the IntelliPort Project will leverage people, processes and technology into a seamless, intelligent platform to optimise business performance. The solution will integrate technology, data, people and equipment to create a Central Heterogeneous Artificial Port Intelligence (C.H.A.P-I). This Artificial Intelligence will support real-time, dynamic decision-making and predictive analytics while identifying and capitalising on opportunities to add value in other areas of the global supply chain.

6.7.4 Challenges, recommendations and prospects

In this section, we will discuss the challenges posed by the adoption of 4IR technologies in regional integration in Africa. We will also present the key limitations standing in the way of widespread adoption of 4IR technologies and recommend actions to unlock the potential of using 4IR technologies in regional integration. The challenges, recommendations and prospects are based on our analysis of information that we collected from stakeholders during field visits and interviews.

Blockchain

The application of Blockchain in cross-border trade presents some major challenges in aligning supply chain stakeholders and in regulatory aspects.

For Blockchain to contribute to an increase in cross-border trade in Africa, it would have to bring together all the participants in the supply chain from the original supplier of the goods to the final destination, as well as customs and other border services at the points of export or transit/trans-shipment. For this to happen, there must be an overwhelming incentive for everyone to participate and every node in the supply chain would need to have IT capabilities as well as access to the internet.

In addition, there are a number of legal implications of Blockchain that would have to be explored. First and foremost, the issue of jurisdiction and ownership in terms of where the data is stored and what are the reporting requirements to the authorities.

Drones, the IoT, Big Data and Artificial Intelligence

Key challenges in the adoption of drones, the IoT, Big Data and AI related to security and data management, connectivity and interoperability also apply here.

Regulation will be needed around the use of these technologies, for example regarding liability for accidents with autonomous equipment.

More transversally, there is an institutional capacity issue given that African countries have not been so successful in conducting complex e-government reforms.
In conclusion, apart from actions such as infrastructure and connectivity, key recommendations which can help unlock the potential of emerging technologies in regional integration in Africa are:

- reflect on the potential use of Blockchain in cross-border trade at the AU level in the context of the operationalisation of the AfCFTA;
- support pilot initiatives such as the one of the Nigerian Customs Service in order to learn lessons which can be shared across the continent with other customs services and contribute to improve public authorities' capabilities;
- explore partnerships with other customs services around the world which have been successfully using emerging technologies to alleviate fraud, counterfeiting and increase efficiency (Korea for example);
- provide support to start-ups and larger companies which are using emerging technologies in supply chains and logistics to make cross-border transportation across Africa easier and cheaper;
- enact proper regulation on emerging technologies which include, amongst other things, the following: data privacy and security, intellectual property rights on data collected, liability for accidents with autonomous equipment and responsibility for AI-powered decisions.

PART 04
unlocking the potential of the fourth industrial revolution in Africa

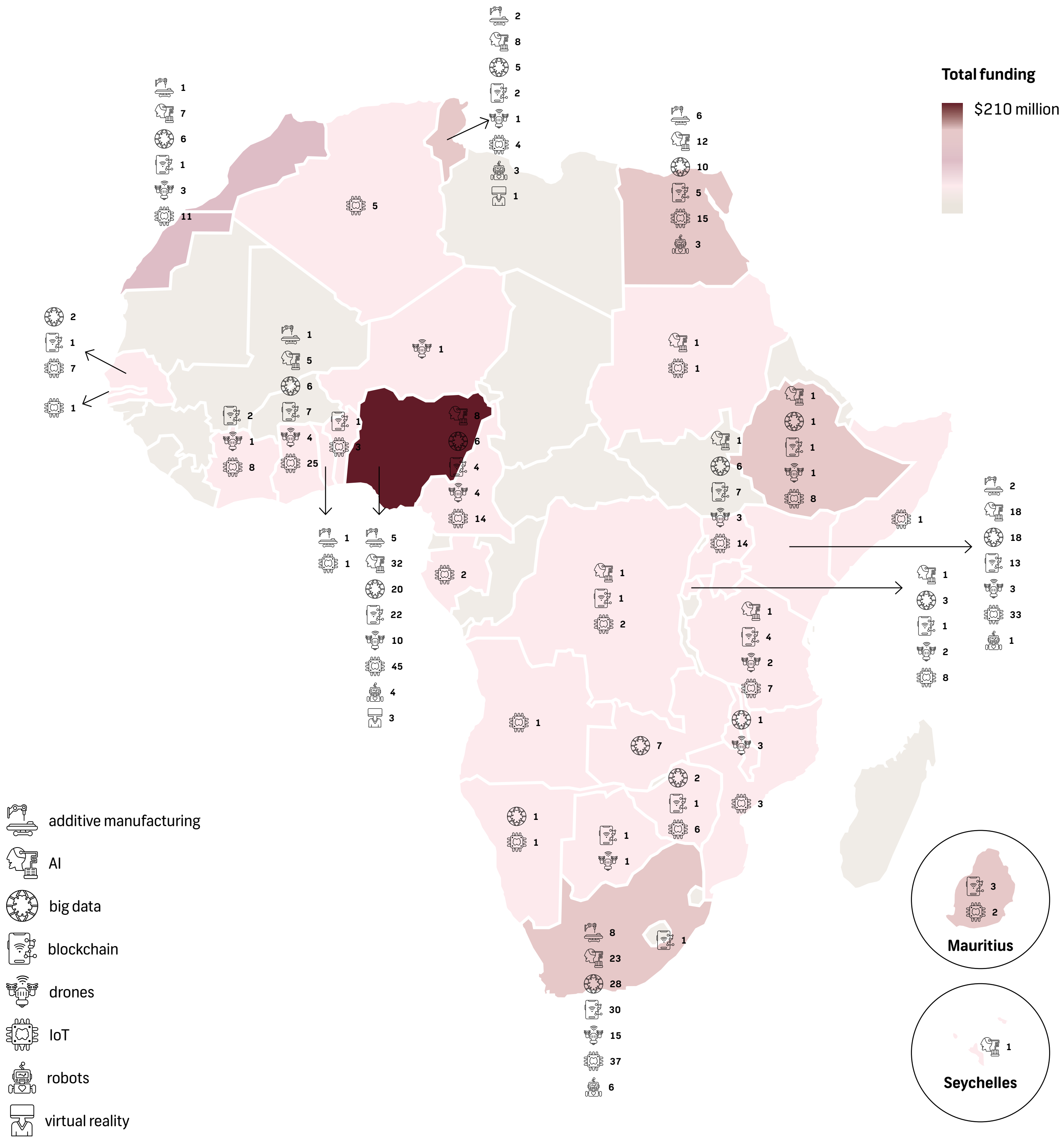
7
the business case for investing in the fourth industrial revolution in Africa

With a growing number of business users and end consumers, the 4IR is a reality in Africa. Studies dating back to 2015 have projected high growth in African start-up entrepreneurs in the field of technologies, having identified 3,500 new tech-related ventures and an anticipated $1 billion in venture capital by 2018 (WEF, 2015). In 2019, our study reveals that reality has surpassed projections, as approximately 6,500 technology start-ups were identified on the continent, among which around 10% develop 4IR applications (712 start-ups). They received $210m of venture capital investments out of the overall $2.27 billion investments in technology start-ups (see Figure 42).

f

figure 42

number of startups developing 4IR technologies in Africa



ADAPTED FROM
Technopolis Group (2019), based on desk research and interviews

7.1 THE MARKET TRENDS FOR 4IR TECHNOLOGIES IN AFRICA

There are considerable differences from one country to another. Even if, in some countries, 4IR technologies are beginning to take root in multiple sectors such as agriculture, energy, industry, services, healthcare, education, banking, entertainment and transport, other countries still display very low levels of preparedness and take-up of 4IR-related technologies. For example, Nigeria, South Africa, Kenya and Egypt, which are the economic leaders of Africa, are unsurprisingly the most dynamic in terms of creating 4IR start-ups and venture capital attractiveness.

On the supply side, as of today Africa cannot be characterised as a producer of 4IR technologies, but rather as an adopter of existing technologies which are produced and developed elsewhere in the world. These products and services are often developed by foreign corporations or start-ups (Thales, Airbus, Zipline) but also African corporations or start-ups (see use cases in previous chapters) to meet African demand.

Africa's large population, which is expected to double by 2050 to 2.4 billion, presents both a source of data to feed innovation in 4IR technologies as well as a valuable market. According to the present analysis, there is margin for growth on the supply side as proposed products and services in Africa stand way below the estimated demand levels.

While there is no data available on the turnover of companies proposing 4IR applications, looking at the current level of capital investments is a first step to approximate the current supply levels. Concerning the IoT applications, while they are steadily emerging in Africa, $110.8 million of venture capital was injected into African IoT start-ups by 2019, making it by far the most attractive 4IR technology for investors on the continent. The IoT market is projected to reach a value of $12.6 billion by 2021 in Africa and the Middle East, with a high potential for growth for producers of IoT applications on the African continent. As for Big Data, by 2019, $9.5 million worth of capital investments financed Big Data start-ups on the African continent (Crunchbase). In Kenya and Nigeria, IBM has estimated that up to 40% of businesses are in the planning stages of Big Data projects.

Additive Manufacturing (AM) is the second promising 4IR technology on the continent. About $47 million was invested in AM in Africa by 2019, according to Crunchbase. On the demand side, Africa's AM market represented $300 million in 2016 and is estimated to reach $1.3 billion by 2022.

Concerning AI, UAVs and Blockchain, the volume of these African markets is not yet known. However, there was $17.5 million worth of capital invested in African AI start-ups by 2019 (Crunchbase) while studies estimate global economic activity linked to AI to increase by 16% by 2030 compared to 2018. $7.9 million was injected in African start-ups developing drone applications by 2019 (Crunchbase), while the global market size will be worth $100 billion by 2020. Finally, $14.9 million was injected into African start-ups working with Blockchain in 2019 (Crunchbase) for a global market which is expected to grow by 62.1% between 2015 and 2025, by which time the market would be worth $16.3 billion.

Incidentally, start-ups proposing robot applications were the least funded by 2019 in Africa ($2.3 million).

7.2 ANTICIPATED IMPACTS

African public leaders and cooperation partners wonder if Africa can and should seize the opportunity of the Fourth Industrial Revolution or whether it is too risky to invest in it. Threats to the job market (see AfDB report on The Future of Work) and the risk that it will only benefit a few and leave aside the vast majority due to an entrenched technology divide are among the reasons for decision-makers to hesitate as regards whether they support the development of 4IR technologies. These hesitations are not new per se and represent the same concerns induced by any type of innovation. They remain very legitimate as the cost of investing in the 4IR as well as the benefits are not always clear to decision-makers.

The following tables presents the costs and benefits of the status quo (Table 13) and of adopting 4IR technologies (Table 14) and aims to provide the necessary information to feed any decision-making process:

table 13

general figures on the benefits and costs associated with the status quo

agriculture

Economic benefits/costs	Sustained dependency of the African continent on imports; Anticipated at $110 billion by 2025 ($65 billion in 2017)
Political benefits/costs	**No political risk taken in investing in 4IR take-up;** Sustained dependency of African countries to foreign nations; Increased risk for political instability fed by poverty, hunger and corruption
Societal benefits/costs	Increased unemployment rate (37% to 67% in 2018), increasing the proportion of the working poor; Increasing poverty and hunger in a context of rapid demographic growth (population x2 in 30 years' time) and stagnation of economic perspectives
Environmental benefits/costs	Increased pressure on lands with non-optimised consumption of fertilisers to feed two billion people

energy

Economic benefits/costs	Sustained dependency on fossil fuels ($17 billion a year)
Political benefits/costs	**No political risk taken in investing in 4IR take-up;** Sustained dependency of African countries to foreign nations; Increased risk for political instability fed by poverty, hunger and corruption
Societal benefits/costs	Increased unemployment rate (37% to 67% in 2018), increasing the proportion of the working poor; Increasing poverty and hunger in a context of rapid demographic growth (population x2 in 30 years' time) and stagnation of economic perspectives
Environmental benefits/costs	Increased contribution to pollution and climate change

industry

Economic benefits/costs	Stagnating GDP per capita ($700 GDP per capita, compared to $2,500 in Latin America and $3,400 in Asia)
Political benefits/costs	**No political risk taken in investing in 4IR take-up;** Sustained dependency of African countries to foreign nations; Increased risk for political instability fed by poverty, hunger and corruption
Societal benefits/costs	Increased unemployment rate (37% to 67% in 2018), increasing the proportion of the working poor; Increasing poverty and hunger in a context of rapid demographic growth (population x2 in 30 years' time) and stagnation of economic perspectives
Environmental benefits/costs	Steady contribution to pollution and climate change

regional integration

Economic benefits/costs	Sustained dependency on exports out of Africa
Political benefits/costs	**No political risk taken in investing in 4IR take-up;** Sustained dependency of African countries to foreign nations; Increased risk for political instability fed by poverty, hunger and corruption
Societal benefits/costs	Increased unemployment rate (37% to 67% in 2018), increasing the proportion of the working poor; Increasing poverty and hunger in a context of rapid demographic growth (population x2 in 30 years' time) and stagnation of economic perspectives
Environmental benefits/costs	Steady contribution to pollution and climate change

wellbeing

Economic benefits/costs	Stagnating quality and access to healthcare services; Rapid and hectic urbanisation resulting in a demographic, political and human disaster
Political benefits/costs	**No political risk taken in investing in 4IR take-up;** Sustained dependency of African countries to foreign nations; Increased risk for political instability fed by poverty, hunger and corruption
Societal benefits/costs	Increased unemployment rate (37% to 67% in 2018), increasing the proportion of the working poor; Increasing poverty and hunger in a context of rapid demographic growth (population x2 in 30 years' time) and stagnation of economic perspectives
Environmental benefits/costs	Increased pressure on natural and water resources in ever concentrated and expanding urban areas

SOURCE
Technopolis (2019), examples collected from several sources

table 14

general figures on the expected benefits, costs and threats of adopting 4IR technologies or producing these technologies

agriculture

Economic benefits/costs	**Transformation of the agriculture sector (65% of the world's remaining uncultivated arable land) and boosting of agro-industries (enhancing the value chain on the continent);** **Decreasing Africa's reliance on imports and increasing its self-reliance;** **Increasing productivity while providing technical support to small farmers, better security of land tenure, mitigating climate change effects, access to subsidised inputs;** Loss of low added value jobs is not that much of an issue as there are not so many prospects for automation in a five year time frame
Political benefits/costs	**Food independence of African nations;** **Improvement of hunger and poverty ratios**
Societal benefits/costs	**Creation of wealth of small farmers;** **Better access to agro-food products at cheaper prices (rather than import prices);** **Secured traceability of products;** **Settlement of disputes on land tenure**
Environmental benefits/costs	**Better use of fertilisers and chemicals;** Increased pressure on lands

energy

Economic benefits/costs	**Modernisation of energy utility companies (production and maintenance);** **Increasing energy access with pay as you go schemes (640 million Africans lacking access in 2017);Enhanced business for small businesses and companies relying on energy;** Costs of energy consumption of data centres; Costs of pay as you go schemes
Political benefits/costs	**Renewable energy independence of African nations;** **Improvement of poverty ratios**
Societal benefits/costs	**Increasing energy access with pay as you go schemes**
Environmental benefits/costs	**Adapted energy production and consumption, hence reduced effects on the environment;** Increased pressure on energy resources

industry

Economic benefits/costs	**Increased value added in value chains;** **Increased productivity by up to 40% with AI, and overall between 10% and 30% over the next decade[373];** **Diversification of production;** **Attractiveness to market-seeking FDI from big technology companies (Facebook, Uber, Oracle) and technology spill over;** **Reducing the cost for tooling;** **Improving the balance of trade (consumer market of over 200 million Africans);** High cost of necessary infrastructure (data centres, roads for transportation); Uneven access to data; Cost of upskilling workers and users; High bureaucracy and taxes
Political benefits/costs	**Improvement of GDP per capita ratios**
Societal benefits/costs	**New jobs for the booming youth population by leveraging its demographic opportunity in STEM, data analysis, computer science and engineering, digital-mechanical engineers and business** **operations' data analysts, user interface experts, digital creators, designers and markets;** **Dramatically raising per capita incomes;** **High-skilled jobs;** **Entrepreneurship development;** **Improving worker conditions;** Concentration of wealth creation on a happy few; Threats of job loss (41% of all work activities in South Africa are susceptible to automation, as are 44% in Ethiopia, 46% in Nigeria, 48% in Mauritius, 52% in Kenya and 53% in Angola)
Environmental benefits/costs	**Better use of natural resources;** Increased pressure on natural resources

regional integration

Economic benefits/costs	**Increasing intra-region trade (14.4% of total African trade; 59% of total Asia trade);** **Boosting cross-border investments ($12 billion in 2018);** Cost of setting up the necessary legal frameworks, rule of origins markers and systems and incentives; Cost of upgrading the e-governance systems across African countries for interoperability
Political benefits/costs	**Creation of new economic inter-dependencies, thus new political equilibrium between African nations;** **Improvement of interregional financial markets, thus improved access to finance**
Societal benefits/costs	**Access to goods and services produced in Africa which enhances citizens' feeling of belonging to the African nation**
Environmental benefits/costs	**Shortening production and transport circuits from international to inter-African routes, hence reduced effects of trade on the environment;** Increased pollution due to transportation of goods

wellbeing

Economic benefits/costs	**Technology can leap ahead of education: Sub-Saharan Africa is already ripe with education innovations[374]. The e-learning market in Africa is growing and will be worth $1.4 billion by 2022[375]; increasing access to education for 200 million aged between 15 and 24);** **Increasing health indicators (some of the worst in the world) and quality and access of health care services;** Entry cost for technologies; Cost of setting up connectivity and inter-operability in rural areas; Cost of setting up the necessary legal frameworks; Algorithmic bias in AI and machine learning being accused of being a 'black box' of incomprehensible decision models[376]
Political benefits/costs	**Building high quality good governance systems;** **Making the provision of public services and good governance more participatory and democratic[377] (real-time feedback on the impact of public policies);** **Improvement of education and health indicators**
Societal benefits/costs	**Access to better quality of living;**
Environmental benefits/costs	**Avoiding some transport through tele-services**

SOURCE
Technopolis Group (2019)

7.3 GAPS IN KEY FACTORS TO UNLOCK THE 4IR

A number of key factors play a major role in enabling African countries to enter and benefit from the 4IR. Among these are an environment for healthy competition between technology companies, the existence of technological skills among workers and accountability of governments to citizens' online rights. Adopting a systemic view of these factors leads one to dissect the overall entrepreneurial ecosystem into six factors which allow enterprises to realise their growth potential:

- Markets (availability and cost of digital infrastructure, availability and cost of internet access, digital selling points and value chains, level of financial inclusion);
- Human capital (presence of engineers and developers, level of qualification of developers, level of competency in management and accountancy, creativity, presence of a qualified workforce);
- Policy and regulation (R&D institutes, legislation for firms, fiscal system, foreign business settlement, support for the digital industry, strategy and stability for entrepreneurship);
- Culture (entrepreneurial activities, entrepreneurship culture, risk adversity or propensity for risk, confidence, social network use, role models) and support systems (technology hubs, networks and professional associations, events and conferences);
- Accessibility and diversity of financing (business angels, venture capital, loans, capital markets, foreign investments);
- Infrastructure (internet speed, energy, logistics and transport).

In Africa, the level of performance and maturity of these entrepreneurial ecosystems vary. The World Intellectual Property Organization (WIPO) 2018 report on Global Innovation (CITE) provides an analysis of the strengths and weaknesses in innovation drivers' indicators for 28 African countries. Overall, based on the ratio of strengths to weaknesses (number of strengths divided by the number of weaknesses by indicators) of the GII report, African countries show strengths in innovation linkages, regulatory environment, credit and education and are associated with weaknesses in knowledge workers, online creativity, information and communication technologies and human capital in R&D.

The Technopolis 2019 survey (see Appendix A) indicates that telecommunication infrastructure, national security regulation and institutions' presence and quality are considered by at least 30% of the respondents to represent a strength in the countries surveyed. Meanwhile, governance transparency, sectoral regulation and local education systems (adapted to business) represent the widest scope for improvement (according to more than 85% of the respondents) (see Figure 43).

Following a Ward's method cluster analysis (see Appendix C), African countries can be grouped into six clusters.

- South Africa, Rwanda, Namibia, Botswana and Mauritius are showing strengths especially in human capital, institutions as well as in market sophistication;
- Senegal, Algeria, Egypt, Morocco and Tunisia are showing strengths in infrastructure and knowledge and technology outputs;
- Nigeria, Benin, Guinea, Zimbabwe, Zambia and Madagascar have strong creative outputs and business sophistication strengths but low indicators' values in human capital;
- Ghana, Mozambique, Malawi, Cameroon and Mali are rather average and cannot be defined as a group of African innovators or followers (last tier) although they show strengths in business sophistication and weaknesses in institutions;
- Uganda, Kenya and Tanzania are characterised by weaknesses in all domains, notably infrastructure, institutions and knowledge and technology outputs;
- Niger, Burkina Faso, Côte d'Ivoire and Togo show the lowest values for indicators in business sophistication, creative outputs and market sophistication.

The following paragraphs qualitatively explore the gaps in the key factors to be addressed in order to unlock the 4IR in Africa. They are presented by order of importance.

7.3.1 Human capital development

Key challenges related to human capital development to unlock the 4IR in Africa include:

Low rate of high-skilled workforce

While the 4IR may be disruptive to many occupations, it is also projected to create a wide range of new jobs in fields such as STEM, data analysis, computer science and engineering. There will be strong demand for professionals who can blend digital and STEM skills with traditional subject expertise, such as digital mechanical engineers and business operations data analysts, who combine deep knowledge of their industry with the latest analytical tools to quickly adapt business strategies. There will also be more demand for user interface experts, who can facilitate seamless human-machine interaction[378]. For Sub-Saharan Africa, long-term benefits can be found in the promotion of home-grown African digital creators, designers and makers, not just digital deliverers[379].

On average, Sub-Saharan Africa exhibits a high-skilled employment share of just 6%, in contrast to the global average of 24%. Some of the most common types of high-skilled employment on the continent are mainly non-STEM related[380]. Since developing 4IR technologies (or even applying them at a high level) requires STEM skills competencies, this is a challenge which needs to be addressed (see box 21).

A lack of entrepreneurial skills

Entrepreneurs in Africa are often lacking technical and managerial skills as to how to develop successful business models and run a business and may lack the soft skills needed to effectively pitch to investors (speaking their language). There is a need for more targeted capacity-building (e.g. through mentors).

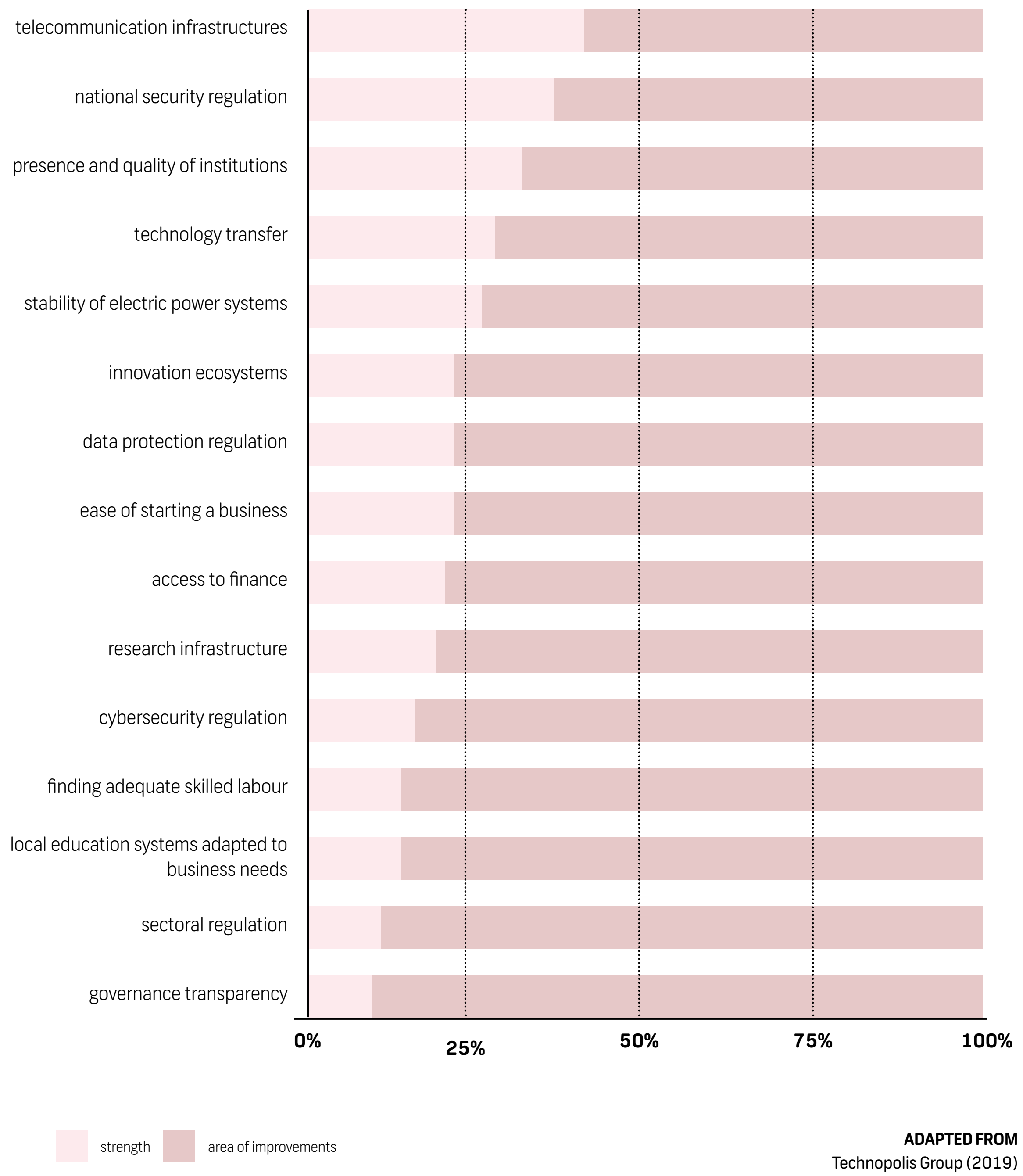
Gender imbalance

Three quarters of employed women in Sub-Saharan Africa are in informal employment, compared to 61% of men[381]. Only 17% of students pursuing degrees in science and technology subjects in Kenya are women, as are 24% in Tanzania, 18% in Uganda and 27% in Rwanda[382]. Therefore, women are at risk of staying at the margin of 4IR development in Africa.

f

figure 43

technology adoption preconditions: characteristics



ADAPTED FROM
Technopolis Group (2019)

b

box 21

Various initiatives have been carried out across the continent to bridge the digital and skills gap in the context of the 4IR.

For example, a preschool reform in rural Mozambique had positive effects on socio-behavioural development: participating children were better at interacting with others, following directions and regulating their emotions under stress[384].

Kenya is addressing the challenge of schools without computers by converting a bus into a mobile and solar-powered ICT classroom. The Craft Silicon Foundation's Mobile Lab is equipped with 34 computers and supporting technology and it has been used by over 6,000 young people in slums. Youth interested in further advancing their ICT skills as well as their communication, business and entrepreneurial skills can also pursue training opportunities at the Craft Silicon Foundation Centre in Nairobi, Kenya[385].

The City of Johannesburg is working with Microsoft South Africa to teach one million residents the basics of digital literacy through the city's public libraries[386].

Eneza, a private sector programme operating in Ghana, Kenya, Tanzania, and Zimbabwe provides students with mobile access to quizzes connected to the national curriculum. After completing the assessments via text, students receive feedback and mini-lessons targeting areas where they need support. Teachers use their phones to track student progress, identifying students' strengths and weaknesses. The results of such interventions are promising. Internal evaluation results showed that students who used Eneza increased their scores by 5% compared to a control group[387].

The Democratic Republic of Congo and Tanzania offer 'bridging' arrangements that enable vocational graduates to continue to university[388].

The Faculty of Architecture and Environmental Design at the College of Science and Technology-University of Rwanda has promoted learning strategies that include open-ended assessment, feedback opportunities and a progressive curriculum that balances academic challenge with student support. These approaches have improved the critical thinking skills of students[389].

The Youth for Technology has established a 3D printing academy for girls in Kenya and Nigeria. It is aimed at providing opportunities for young women to design and 3D-print their own products and assist them in developing their entrepreneurial skills to bring these products to market[390].

Lack of data for long term planning and reform

Reliable and timely data on the structure of employment and skills in Sub-Saharan Africa is difficult to obtain. There is scarce information on the number of existing jobs, of newly created jobs, on the needs of the industry and of unfilled vacancies in specific sectors, undermining efforts to systematically assess and develop the continent's skills base, notably related to 4IR[383]. Unlocking the potential of 4IR will include relying on data that can inform the design of sound policies in the field of human capital development.

7.3.2 Governance, policy and regulations

Overall, lack of awareness and uninformed public opinion, obsolete governance systems and low levels of human capital development represent the biggest challenges in adopting and absorbing the emerging 4IR technologies on the African continent. Many African countries have struggled to implement telecom reforms, primarily as a result of misalignment with the institutional endowments of countries, the lack of state co-ordination and implementation, and conflicting institutional arrangements which impact their ability to perform the critical functions on which the wider ICT ecosystem depend. Numerous regulatory and governance challenges related to the 4IR lie ahead:

Uneven digital inclusion

Connectivity and access to new technologies remain tenuous for many African countries and citizens. Many people in Africa are unable to benefit from the opportunities offered by the emerging technologies due to poor connectivity, high cost of access and low levels of human capital development. In Africa, the shift to data-driven governance and regulations is being delayed in some parts because so many Africans are either unconnected[391] or barely connected (meaning if they are online, they can only afford low-quality connections or devices or to be online for limited periods). Many of the Africans that are connected remain mere passive consumers rather than making productive use of the internet and other emerging technologies[392]. If not governed cautiously, these new technologies bear risks that will exacerbate the digital divide within and across the African continent.

Siloed approach and inadequacy of the current governance and regulatory framework

Emerging technologies can have multiple uses (for instance Blockchain can be used for a different number of uses, ranging from financial transactions to management of intellectual property assets), and thus require different governance and regulatory structures. Innovations become interdisciplinary and technologies converge. For instance, if a ride-hailing company begins to offer food delivery, it can also be overseen by public health stakeholders and not just transportation authorities. Platforms are different from traditional operators in the markets as they are made up of numerous relevant markets that have multiple 'sides', each with specific competition dynamics. Similarly, Over the Top (OTT) products and services can appear to be vertically integrated when in fact they are complementary and competition enhancing[393]. These kinds of challenges require equally adaptive regulators able to manage such complexity in the public interest. Less developed countries in Africa may, for example, be less capable of managing the risks that accompany emerging technologies than their wealthier counterparts or even of shaping their own governance agendas where global resources are concerned[394].

Another interesting example of a siloed and inadequate approach in regulating 4IR technologies is drone regulation across Africa. According to Devex, only 14 out of 54 African countries currently have drone regulations in place. Some of these regulations are stringent and restrictive, prohibit civilian use of drones and lack licensing and certification standards. These constricting regulations might negatively influence the development of precision agriculture on the continent, which in turn can ultimately have a negative impact on addressing climate change in Africa[395].

Spatial and temporal issues related to the governance and regulatory framework

Emerging technologies transcend national and regional boundaries. Effective governance models need to take into account different jurisdictional issues that might arise in this respect. With digital and e-commerce platforms increasingly underpinning global and cross-border trade and commerce, the integration of traditionally distinct areas of regulation has become increasingly important. Findings from a study by i2i and RIA (2018) identified more than 300 unique digital platforms in Ghana, Kenya, Nigeria, Rwanda, South Africa, Tanzania, Uganda and Zambia that match providers and consumers of goods and services (also known as multi-sided platforms) with 4.2 million workers across these countries[396]. These platforms operate in diverse economic sectors, including transportation, online shopping, asset sharing and professional services. More than 80% of the platforms originate in their countries, with workers only making up only 3% or 4% of internet users.

The emerging technologies of today have a highly uncertain future. Governments might overregulate and build stringent governance structures that might suffocate the development of these technologies. On the other hand, few governments tend to adopt laissez faire approaches and do nothing. Emerging technologies tend to develop quickly and disruptively. On the other hand, public policy cycles may take years to develop.

Competition

The emerging technologies of the 4IR are likely to increasingly challenge the effectiveness of traditionally siloed legal approaches to dealing with anti-competitive practices through competition and sector regulation. Digital dominance, for instance, is difficult (if not impossible) to address using competition law alone. It requires competition and data protection authorities to have a clear understanding of not only the way multisided digital platforms work from an economics and technical perspective, but also the significance of data for fuelling their dominance and potentially hampering future innovation and the development of emerging technologies[397].

Digital privacy encroachment

The digital personas and the personal data of African citizens are being used to feed into, improve, and alter emerging technologies and their privacy is therefore at risk to the same degree as active data subjects in the global north[398]. The Zimbabwean government, for instance, recently concluded a partnership agreement with a Chinese start-up (which, in turn, supplies products to the Chinese government) to unroll a facial recognition programme in the country[399]. While such public-private partnerships might reduce algorithmic bias, they tend to be accompanied with insufficient oversight to prevent the potential abuse of accompanying surveillance capabilities. Using Africans as data sources (with or without their informed consent) might have far-reaching ethical, legal and political implications for the way people are or will be seen and treated by not only emerging technologies and the private sector often responsible for them, but also by African governments[400]. An illustrative example is IoT devices that use microphones to enable voice commands and are constantly recording information to detect an instruction, while storing data in the cloud.

Contradictory responses to governance challenges

Libertarian notions of freedom and openness that underpin emerging technologies have clashed with offline realities of national control and coercion, such as internet shutdowns, to manage dissent. In Cameroon, for instance, the government tried to curb potential dissent on social media platforms following protests against linguistic, political and economic discrimination by shutting down or slowing down the internet in the country's south west and north west areas for an estimated 230 days between 2017 and 2018[401]. Elsewhere, in Uganda, the government introduced a daily social media levy of UGX 200 (about $0.05) in July 2018 to "tame 'idle talk' online and raise revenue". Applicable to more than 60 online platforms (including Facebook, WhatsApp and Twitter), more than 2.5 million Ugandans have stopped their internet subscriptions since the levy was introduced[402].

7.3.3 ICT markets

On the supply side, the reduced extent and speed of the internet hinders the take-up of 4IR technologies[403]. As highlighted in the PwC country Connectivity Index, which measures current connectivity levels, quality of connectivity and growth momentum, connectivity varies widely across the continent: while South Africa ranks highly with 83%, Kenya and Côte d'Ivoire perform well (with respectively 75% and 74%), Nigeria stands out as a market with cost of mobile broadband services being too high and the DRC and Madagascar are markets with poor bandwidth availability and very expensive broadband services.

However, more often than not, 4IR technologies do not require substantial investments in software, platforms or systems. Ever-increasing processing power and storage capacity are expanding the quantity and quality of data that is available to those who are connected. The adoption of these technologies can be low-cost provided that highly-effective governance and regulatory systems are in place. Additionally, the pricing data from the RIA African Mobile Pricing (RAMP) index shows, overall, falling prices of access to data in 46 African countries.

On the demand side, however, a large number of individuals and households do not use the internet or do not have devices used to access the internet. RIA's After Access Survey[404], conducted in 2017 by Research ICT Africa, finds that South Africa has the highest internet penetration rate in Africa at 45%. Predictably, Rwanda and Mozambique, countries with amongst the lowest GNI per capita among the surveyed countries, have the lowest internet use. Perhaps surprising considering its 90% 3G coverage as a result of a substantial World Bank-funded supply-side intervention and it being held up as a model to the rest of Africa, is Rwanda, with the lowest internet penetration at only 9%, and the biggest internet gender gap of the African countries surveyed at 60% - despite being the African country at the top of the GSMA's Mobile Gender Gap Report 2018[405] and the WEF Global Gender Gap Report[406]. Low GNI, however, does not necessarily mean the lowest internet penetration or gender gap. Tanzania, one of the least developed counties surveyed, has 13% internet penetration and a comparative gender gap of only 32%, with less than half of the rural population not connected to the internet.

In fact, potential consumers of use cases are mainly the working poor and in the informal sector. This may hinder large scale and widespread adoption of 4IR technologies unless the applications are designed accordingly (cheap, easy, simple to access) to meet the specificity of this consumer base.

b

box 22

Digital government initiatives and open data initiatives are public policy and governance instruments that offer opportunities for African governments to harness the power of the 4IR. Several African governments, such as Morocco, Ghana, Kenya and Tanzania, have already created central data portals as part of their open government implementation. Another good practice example at the regional level is the Africa Information Highway, an open data portal that curates open data initiatives in Africa. One such initiative is the Kenyan Huduma program, under which the government of Kenya is advancing citizen-centred public service delivery through a variety of channels, including deploying digital technology and establishing citizen service centres across the country. Since 2017, Ghana has been investing in improving online delivery of services through the initiatives of e-Ghana and e-Transform. In Uganda, leaders can identify trending concerns or urgent matters and immediately take action where needed using data gathered by IBM text analytics and machine learning. This free SMS-based reporting tool called U-report allows Ugandan youth to communicate with their government and community leaders using their cell phones. The deployment of technologies for open government and citizen engagement in countries in which there is not a democratic culture of engagement, transparency or accountability or where people are simply excluded from digital participation by lack of access or affordability or where participation is limited by irrational regressive taxation such as social networking, mobile money and blogging taxes, is likely to have little positive impact either for economic and political participation or innovation.

7.3.4 ENTREPRENEURIAL AND INNOVATION SUPPORT SYSTEMS

African innovation ecosystems face a range of challenges that make it difficult for entrepreneurs and 4IR innovations to thrive.

Weak technology transfer systems and lack of R&D investment

Africa is showing a limited ability to absorb external knowledge while it is a starting point to fill the technology gap. Universities are still too focused on publications and admit a gap in their capacities to transfer knowledge. Elsewhere, public funding is suboptimal.

Technology hubs, incubators and networks of mentors are yet to acquire a good level of professionalism

These newly-developed support structures are often headed by people lacking their own start-up experience. Many technology hubs also struggle with maintaining a pipeline of high-quality start-ups that they can support, which is also linked to a lack of comprehensive and reliable market data. As a consequence, many incubation support programmes are underdeveloped and not sufficiently targeted, with many technology hubs not providing much more than co-working space for start-ups, as confirmed by several of the African incubators interviewed. Another challenge is that African technology hubs tend to cluster in specific regions and cities, leaving entrepreneurs in large parts of the continent cut off from such support systems. Some hubs are not integrated into wider networks, making cross-country partnership within Africa more difficult. This isolation, in turn, makes it difficult for best practices on how to run incubators and hubs to spread.

Another problem afflicting many incubators concerns their operating model and source of funding, which is aggravated by the high cost of internet connections and other infrastructure for these organisations. In contrast to Europe, where many incubators are run on a for profit basis or grew out of and are linked to universities and research institutes, African hubs tend to rely on grants from international donors, which can fluctuate, and cannot count on their own governments' support. Lack of finance is also an issue for technology hubs wishing to carry out technology transfer. This lack of a stable source of finance and sustainable business models means that technology hubs come and go in Africa.

7.3.5 ACCESS AND DIVERSITY OF FINANCING

Key challenges related to access and diversity of financing to unlock the 4IR in Africa include:

On the supply side, a lack of financing, either through debt or equity. African businesses, in particular MSMEs, face problems to access debt financing. African businesses cannot compete with the cheap costs of capital in many developed countries, particularly in the current post-crisis quantitative easing period. Africa currently has declining FDI levels which only account for a small share of world inward FDI.

The large-scale infrastructure projects required to unlock the 4IR cannot be completely financed by the public. However, mobilising finance for long-term private infrastructure from private investors requires political stability and government guarantees to lower investor hurdle rates to levels where projects can be realised.

On the demand side, a high rate of unbanked Africans. While mobile money boosted the number of Africans with access to financial services, three out of five African adults are still unbanked. Moreover, women are still more likely to be unbanked. There are still significant hurdles to access to finance for people working in the informal sector.

7.3.6 Infrastructure

Poor infrastructure is one of the key obstacles to investment and growth in Africa. In 2015, for example, nearly 600 million people in Sub-Saharan Africa lacked access to electricity[407]. But while Africa's infrastructure still lags behind that of other developing regions, significant progress has been made: Africa's annual investment in infrastructure has doubled to around $80 billion a year since the beginning of this century[408]. That represents a big opportunity for investors and entrepreneurs with the imagination to help solve Africa's infrastructure challenges.

However, there are areas in which the African continent demonstrates concrete opportunities for infrastructure under Africa 4.0. These include the opportunity to install the latest ICT infrastructure, bypassing the need to upgrade existing, outdated infrastructure at great cost. Along these lines, a recent article by academics at the University of Pretoria in South Africa suggests a hybrid approach of building new infrastructure and decoupling existing infrastructure as a strategy for transformation in medium cities[409]. This is particularly linked to the realisation of smart cities in light of Agenda 2063, the African Union's strategic framework for the socio-economic transformation of the African continent[410].

7.4 SCENARIOS

There are three paths or scenarios for Africa and the 4IR:

- The first is to maintain the status quo and miss the revolution, as Africa did for the previous ones. The points raised within the present study seem to discard this scenario;
- The second path is to bypass the 4IR. Even though the path is paved with difficulties to be overcome, Africa has more to benefit than to lose from undergoing the necessary steps to unlock the 4IR;
- The third path is to become a producer of 4IR technologies. This path is rather ambitious and not foreseeable in the medium term (five years' time) as it would require the human capital gap to be bridged (which requires at least five years). Ambitious countries may still opt for this scenario and start to build their human capital now to see beyond the 4IR.

8 recommendations

The Fourth Industrial Revolution is essential for Africa as the continent is experiencing increasingly intense environmental, social and demographic pressures as well as stagnating industrial production. Climate change is certainly the most pressing of these as it threatens the very survival of populations. Ever increasing social inequalities and demographic growth threatens the progress made thus far in reaching the Sustainable Development Goals (SDGs). African countries have too much to lose by not embarking on the 4IR train.

8.1 WHY ACT TO UNLOCK THE FOURTH INDUSTRIAL REVOLUTION IN AFRICA?

The 4IR presents various opportunities and challenges. Many businesses are certainly ready to make the most of the opportunities offered by the 4IR in Africa (see Technopolis Survey to African Private Sector, 2019).

Legal developments on the continent indicate that the collection, use and processing of data is a cross-cutting concern of the 4IR. This has a considerable impact on an array of traditionally isolated legal disciplines, including data protection and justice, cybersecurity, intellectual property rights, the regulation of digital financial services, competition law, e-trade and taxation and technology transfer law. Traditional governance models face a number of challenges in addressing the disruptive nature of the emerging technologies, ranging from the sheer volume of obsolete rules and issues in coordination to regulatory silos.

8.2 WHAT NEEDS TO BE DONE?

8.2.1 For African policy makers and regulators

Develop a united vision to seize the opportunities of the 4IR, coming in the wave of the Continental Free Trade Area in March 2018, the launch of Smart Africa in 2013[411] and Agenda 2063 as an even grander vision.

Bolster or redesign existing governance institutions to better prepare for challenges posed by data circulation. New institutions may also need to be created to ensure the safety and security of organisations and individuals. This will include developing frameworks and skills to oversee both the technical management of critical facilities and infrastructure that are increasingly exposed to sophisticated and threatening malware, as well as the processing of the substantial amounts of data being generated to fuel the 4IR.

To address these 4IR challenges, there is a need for far greater state coordination across different economic and social sectors and for public and private sector collaboration to build globally competitive digital economies and societies. Institutional arrangements will need to be reviewed and the traditional regulation of nationally licensed and regulated players and industries must be aligned with global internet governance systems.

African governments should create adequate legal and ethical frameworks and guidelines to ensure that AI systems are not used for malign purposes, but rather for the economic and human-centred advancement of African societies. While doing so, governments can rely on good practices developed by countries around the globe, such as the European Commission's approach to setting ethical guidelines for AI[412].

Develop collaborative and adaptive regulation. Besides public-private interplays and other collaborative governance approaches, greater regulatory agility and insight are needed to manage digital exclusion and tensions between the different policy objectives of competing emerging technologies. This will need to be reconciled with safeguarding the public and social value of the internet through the extension of the Spectrum Commons, unlicensed spectrum and social use spectrum. In developed and developing countries alike, most spectrum is largely unused outside main metropolitan areas. In the sharing economy, voluntary infrastructure-sharing by operators is already occurring today. These types of collaborative approaches need to be embraced by governments from a critical resource management perspective. Enabling secondary spectrum use would allow for dynamic spectrum sharing, which operates at a fraction of the cost of the GSM network and could be deployed in new business models in the largely unused spectrum in rural areas. Such an approach could instantly provide low-cost, high-quality bandwidth.

With the long-term evolution of 5G underway, African governments need to ensure that the potential of 5G technology which operates within a spectrum-sharing environment with data offloading to proprietorial and open public Wi-Fi is harnessed for public purposes and not just for niche commercial applications. Accepting that large numbers of Africans will not be able to afford this (even if GSM broadband prices were cost-based), deploying spectrum to create and extend the Commons (unlicensed spectrum) would be a key enabler of the 4IR. Extending commercially available public Wi-Fi from elite urban areas, possibly through deploying poorly utilised universal service funds or other public resources to all public spaces, offers a viable way of increasing the intensity of use in urban areas and enhancing network effects that would contribute to more inclusive digital development.

Seek harmonization of data protection frameworks at regional level (REC) through compatibility between national legislations, based on a set of a core agreed data protection principles[413], still considering national differences in terms of existing frameworks, or advancement in technological innovation. It is recommended for regional organisations to focus on unifying initiatives that are internationally compatible, instead of pursuing multiple endeavours[414].

Start to prepare the next generation Africa 4.0 workforce. It is evident that digital skills are becoming essential for the jobs of today and tomorrow. In the 21st century, digital literacy is a skill that each citizen must have. From digital literacy to computer science education, these skills can open the door to greater economic opportunities in the workplace of the future. Unfortunately, these skills are currently beyond the reach of too many young people across Africa.

Initiatives aiming to reduce the digital gap are flourishing across the continent and entail collaboration between the private sector (technology providers), governments and non-profit organisations to empower African youth to realise their full potential. However, digital literacy must be incorporated in a more structural manner by revising curricula and including digital courses as a key requirement in primary and secondary education. This implies equipping schools with computers and the internet and employing teachers who can deliver digital content courses. African governments should earnestly commit themselves to these investments, which are not a luxury but rather a necessity to prepare the 4IR era. The opportunity cost of missing the 4IR train is high and will include future investments in the workforce, competitiveness disadvantages, inefficiencies and lack of productivity.

Enhancing quality education in STEM and Industry 4.0-related fields is strategic if Africa wants to yield the maximum value-added of the Fourth Industrial Revolution. STEM-oriented economies perform strongly on a number of economic indicators[415]. Currently, there is a shortage of trained scientists in Africa. Many African countries are investing in STEM research and education, with the African Union encouraging its members to spend 1% of their GDP on STEM. This is a domain where the AfBD can valuably complement the efforts by launching an Africa 4.0 Centres of Excellence Initiative. This initiative can identify, label and support Regional Centres of Excellence in STEM and Technologies 4.0. Those Centres of Excellence must provide cutting-edge training, be strongly linked to the private sector, have strong R&D components, be integrated and exposed to the worldwide R&D ecosystem and build network-sharing knowledge. These Centres of Excellence will offer fertile terrain where applications of 4IR technologies can be developed and tested, in order to be monetised in the private sector. They will concentrate R&D efforts across countries rather than individual efforts with less probability of scalability. The Centres of Excellence should be linked to existing technology hubs and start-up incubators and accelerators to make sure that trained youth find employment in enterprises working on 4IR solutions. A specific focus on gender is a must.

Nurture inclusive institutions favouring and promoting widespread innovation to adopt 4IR technologies in productive and service sectors. Given the cross-cutting nature of 4IR technologies, policy and governance approaches can no longer be designed in a vacuum or in silos by focusing on a particular sector or supply-side issues alone, as has been done in the past. Policy success will be as dependent on demand-side interventions to ensure sufficient absorptive capacity of new technologies. Mechanisms to ensure the affordability of devices and data services for end users and affordable bandwidth and energy will be a critical input of 4IR technologies. Development of relevant local content and applications in local languages, along with the enhancement of citizens' digital literacy skills, but also a higher level of engineering, coding and economic and creative capacity are all vital to creating an enabling environment necessary to harness the opportunities offered by 4IR. Currently, these conditions are highly uneven between and within regions in Africa. Without active steps to address existing inequalities offline, inequalities will simply be replicated, or even amplified, online.

African governments should draw on good practices in 4IR governance and public policymaking that are being deployed by governments around the globe. These practices include the establishment of policy labs, regulatory sandboxes, crowdsourced public policymaking and private-public partnerships.

8.2.2 For business associations

Raise awareness and provide information about technologies' potential and markets. Many entrepreneurs or companies do not yet know the advantages and drawbacks of adopting 4IR technologies. They would certainly benefit from having access to detailed information on technologies and their market potential.

Increase investment in training. Following the example of the Morocco Federation of ICT and offshoring Technologies (APEBI), business associations should launch measures to favour the integration of foreign competencies in ICT and invest in specific training. This can take the form of converting scientific bachelor's degrees in IT with a nine month period of training or in the form of private partnership training sessions following the Harambee model.

8.2.3 For development partners

Raise awareness among African governments that sustained public investment in scientific research and development (R&D) is necessary. It is equally important to nurture a strong start-up culture and to ensure the protection of intellectual property. A continent-wide forum on the 4IR would be beneficial, as well as a series of national forums.

Finance research projects on the impact of the 4IR on the African economies and societies. These could in turn feed approaches supporting the unlocking of 4IR technologies at regional or national level as well as the rationale for awareness-raising.

Support the creation of regional R&D centres and foster linkages with international R&D centres and regional and international cooperation as well as exchange programmes (preventing the need to reinvent the wheel) where countries can learn from more established players. There should be a focus on demonstration projects of use cases of 4IR technologies in specific sectors and countries with the greatest potential for successful disruption in Africa. This should focus on specific intervention areas, rather than trying to bring the 4IR to the whole continent. Some examples are AI & healthcare, drones & agriculture, Blockchain & FinTech, IoT & smart cities.

Support pilot projects for opening up data held in the public and private sector using public-private partnerships. For instance, corporates may lobby the government to open up sectors such as healthcare to new technology by sharing data if there is money to be made not only for the corporates/start-ups but also for the government, by increasing efficiency within healthcare for example. An example is the cooperation between NGHub and the Medical Research Institute in Nigeria.

Offer finance using blended finance and innovative financial instruments such as guarantees to help lower the hurdle rates of international investors and increase their participation on the African continent, thus leveraging additional capital. Instruments such as local currency lending are also important in reducing exchange rate risks and volatility.

Providing a stable investment climate does not only include actions to improve capital markets and reduce political risk (e.g. through currency manipulation or capital controls) but also requires strong signalling and demonstrator effects from international financial institutions. Existing pilot projects funded by transnational corporations, global funds and development banks signal potential opportunities to the private sector. Moreover, it is important that finance be channelled to 4IR-ready and 'future-proof' infrastructure such as renewable technologies or ICT-ready road infrastructure to avoid locked-in capital and expensive retrofitting for obsolete infrastructure.

Lowering the barriers for foreign direct investment thanks to the digitalisation of international payments and internationally-connected African capital markets is also vital. It is, however, also important to focus on intra-African and domestic investments to avoid the risk that international investors withdraw equity. Also, technology-seeking outward FDI can allow African businesses to access 4IR technologies.

8.3 AfDB POTENTIAL INTERVENTIONS

8.3.1 Using elements of 4IR in AfDB operations

This section assesses the current initiatives within the AfDB to develop systems and the capacity of staff for the 4IR[416].

The AfDB is working on a new initiative called Digital Transformation, whose aim is to improve the efficiency of the bank. AfDB teams were invited to see the World Bank's Innovation Lab (The World Bank innovation lab produces novel 4IR-related technologies for World Bank projects in client countries), after which the AfDB team decided to work on Blockchain, although this has yet to be implemented. Currently, there is no committee that works on leading innovation for operations within the AfDB.

AfDB does not have a CIO but rather a Director of Corporate ICT. This current position does not allow for a sufficiently forward-looking agenda. Despite considerable interest in the unit to incorporate new 4IR technologies, resources are currently directed towards the maintenance of existing systems. In 2017, the board approved the Corporate Digital Strategy of the Bank, prepared by the corporate IT department. One of the core components of the strategy is to revamp the Bank's SAP platform to support the effective implementation of the Development and Business Delivery Model (DBDM). Wakanda is a cross department project that will implement the new system that will allow the Bank to make its processes more transparent and efficient, as expected by the shareholders.

r recommendations for AfDB

RECOMMENDATIONS FOR AfDB INTERNAL OPERATIONS (MAKING AfDB A SMART BANK)

An audacious digital agenda for the AfDB in its internal operations is vital to foster a greater appreciation of digital technologies. The agenda should include piloting of elements of the 4IR, while managing expectations and risks given the high-risk and untested nature of these technologies. Digitalisation is a precursor to the 4IR, so having an aggressive digital agenda within the AfDB would not only make the bank smarter and more efficient but lay the foundations for it to gradually incorporate 4IR technologies. For instance, the Asian Development Bank (ADB) has undertaken the digital agenda 2030[417] to revamp the bank's digital ecosystem.

The AfDB could benefit from including CIO functions in the current Director of Corporate ICT position. This will allow for flexibility to innovate within the unit and also design and deploy forward-looking systems for the Bank. Certainly, resource commitment for fulfilling such a mandate is a prerequisite. As has been stressed in this chapter, the AfDB should be careful of the hype surrounding the 4IR. While the Bank should invest in internal operations to become a smart bank, it ought to develop proper risk management and mitigation plans and, more importantly, a mechanism to capture and learn lessons from any failures. 4IR technologies are transformative and setbacks should not dampen the commitment to use these technologies for benefit in the long run.

Efforts could be directed towards the following areas, for example:

- Internal procurement for greater transparency, using Blockchain technology;
- Big Data analytics criteria for country loan assessments and debt sustainability (risk analysis);

Greater collaboration between the corporate ICT team and other (mainly client-serving) units of the bank will help to foster greater experimentation with 4IR technologies as part of the AfDB's core business. The World Bank's IT Solutions Lab offers interesting insights. The lab (mentioned earlier in this chapter) creates Technology Alert System programme provides an illustration of how such a mechanism works at a global level. Employing those principles, the experts within the corporate IT department could not only create a mechanism to keep themselves up-to-date on emerging issues in 4IR technologies but also disseminate key relevant findings to the entire AfDB. Such dissemination via 'Brown Bag Lunches', periodic (quarterly, for example) newsletters or seminars will not only help to break 'silo' mentalities but also create greater knowledge exchange. It is stressed here that management may have concerns that such activities may prevent corporate ICT from focusing on its core tasks, but experience suggests that such a risk is very limited and the upside in terms of a more integrated bank is much higher.

8.3.2 Adopting a stage by stage approach to developing specific products for financing 4IR technologies

This section analyses new loan products and technical assistance programs that the AfDB could consider designing, aimed at the 4IR needs of client countries.

There are currently no concerted efforts to develop a deeper understanding among staff on the 4IR and its implications for development. While there have been certain attempts to create communities of practice (COP) on innovation, these have not been funded or received high-level patronage. While digital transformation is indeed high on the agenda of the AfDB, increased awareness of the disruptive potential of 4IR technologies is needed. The bank is providing resources to train staff in digitalisation. Digitalisation is high on the agenda of the Vice President of AfDB, and similar priority should be given to the 4IR.

There is a growing realisation in many units that standard loan safeguards and frameworks may need to be revisited in the coming years in view of the 4IR. For instance, the environment and sustainability safeguard framework for loans would need to be reevaluated for projects involving the 4IR. For that matter, 4IR-related technologies may be needed to address many of the safeguard concerns.

The AfDB has a relatively small portfolio of policy loans (which trigger disbursement upon the client country

achieving certain benchmarks– typically regulatory or legislative) compared to investment loans. At this stage, client demand for 4IR-related loans is extremely weak to non-existent, both from governments and the private sector. There is, however, a demand for loans related to digital transformation more broadly. Investments in funds that focus on technology-enabled businesses in Africa is a very new trend. Only a handful of Venture Capital funds have started operation. Therefore, it is still too early to analyse their performance as it is a new asset class in Africa. This is a new activity for the AfDB too and so extending these types of investments in the 4IR may seem premature.

ICT and digitalisation are not included in the High Five priorities of the Bank as a separate priority but instead fall under industrialisation. At this stage, there is no committee that is working on pushing the innovation agenda. This can be explained by two factors. First is that the topic is new and has not yet received sufficient attention. Secondly, possible loans or projects related to this are unlikely to be big ticket items. Hence, unless a massive impact is envisaged using relatively small funding operations, the bank is unlikely to view this topic as a priority.

The AfDB does not have a risk-finance mechanism in the way that the Inter-American Development (IADB) has MIF (Multilateral Investment Funds, recently renamed as IADB Labs). IADB has a dedicated operation called MIF which provides small grants to non-government actors in client countries to help establish an innovation ecosystem. Small technology-based firms and start-ups that benefit from such funding become a pipeline for IIC (IADB Investment Corp), the private sector arm of IADB. AfDB does not have such a dedicated operation.

The AfDB is relying on other multilaterals (such as ITU for the topic of AI policies in health) and donors to develop knowledge products. While this is indeed a wise strategy and an optimal use of resources, the AfDB would benefit from generating these knowledge products specifically for the African context. This is because the AfDB may have unique insights into the ecosystem of these countries as regards their digital preparedness and also because the AfDB has the convening power as well as the financial wherewithal to implement solutions. There is currently no initiative to approach donors for obtaining financing for 4IR related projects. There are some programmes, however, such as the Drones in Agriculture Fund. That being said, there is no central initiative for digitalisation and industrialisation.

RECOMMENDATIONS TO DEVELOP CAPACITY WITHIN THE AFDB ON THE 4IR TO BETTER RESPOND TO CLIENT NEEDS. The AfDB has a training centre for regional member countries (RMCs) called the African Development Institute (ADI). This institute provides training to officials and ministries on a variety of topics (e.g. debt, financial management etc.) and some training has included digitalisation/4IR. However, given the enormous need in Africa for digitalisation, the scope of such training should be substantially increased. This would engender greater appreciation of the 4IR in client countries, which could foster demand for AfDB interventions in the digital space and subsequently for 4IR.

The ADI should also develop knowledge products aimed at cross-cutting issues and country- and sector-specific issues. This report assesses many sectors and countries and provides insights that should be built on while assessing the digitalisation ecosystem of specific countries and industries and technology maturity. These knowledge products could involve universal issues such as principles of data privacy/security laws as well as country-specific regulatory issues.

Given that the 4IR is still at an early stage, it may not be prudent for the AfDB to attempt to establish an MIF type entity. However specific pilots modelled broadly on MIF principles should be attempted by team leaders in selected countries. The focus of such interventions should especially be tailored to broadening the adoption of digital technologies more generally (at least initially) as they are the precursors to 4IR technologies. The lessons learnt from these experiences can then inform the need for an MIF-type operation for innovation more generally or 4IR more specifically in the coming years. Since the generation of a good pipeline of investable projects is a key challenge in Africa, such a staged approach may be fruitful. In existing interventions and programmes such as *Jobs for Youth*[418] trust fund activities, incorporating activities that have 4IR elements (supporting entrepreneurs using 4IR technologies) could be useful and serve as pilots.

Many types of financing products would be needed to prepare the ecosystem of the 4IR. The AfDB would need to experiment with more policy loans in the digital space on topics such as data privacy and protection as such policies form the basis of data monetisation, which is key for 4IR. Naturally, investment loans also have their place within the creation of infrastructure for digitalisation. It is stressed that, while policies and regulations on almost all economic development issues are critical, it is also imperative on data-related matters. To quote the cliché: data is the new oil in the 4IR. Hence, it stands to reason that data policy related issues should be key to preparing client countries for 4IR. Developing capacity within the AfDB on these matters is therefore critical and the aforementioned COPs ought to start to prepare these data-related topics.

The Bank's strategy unit may want to consider proposing the inclusion of digitalisation as a standalone priority (in the High Five) in the coming years or increase the salience of digitalisation within the industrialisation priority. A gradual and measured approach for client projects (lending as well as Technical Assistance) may be more prudent given the specific challenges in Africa and the risk involved with emerging 4IR technologies.

An establishment of community of practice (COP) within the AfDB which has visible support from the president's office would be critical in marshalling the AfDB staff concerned to improve their understanding of 4IR. The COP would serve to not only share experiences within the AfDB but also to develop linkages with the international knowledge stock. Given the rapid advances in 4IR technologies, such a mechanism to keep abreast of the latest thinking would be ideal without having to commit substantial resources. The COP can then, in the coming years, develop a body of thinking on new products and projects in the 4IR that could be implemented in client countries.

A programme that incentivises innovation within the AfDB and fosters experimentation with 4IR technologies may be useful. For instance, the World Bank's SME Launchpad[419] gives grants (on a competitive basis) of up to $50,000 to World Bank team leaders who wish to introduce a novel component within an existing project or initiate a small pilot. Such low-cost interventions not only remove the stigma of experimenting with something new and possibly failing, they also help to obtain vital insights and, in many cases, lead to bigger interventions by the World Bank.

While the AfDB should be wary of the hype surrounding 4IR it should earnestly begin the task of including 4IR in its various offerings (loans to governments, technical assistance, venture financing etc.) in interventions for clients. Given the untested nature of these technologies, appropriate risk management and, more importantly, learning from failures, is critical. Greater emphasis on digitalisation is imperative as it creates the foundation for the 4IR. 4IR technologies are transformative and setbacks should not dampen the commitment to use these technologies in the long term. Showcasing success stories and disseminating the lessons learnt from failures should form part of the overall strategy.

APPENDIXES

A
results of the survey on unlocking the potential for the fourth industrial revolution (4IR) in Africa

The survey consisted of fifteen questions on the profile of the respondent, the number of organisations that they incubate or support, their assessment of the use of the 4IR technologies, their assessment of the readiness of African businesses to adopt them, their assessment of the potential impact of those technologies on different socio-economic aspects and of the area of improvement in domestic sectors and markets and finally on possible recommendations to policy makers and stakeholders. The question list is as follows:

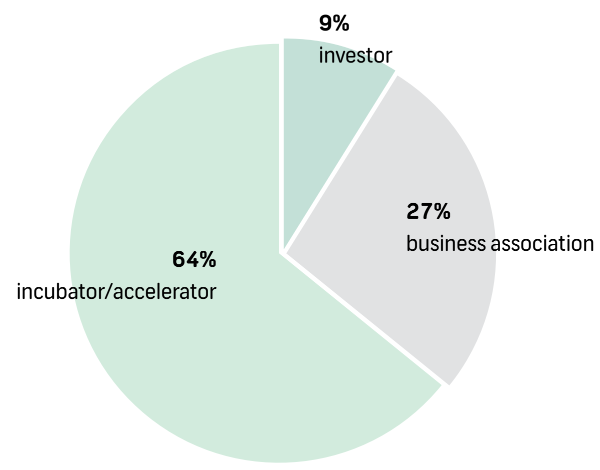
1. Which type of organisation are you?
   What is the name of your organisation?
2. What is your geographical coverage?
   How many companies do you have in your portfolio since the creation of your organisation?
3. In which sector(s) do those firms operate?
4. Which are the technologies that those firms are using or planning to use?
5. Can you provide examples of application of those technologies?
6. What is your assessment of the readiness of the firms for the adoption of these technologies?
7. To your opinion, what is the potential impact of the technologies on [socio-economic aspects]?
8. Can you characterize whether the pre-conditions contained in the following table are strengths or areas of improvement in the countries you are covering?
9. Concerning the areas of improvement, you selected, could you specify exactly what are the obstacles?
10. To your opinion, what would be the costs of NOT taking up the technologies by domain?
11. To your knowledge, who are the main business stakeholders of the technologies in the countries you are covering?
12. What are your recommendations to donors and to African governments in order to improve the adoption of 4th industrial revolution concerning [socio-economic aspects]?
13. What project(s) would you foresee in order to fill a gap for the adoption of the 4th industrial revolution's technologies?

The survey was sent to 32 African business association, 288 incubators and 104 investors. There was a total of 33 respondents, representing a response rate of 25% for the first group (9 business associations), 7% for the second group (21 incubators) and 2% for the third group (3 investors).

The small number of respondents do not allow us to proceed to complex statistical analysis (of the responses and country trends) without being subjected to a significant sample bias. Hence, the analysis of the survey results is purely descriptive.

Question 01
Which type of organisation are you?

Figure A1
Respondents by type of organisations (n=32)



Question 03
Number of respondents by geographical area
The geographical distribution of the respondents across the western, northern, eastern, southern and central part of the African continent is balanced between 15% (for central Africa) and 27% (for southern Africa). A total of thirteen countries are represented: Cameroon, Democratic Republic of Congo, Egypt, Ethiopia, Gabon, Côte d'Ivoire,

Kenya, Morocco, Namibia, Nigeria, Senegal, South Africa and Tanzania.

Figure A2
Respondents by geographical area (n=33)

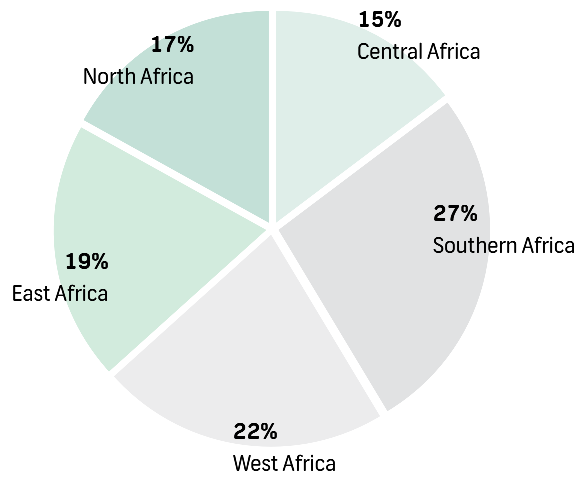
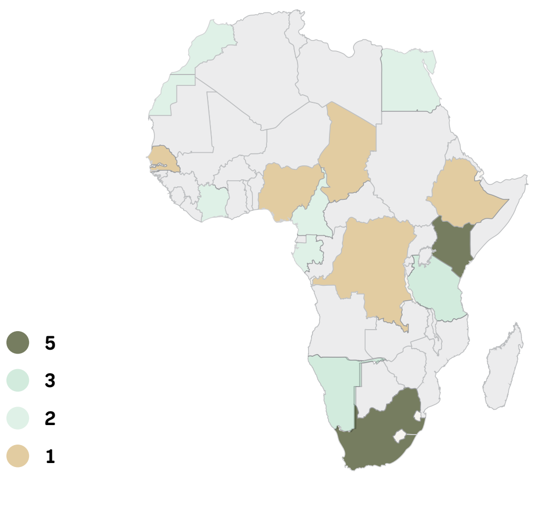


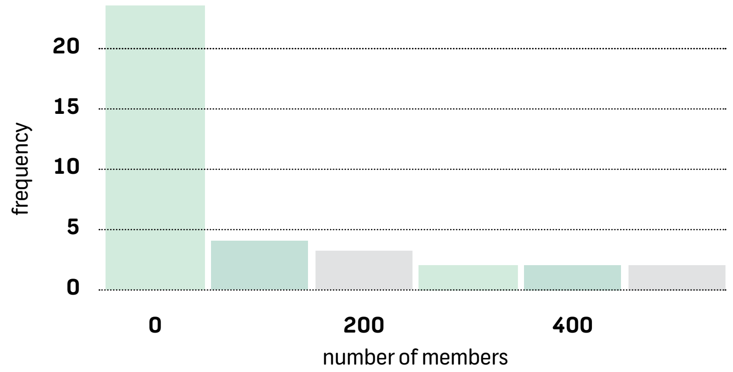
Figure A3
Number of respondents by country



Question 04
How many companies do you have in your portfolio since the creation of your organisation? (n=33)

Business associations, incubators and investors in our sample have an average number of 38 members with the highest number being 2160.

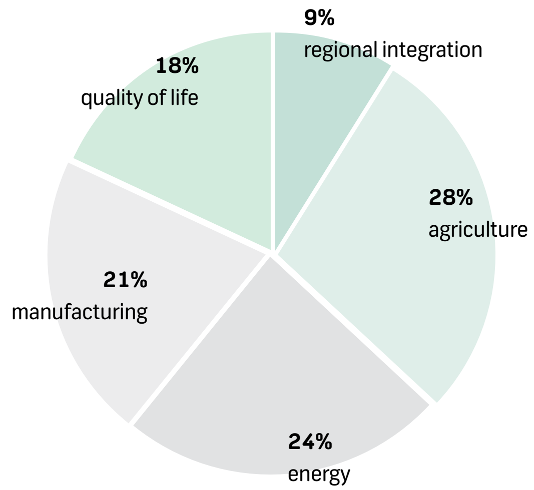
Figure A4
Histogram of respondents' number of members (three outliers over 500 are deleted in order to bypass cluttering issues)



Question 05
In which sector(s) do those firms operate? (n=33)

The main sector — represented by the respondents' organisation — is the agricultural sector, followed by the energy sector, manufacturing, quality of life and finally regional integration. As respondents were able to select multiple sectors (diversified portfolios of companies imply multiple sector specialisation) the sum of the number of respondents by sector exceeds 33.

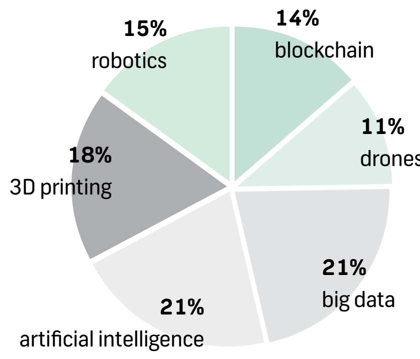
Figure A5
Sectoral distribution



Question 06
Technologies planned (n=33)

In our respondents' sample, about 21% of associated organisations apply AI and Big Data technologies in their activity, followed by 3D printing (18%), Robotics (15%), Blockchain (14%) and Drones (11%).

Figure A6
Use of technologies by companies



Question 07
Can you provide examples of application of those technologies?

Respondents were asked to provide examples of applications of technologies of the fourth industrial revolution by their members (for business associations), by their incubated start-ups (for incubators) and by companies in their portfolio (for investors). The table below synthesises the given answers by category (when possible).

Table A1
Use of technologies by companies

3D printing
Prototyping
Proof of concept
Production of replacement and spare parts
Marketing purposes
Health products (e.g. protheses)
Educational program

Artificial intelligence
Educational program
Recruitment, talent matching, HR management
Trend analysis: customers, health records, credit, risks
Logistics (e.g. fleet management)
Identification of biological anomalies (e.g. plants)

Blockchain
Information sharing in transport & logistics
Anti-piracy, cybersecurity, client data protection
Traceability
Payments, online banking, FinTech, transfers, e-commerce

Big data
Trend analysis and decision support, customer analytics
Process optimization
Data gleaning/mining
FinTech
Cybersecurity

Big data
Trend analysis and decision support, customer analytics
Process optimization
Data mining gleaning/mining
FinTech
Cyber-security

Drones
Last mile delivery
Emergency transportation (e.g. health sector)
Cadastral management, inspection of agricultural and mining sites
Robotics
Automation of engineering and financial tasks
Educational programs
Manufacturing and food processing
Large-scale production

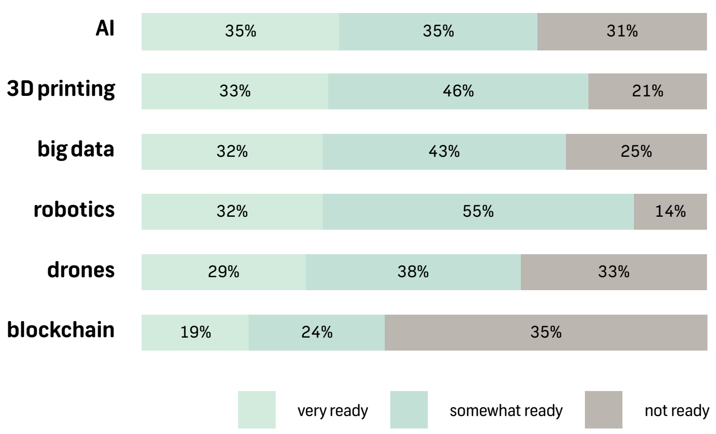
Question 08
Technology readiness (n=32)
According to the respondent's own assessments, the technologies Artificial Intelligence, 3D printing and Big Data are associated with a "high readiness" index (according to 36% of the responses obtained), while Blockchain, Drones have the highest "not ready" scores.

It is worth noting that Artificial Intelligence is also associated to "non-readiness" by some respondents of our sample, showing great variance throughout the African continent.

Figure A7 illustrates the results. The first stacked bar reads: 35% of respondents indicated that companies in their respective countries were ready to apply the Artificial Intelligence technology, while 35% answered they were "somewhat ready" and 31% that they were not ready.

Question 09
To your opinion, what is the potential impact of the technologies on: (n=33)
Respondents were asked about their opinion on the impact of the fourth industrial revolution' technologies on a set of institutional and socio-economic aspects.

Figure A7
Readiness assessment



According to them (see figure A8), employment structure would be deeply positively affected by those technologies. Low skilled jobs would face an important decline while high skilled jobs would become more prevalent.

Other impacts include an important raise of African and international competitiveness and entrepreneurship while government services transparency and access might be strongly improved. Human development would also know a positive evolution in terms of health, education and gender equality.

Figure A8 illustrates the share of respondents impact assessments (strong decline, decline, growth, strong growth) of the fourth industrial revolution' technologies.

Question 10
Can you characterize whether the pre-conditions contained in the following table are strengths or areas of improvement in the countries you are covering? (Select one option per pre-condition, n=33)
The results in figure A9 indicate that telecommunication infrastructures, national security regulation and institutions' presence and quality are considered by at least 30% of the respondents to represent a strength in the investigated countries. Meanwhile, governance transparency, sectoral regulation and local education system (adapted to business) represent the widest scope for improvement (according to more than 85% of the respondents). The results, however, for the "cyber security regulation" should be taken with caution since only six respondents provided answers to this question.

Figure A8
Potential impacts of 4IR technologies

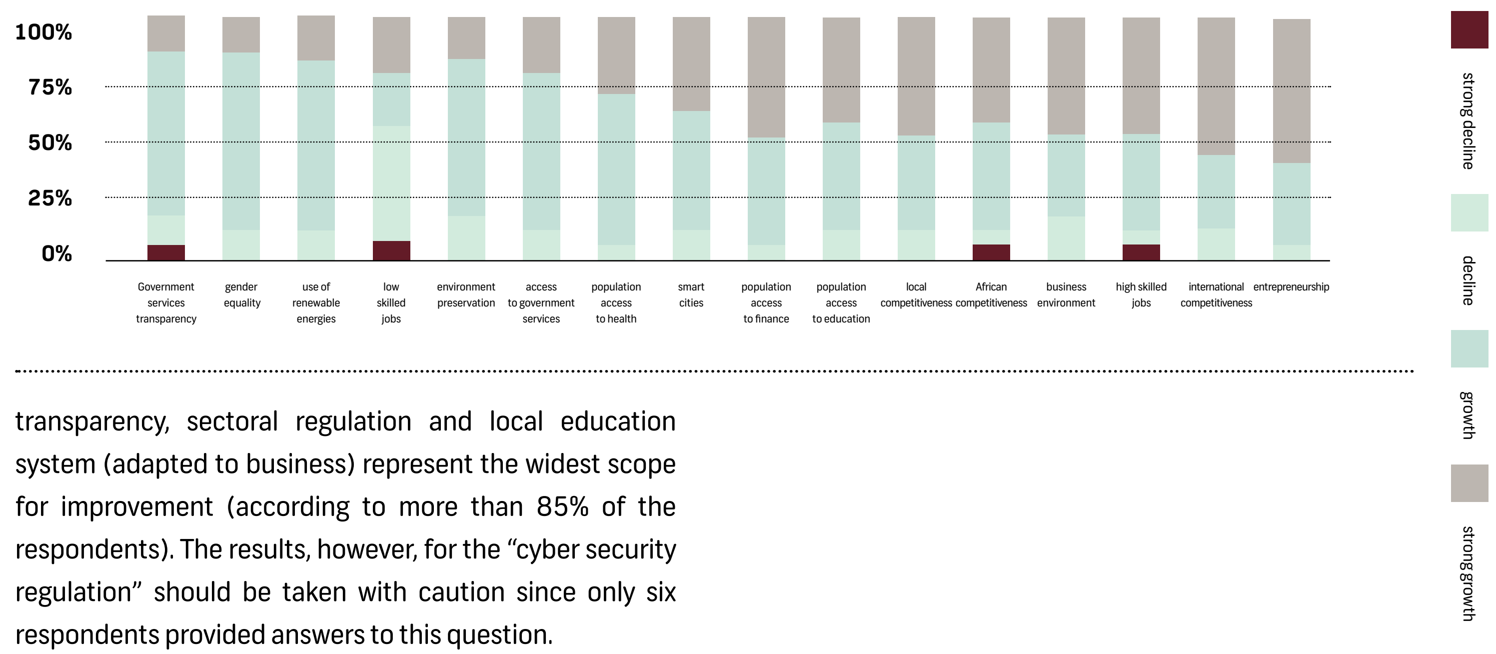
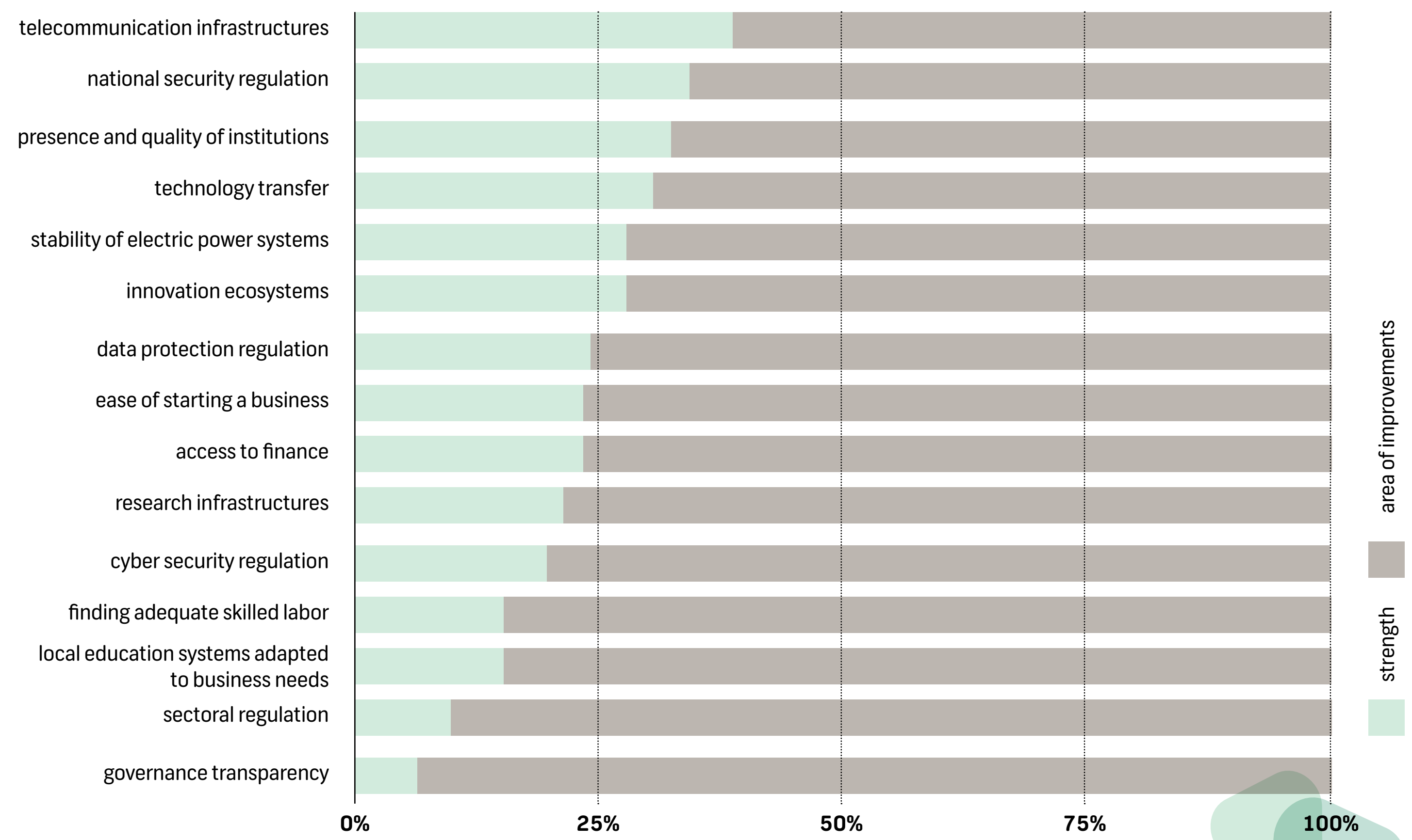


Figure A9
Technology adoption preconditions characteristics



Question 11

Concerning the areas of improvement, you selected, could you specify exactly what are the obstacles?

Respondents were also expected to provide suggestions for areas of improvement, or in other words, to list potential obstacles to the implementation of technologies of the fourth industrial revolution.

- First, respondents stated that it is still highly difficult to gain access to finance, mostly due to: risk-averse managers, lacks of equity and venture capital in Africa, high interest rates along with costly provision of collaterals as requirement, lack of long-term credit provision or even guarantee fund. It has been also addressed that financial institutions lack confidence in early-stages start-ups and that they might be reluctant to provide financing due to high-interest cap in some cases. Finally, communication issues may also explain part of the access to finance issues according to some respondents: banks advertise little about offers to start-ups and some entrepreneurs may not be aware of their availability;
- Respondents stressed that local education systems might not always been adapted to business needs due to a limited entrepreneurial education, to limited funding in education, to the fact that training is more theory-oriented than applied. The lack of interaction between industries and universities is also given as an obstacle to effective job market matching. Also, in some francophone countries, it has been mentioned that "school curricula for the most part do not include courses on entrepreneurship or entrepreneurial culture" and that "young people [mostly] study to become civil servants";
- The atomicity of institutions, the constantly changing regulatory requirements and the bureaucratic red tape are often cited as obstacles to start a business, although the low capital requirement is seen as very positive;
- Finding adequate skilled labour is made hard by the brain drain and by the presence of multinational companies that generate unfair competition. The educational system produces poor output or "not industries adequate" skills. It might be costly to employers to train new recruits;
- Regarding sectoral regulation, respondents often welcome government efforts, but they also criticize fragmentation, opacity, unpredictability of changes as well as the poor enforcement of those regulations. Also, sectoral regulation adds to the red tape issue mentioned previously as well as constantly changing requirements and resources spent on managing bureaucratic regulatory systems (and navigating through them);
- The "very low awareness and know-how" in the data protection area is often cited as a significant limitation. Respondents stated that data protection is often not taken seriously and that regulation is (still) not implemented or enforced. Also mentioned is the lack of cybersecurity standards and adequate tools. Even if they are seen positively by most respondents, some regulations are described as restrictive for data-intensive projects;
- Regarding regulation on national security, low awareness and low transparency, over regulated, sometimes too weak due to corruption. There also seems to be a lack of sensibilisation and experience in cyber security regulation;
- Presence and quality of institutions: The institutions are present, but their accountability is an issue. They are described as limited and constrained by finance. Also, informality and corruption has made them compromised;
- On governance transparency: corruption is a major issue, with a lack of consequence management and of consistent policy. Respondents recommend digitalising some processes. Also, since some laws can be passed in haste, with no clarity or direction, businesses could be functioning illegally (despite the efforts to comply with regulations);
- On telecommunications infrastructures: Good access to broadband internet, mobile and LTE solutions and fibre coming online in the larger cities but very low connectivity in rural areas. According to a respondent, access to some services might even be blocked. The internet provider market is also deemed monopolistic or oligopolistic in nature and therefore access is sometimes very costly. However, mobile internet is considered to have a high broadband speed;
- Stability of electric power systems is characterised as one of the main obstacles to the application of the technologies of the 4IR: unstable power supply and too many electric outages ("of high and low voltages, can sometimes last up to five hours and therefore spook both domestic and foreign investors"). Electricity charges are also considered too expensive for start-ups. A lot of people have resorted to alternative sources like solar power. In one case it is said that the national power system does not have the resources for the "last miles", i.e. in order to connect remote area to the grid;
- On research infrastructures: they are negatively affected by economic downturn, shortage of funds and of skills, limited access to data and transparency about the results of their research;
- Regarding the innovation ecosystems, the main issue is the low connectivity between local players and international hubs or ecosystems. There seems to be an overall lack of "entrepreneurial culture", though some progress made in the last decade (according to the respondents). One respondent answered that "There is no coherent developed and implemented system of innovation, everything seems fragmented and existing platforms suffer from a lack of required skill". When present (as assessed by some respondents) communication is troublesome and there seems to be no long-term perspective;
- There is low awareness on the potential of technology transfers. It is said to be "not yet widely known, understood or accepted". A respondent also stated that her/his university attempted to pilot a TTO (technology transfer office) but "failed because of low funding, lack of skills to drive and low knowledge from executives". It may, however, be improving in some African countries as it is taking place in learning institutions but mostly hubs and makerspaces are enhancing them. According to one respondent there seem to be "very little to no cross-pollination of ideas across the continent or with other nations facing similar challenges".

Question 12

To your opinion, what would be the costs of NOT taking up the technologies by domain? (Please provide an answer per domain. For example: lack of competitivity, quality of end products, etc.)

Respondents were asked to give their opinion on the costs that would be raised if these technologies were not adopted on the African continent. A summary of their suggestions by sector is given below.

- In the agricultural sector, avoiding these technologies could lead to a lack of professional training (adapted to the sector needs) and be an obstacle to the sector modernisation. As impacts, respondents mention the decrease of food production and quality, hunger (food shortage), the increase of smallholder farmers poverty, the lack of competitiveness and productivity, and the increase of impacts of climate change;
- According to respondents, not taking up these technologies could also imply a severe increase of prices and a lack of production in the energy sector. It could also affect the manufacturing sector and have grave consequences on the economy such as waste of energy resources, lack of growth and set barriers to human development;
- In the manufacturing sector, the main impact would be the lack of competitiveness, which could lead to an important decrease of the production and an increase of unemployment;
- The health sector could be deeply affected. According to respondents, it could lead to a shortage of drugs and services, and to a lack of health insurance. Higher prices and volatility would affect the healthcare system, which would also face a decrease of service quality;
- According to respondents, these technologies are essential to the education sector and to acquire new teaching methods, information and tools. Without them, impacts could be lack of education and professional skills, which would lead to lack of competitiveness and to an increase of poverty;
- In the financial sector, not taking up these technologies would make it difficult to access new products and raise the gap in inequality. Without access to credit and funding, new entrepreneurs wouldn't be able

to emerge, and growth could be deeply affected in the continent;

- In the renewable energy sector, impacts would be similar to the energy sector. The sector would face an important lack of competitiveness and production. Moreover, it would lead to a slowdown in the development of new clean energies, which could mitigate climate change;
- In terms of smart transportation, not adopting these technologies could lead to a decrease of return on investments on infrastructure spending and to a lack of modernisation. Impacts would be lack of competitiveness, degradation of the transportation infrastructure, increase of pollution and decrease of economic growth;
- According to respondents, these technologies are very important for the housing sector, which would face a lack of competitiveness and a decrease of return on investment on housing without them. Impacts would be increase of housing prices and the continent could face an important proliferation of slums and informal housing;
- In terms of regional integration, respondents mention a loss of competitiveness, a decrease of exports and an increase of imported products in local consumption. It could lead to a decrease of GDP growth and generate low regional cooperation.

Question 13

To your knowledge, who are the main business stakeholders of the technologies in the countries you are covering?

Table A2 contains the name of the main business stakeholders of the 4IR technologies in countries that respondents are covering.

Table A2

Cameroon

Geographical area	Central Africa
3D printing	Ongola FabLab
Artificial intelligence	Wecash UpCyclop
Block chain	Wecash Up
Big data	–
Drones	Algo Drone Holding
Robotics	–

Egypt

Geographical area	North Africa
3D printing	Fab lab Egypt, Etba3ly, AmTech
Artificial intelligence	Kengine
Block chain	–
Big data	Fawry
Drones	–
Robotics	–

Ethiopia

Geographical area	East Africa
3D printing	MeTec
Artificial intelligence	Icog Labs
Block chain	IOHK, Stellar
Big data	Lehulu
Drones	–
Robotics	MeTec, Icog Labs

Gabon

Geographical area	Central Africa
3D printing	Gabon Meca, Cocograph
Artificial intelligence	–
Block chain	–
Big data	–
Drones	–
Robotics	–

Côte d'Ivoire

Geographical area	West Africa
3D printing	–
Artificial intelligence	Université Virtuelle de Côte d'Ivoire
Block chain	–
Big data	–
Drones	–
Robotics	–

Kenya

Geographical area	East Africa
3D printing	Ultra-Red, Fablab Winam
Artificial intelligence	AI Kenya
Block chain	–
Big data	–
Drones	–
Robotics	–

Morocco

Geographical area	North Africa
3D printing	Fab Lab Casablanca
Artificial intelligence	–
Block chain	–
Big data	–
Drones	–
Robotics	–

Namibia

Geographical area	Southern Africa
3D printing	Fablab Namibia, Namibian University of Science and Technology
Artificial intelligence	University of Namibia
Block chain	Bank of Namibia
Big data	Namibian Ministry of Information and Technology
Drones	Drone Namibia, Namibian Ministry of Tourist and Ministry of Agriculture Afridrones
Robotics	Namibian University of Science and Technology

Senegal

Geographical area	West Africa
3D printing	Ker Thiossane (Fablab)
Artificial intelligence	-
Block chain	-
Big data	-
Drones	Geomatica, Kranth
Robotics	-

South Africa

Geographical area	Southern Africa
3D printing	Megchem, Kisme, Proconics
Artificial intelligence	Data Prophet
Block chain	Custos Media Technologies
Big data	Sasol, Spatialedge, EOH, Standardbank, ABSA, Pick'n Pay
Drones	Proconics, Cloudline
Robotics	Proconics, EY, EOH

Tchad

Geographical area	Central Africa
3D printing	CNRD-TCHAD
Artificial intelligence	WenakLabs
Block chain	-
Big data	-
Drones	-
Robotics	WenakLabs

N/A

Geographical area	Entire continent
3D printing	-
Artificial intelligence	Arifu, Pula, Harvesting, FarmDrive
Block chain	Leaf, Bitpesa
Big data	Pula, Harvesting, FarmDrive
Drones	Vayu, Zipline
Robotics	-

N/A

Geographical area	East Africa
3D printing	-
Artificial intelligence	Safaricom
Block chain	Bitpesa
Big data	Safaricom
Drones	Zipline
Robotics	-

Question 14

What are your recommendations to donors and to African governments in order to improve the adoption of 4th industrial revolution concerning [socio-economic aspects]?

Respondents had the opportunity to provide recommendations to donors and to African governments regarding a better adoption of fourth industrial revolution in the countries they were covering, they are listed by socio-economic aspects in the following tables:

Access to finance

1. Invest in mentorship and on the ground initiatives, where there is personal "skin in the game". Also create funds with a higher risk appetite
2. A shift from the service sector to industrialization and agriculture innovation
3. Find commercially viable ways to deploy these projects (replacing short lived programs) that are heavily funded but lack commercial life after donor funding
4. Seed funding for start-ups is needed. Regulation for financial inclusion need to be reviewed
5. Make financing focused on competitiveness
6. Reviewing the collateral requirements. Ease the access to foreign currency machinery
7. Promote the electronic payment method on a large scale and set up a guarantee fund
8. A single window centralizing all existing financing methods
9. Simplify innovation financing application forms
10. Establish neutral organizations that will judge the relevance of projects and evaluate their performance
11. Set up funding mechanisms for early stage start-ups and start-ups' support organisations
12. Set up an innovative entrepreneurship financing fund in partnership with banks and which can be backed by structures to support innovative entrepreneurship (SAEI/ incubator/FabLab). It can be associated with a guarantee fund to reassure banks
13. Invest in financial infrastructure such as mobile money interoperability or "cash in cash out" [sic]
14. Ensure good regulation and stable economies

Governance

1. Better law and regulation enforcement
2. Accountability should be instituted
3. Better transparency
4. Fight against corruption, clientelism and nepotism
5. Granting tax benefits to companies in the field
6. Digitize processes

Finding adequate skilled labour

1. Invest in bottom-up initiatives that can prove a good ROI and their impact
2. Provide more adequate training
3. Combat brain drain by incentivizing R&D centres to open in market
4. Change in pedagogical approach
5. Curriculum change at basic education and education level need overhaul and should be4IR focused
6. Provide funding to train and develop skills
7. Instead of substituting local with foreign (western) workers to do skilled jobs, use western expatriates to teach and upskill locals. "Or give expats a short-term contract in which they must replace themselves with locals" [sic]
8. Working with hubs and makerspaces would help in bridging the gap
9. Improve collaboration between both private sector and education; increase the offer of short-term training and finally strengthen the "chamber system" [sic] and their involvement in certification
10. Promote science, technology and mathematics education at all levels and encourage training in highly skilled trades
11. Rework teaching curricula in collaboration with industry and based on benchmarks
12. Strengthen the capacity of innovation structures to better support start-ups
13. Allow private education to compete with public education
14. Break out of the paradigm of high-test scores and "brainwashing our children into mindlessly repeating what textbooks and teachers say" [sic]

Infrastructures

1. More spending on small decentralised initiatives with high ROI
2. Ensure infrastructure upgrade as well as maintenance is available to all locations to enable new business development
3. Electricity power system and rail infrastructure need to be fixed
4. Financing the construction of infrastructures adapted to the latest technological requirements
5. Infrastructures that meet international standards
6. Set up the necessary infrastructures for the development of innovative projects and start-ups (Fab Labs, coworking area, research centre)
7. Reduce internet connection costs
8. Improve governmental ICT technology, make it stable and give the support people need to be successful with it - especially less tech savvy elderly.

Regulation

1. Enforce localisation rules, create open systems (e.g. electricity grid deregulation)
2. Participate on the rising wave of "regtech" (management of regulatory processes within the financial industry) to help encourage innovation
3. Deregulate the job market
4. "Regulations should be softer regarding importing 3D printers as it takes 6 months to take the needed approvals. It should be allowed to import WIFI and other communication modules to enable HW start-ups" [sic]
5. Regulations should be fairer to young innovators
6. Prioritize import of prototyping technologies and components; abolish business categories for licensing; ease of getting foreign expert to support small businesses
7. Adopt the (recent) standards that regulate new technologies
8. More transparency and communication on sectoral regulations
9. Set up a regulatory body in the form of an inter-ministerial committee
10. Address the corruption issue
11. "Place more in the hands of the public. It's easy to disconnect from the needs of the everyday citizen working in a sector you're about to regulate the bread out of their hands" [sic]
12. Support initiatives that are bottom-up, fast moving, agile and with a high ROI. Critically re-evaluate the ROI of large institutions. "Large amounts of spending go towards administration and bureaucracy with low ROI" [sic]
13. Improve law and regulation enforcement
14. Push need and urgency of ICT and software and transparencies
15. Accountability need to be instituted by requesting (on a regular basis) the basic data of each institution
16. Various institution services should be improved, for example the intellectual property recording
17. Access to labs and private sector collaborations
18. More accessible institutions with better communication
19. Reduce corruption

Question 15

What project(s) would you foresee in order to fill a gap for the adoption of the 4th industrial revolution's technologies?

On financial aspects

- Investment funds for start-ups;
- Risk capital gap filler institutions to help turn technologies into businesses;
- Invest only in institutions were there is skin in the game, personal commitment and accountability, not top down, public, low-ROI projects;
- Finance the use of blockchain in local manufacturing
- Grant funds to unlock private investment in companies developing solutions;
- Provide tax breaks for tech start-ups/ investors in tech start-ups, provide tax breaks for corporates improving their tech set-up.

On educational and training aspect:

- Development and adoption of the curriculum for the fourth industrial revolution;
- Social impact bond that targets high school or university graduates to put them into jobs. The 4th industrial revolution cannot be achieved if there is an entire continent of unemployed working age people who aren't able to upskill themselves;
- Technical and Vocational Education and Training (TVET) institutions and Innovation hubs including both software and hardware;
- Organize the National Forum on the 4th;
  Industrial Revolution;
- Organize tech camp to promote the use of technology to meet social needs;
- Creating virtual tutors;
- Organize training courses (Hackathon, Barcamp, Creative Workshops) that will bring together all stakeholders in entrepreneurship: public decision-makers, entrepreneurs, catalysts, actors from the associative sector, hubs, technical and financial partners, economic operators. This broad coalition will work for one day to identify, analyse and propose appropriate responses to the challenge of improving the regulatory framework in which innovative companies, start-ups and VSEs operate;
- Community FabLab, professional training structure (in computer coding, robotics and artificial intelligence).

On networking and cooperation aspects:

- Regional and international cooperation and exchange programs (preventing the need to reinvent the wheel) but where countries can learn from more established players;
- Get an R&D centre in place, with linkage to international R&D centres;
- More maker spaces;
- Access to components and technologies;
- Network of smart SMMEs;
- Set up clusters.

Miscellaneous:

- Creating 3D printers with recycled materials.

B
interviews held

B1

with high level stakeholders

- UNIDO Geneva, Chief Business Environment
- ECOWAS, Dr Koffi Raphaël
- UNECA
- SACREEE, Executive Director
- Smart Africa Alliance Secretariat, Executive Director
- The Alliance for the Affordable internet, World Wide Web Foundation, Executive Director
- African Institute of Mathematical Sciences, Vice President and Chief Programs Officer
- PAU, Interim Deputy Director
- African Leadership Academy, VP strategy
- V4Africa, Co-founder
- Global Innovation Fund UK, Senior Investment officer
- GMSA ecosystem accelerator, Head of M4D Utilities and ecosystem accelerator
- GSMA, Public Policy Director, government and regulatory affairs

B2

for the regulatory assessment

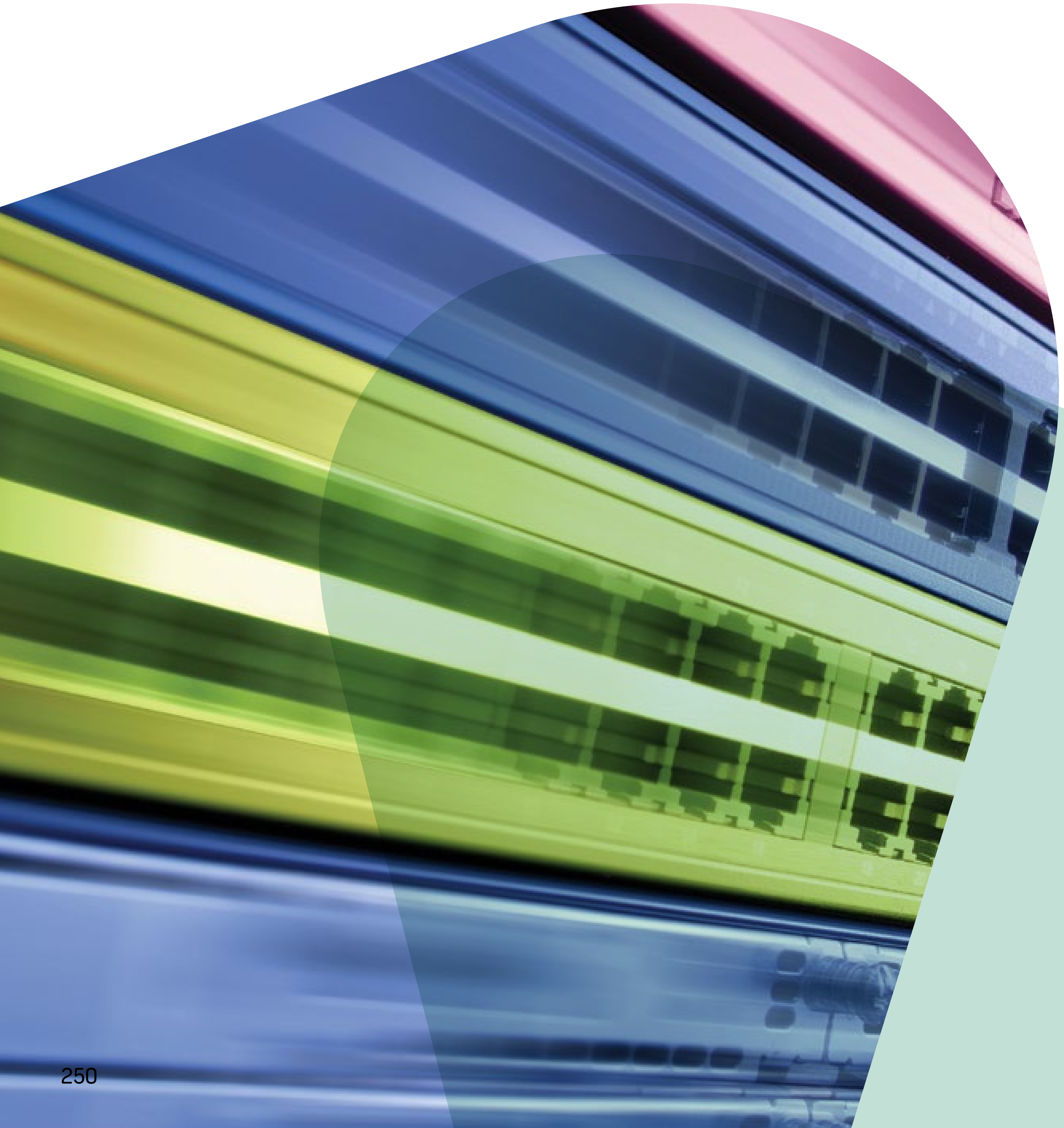
- Le Bihan, J.F., GSMA Director for Sub-Saharan Africa, 18 March 2019 (informal interview).
- Government Affairs Manager, Microsoft, 18 March 2019 (informal interview).
- Ah-Thew, G., Senior Programme ICT Officer, Southern African Development Community, 29 March 2019.
- Legal Expert, South Africa, 2 April 2019.
- Akuetteh Falconer, T. Senior Partner Nsiah Akuetteh & Co., Ghana, 4 April 2019.
- Bazzanella, S. International consultant on harmonisation, 4 April 2019.
- Ujarura Kamutuezu, E., Deputy Director IPRM, Ministry of Information and Communication Technology, Directorate: ICT Development, Namibia, 5 April 2019
- Cull, D., South African ICT Lawyer, representative of Internet Service Providers Association, 5 April 2019.
- Matanga, C., Ex ICT Programme Officer, SADC Parliamentary Forum, 10 April 2019.
- Mrs Madhub, Data Protection Commissionner, Mauritius, 4 June 2019

B3

with AfDB stakeholders

Name	department	function
Monojeet Pal	Renewable Energy and Energy Efficiency	Division Manager, PERN.2
Katja Juvonen	Strategy and Operational Pollicies	Senior Strategy Officer
Wissam Gallala	Agriculture and Agro Industry	Senior Agribusiness Officer
Foster N. Ofosu	African Development Institute	Senior Capacity Building Officer
Nicholas Williams	Industrial and Trade Development	Division Manager, PITD.3
Omar Samatar	Industrial and Trade Development	Principal ICT Specialist
Thierno Diarra	Industrial and Trade Development	Principal IT Solution Architect
Uyoyo Edosio	Education, Human Capital and Employment	Senior ICT, Education and Digital Skills Expert
Christophe Auguste Assamoi	Corporate IT Services	Principal Enterprise Architect
Samia Melhem	Digital Development Team(World Bank)	Global Lead
Fabien Gicguelay	Agence Francaise de developpement	Digital Project Manager
Anthony Nyong	Climate change and green initiatives	
Jalel Chabchoub	Energy efficiency and renewable energy	
Krishna Heeramun	Energy efficiency and renewable energy	Consultant
Rahul Barua,	Energy efficiency and renewable energy	Consultant
João Cunha Duarte	Power, Energy, Climate and Green Growth Comple	Manager, Energy Initiatives and Partnerships
Engedasew Negash	Energy, Environment and Climate Change Department	Manager, Energy Division
Ji In Seol	Renewable Energy and Energy Efficiency Department	

C
cluster analysis



In this appendix, 28 African countries (including our five focus countries: Cameroon, Morocco, Nigeria, South Africa and Uganda) are clustered along their strengths and weaknesses in innovation drivers' indicators extracted from the World Intellectual Property Organization 2018' report on Global Innovation (CITE).

The indicators used are grouped into seven main indicators namely:

- market sophistication;
- human capital & research;
- business sophistication;
- institutions;
- knowledge & technology outputs;
- creative outputs;
- infrastructure.

A total of 111 sub-indicators (referred to as metrics in the GII working document) composed those five groups (a number of 18, 17, 15, 13, 10, 17 and 13 sub-indicators respectively) and represent the basis for our cluster analysis. Those indicators are, for the most part, normalized index on the 0-100 interval (0 being weak, 100 being strong) and for everything else hard data is provided (for example for Electricity output, kWh/cap or macro-economic growth rate).

We use the Ward's method for our hierarchical cluster analysis and identified six relevant clusters (or groups of country) based on the seven main indicators. Table C1 illustrates those six groups.

1. the first group is characterized by countries with strength in the domains of Infrastructure and Knowledge & technology outputs;
2. the second is characterized by only weaknesses in the same domains and in Institutions;
3. the third group, composed of South Africa, Rwanda, Namibia, Botswana and Mauritius, is showing strong strengths in all domains (but Knowledge & technology inputs) and especially in Human capital, Institutions as well as in Market sophistication;
4. the fourth group is composed of the countries showing the highest number of weaknesses and therefore the lowest indicators' values especially in Business sophistication, Creative outputs and Market sophistication;
5. the fifth group refers to the "average group", which cannot be defined as a group of African innovators or followers (last tier) although showing strengths in Business sophistication and weaknesses in Institutions;
6. the last (sixth) group is having low indicators' values in Human capital but strong Creative outputs and Business sophistication strengths.

Table C1
groups characteristics

Group 1

Countries	Senegal, Algeria, Egypt, **Morocco**, Tunisia
Strengths	Creative outputs, Human capital in R&D, Infrastructures, Knowledge & technology outputs
Weaknesses	Business sophistication, Market sophistication

Group 2

Countries	**Uganda**, Kenya, Tanzania
Strengths	-
Weaknesses	Business sophistication, Market sophistication, Institutions, Creative outputs, Human capital in R&D, Infrastructures, Knowledge & technology outputs

Group 3

Countries	**South Africa**, Rwanda, Namibia, Botswana, Mauritius
Strengths	Business sophistication, Market sophistication, Institutions, Creative outputs, Human capital in R&D, Infrastructures
Weaknesses	Knowledge & technology outputs

Group 4

Countries	Niger, Burkina Faso, Côte d'Ivoire, Togo
Strengths	Institutions, Knowledge & technology outputs
Weaknesses	Business sophistication, Market sophistication, Creative outputs, Human capital in R&D, Infrastructures

Group 5

Countries	Ghana, Mozambique, Malawi, **Cameroon**, Mali
Strengths	Business sophistication, knowledge & technology outputs
Weaknesses	market sophisticationm creative outputs, human capital in R&D, infrastructures

Group 6

Countries	Benin, Guinea, Zimbabwe, Zambia, Madagascar, **Nigeria**
Strengths	Business sophistication, Creative outputs, Infrastructures, Institutions, Knowledge & technology output, Market sophistication
Weaknesses	Human capital in R&D

Overall, based on the ratio of strengths to weaknesses (number of strengths divided by the number of weaknesses by indicators) of the GII report, African countries show strengths in Innovation linkages, Regulatory environment, Credit and Education and are associated with weaknesses in Knowledge workers, Online creativity, Information and communication technologies and Human capital in R&D.

The five countries of the focus group are all associated with different cluster groups, namely South Africa belongs to the group of countries with large number of strengths in all the indicators (group 3), Morocco to the group of countries with strengths in infrastructure and knowledge but weaknesses in business sophistication (group 1), Nigeria to the group of countries with strengths in business sophistication and creative outputs but weaknesses in human capital (group 6), Cameroon to the group of countries with strengths in Business sophistication and weaknesses in institutions (group 5) and finally Uganda to the group of countries with strong weaknesses in every indicator but mostly in infrastructure, institutions and knowledge.

Figure C1

Mean differentials in indicators for the six groups

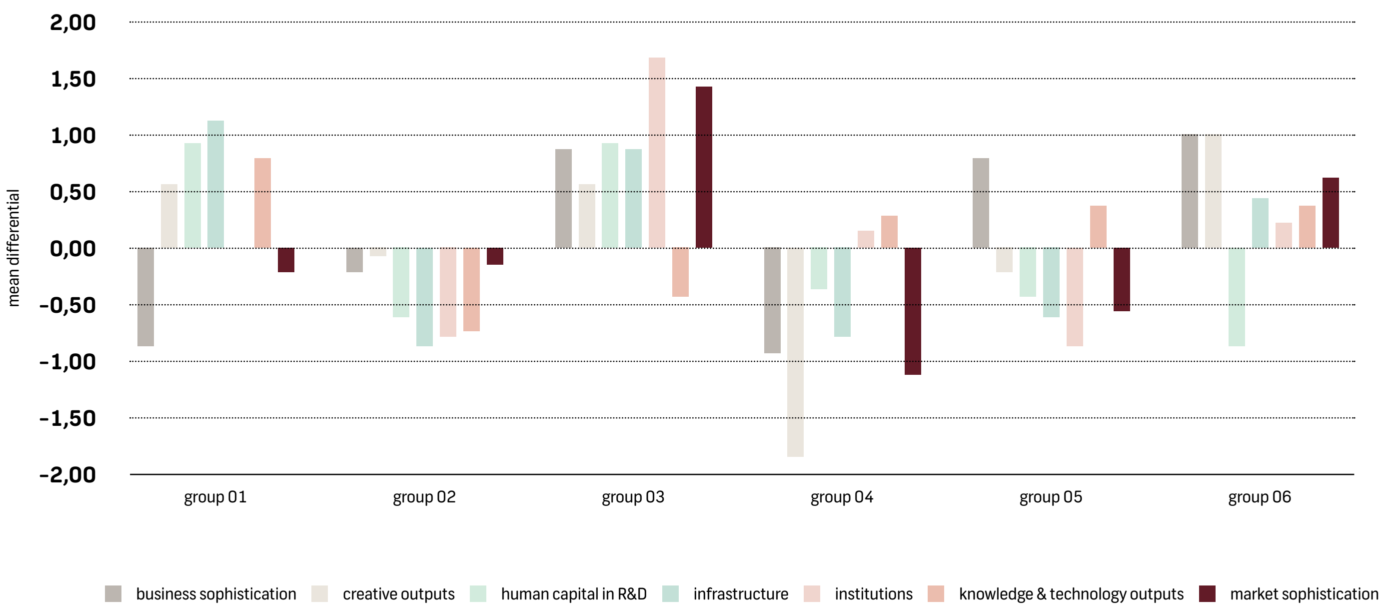
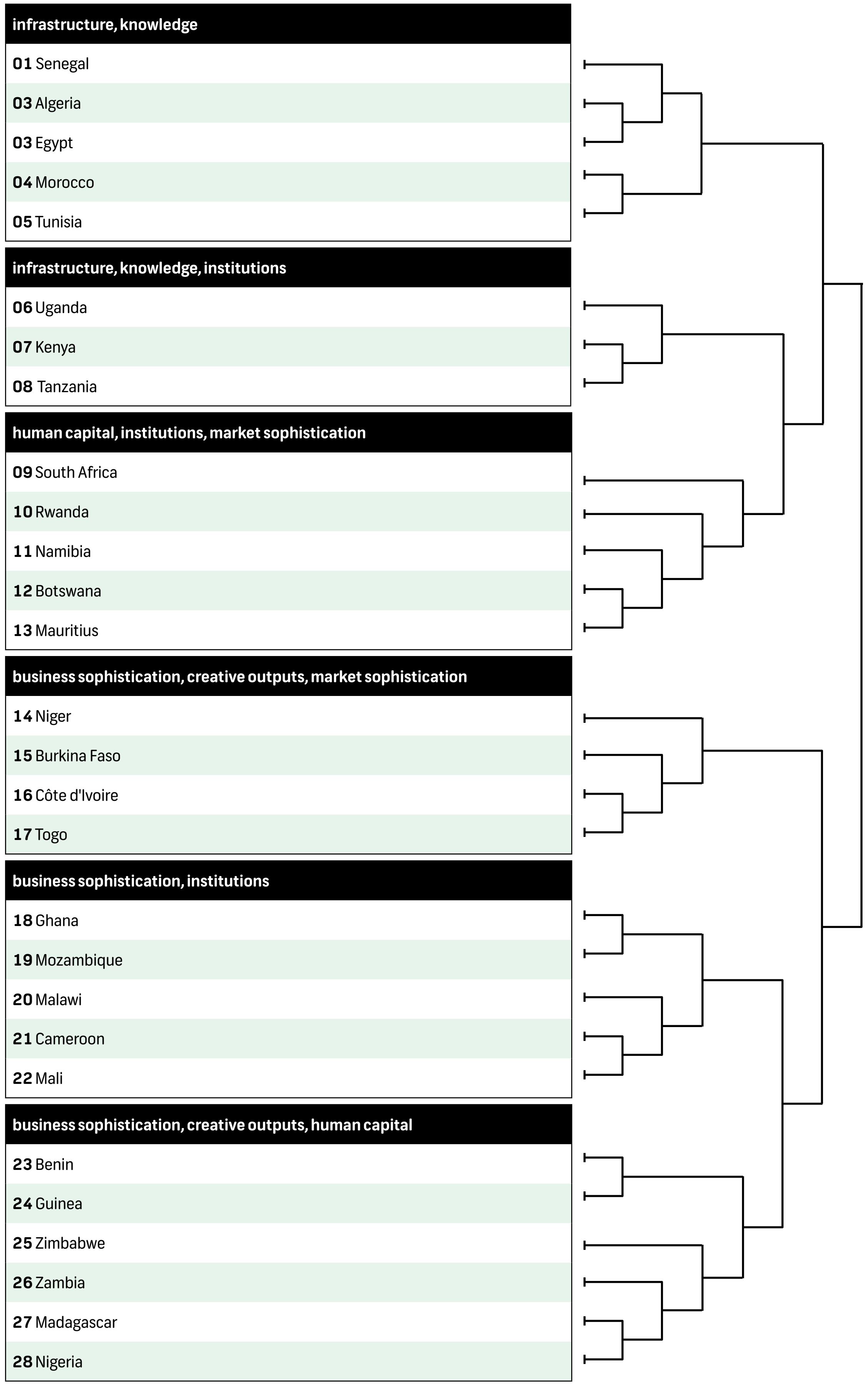


Figure C2

Cluster analysis of 28 African countries based on GII indices



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EN
endnotes

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