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Strategies for effective health care for Africa in the Fourth Industrial Revolution

Bridging the gap between the promise and delivery

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Abstract

Past investments in health care have contributed to the overall improvement of health outcomes in recent decades in Africa, but the persistent high incidence and mortality rates of infectious and non-communicable diseases reveals that there is still more to be done. Now, Africa's health care sector has immense potential to benefit from Fourth Industrial Revolution (4IR) investments and innovations to bridge the gap between health care promise and delivery, including capitalizing on the solutions provided by disruptive technologies such as artificial intelligence (AI) and machine learning, big data analytics, 3D printing, the Internet of Things, automated vehicles and drones, cloud computing, and blockchain technologies. Indeed, investments in health-related 4IR technologies could have the great returns in terms of business, and, more importantly, health outcomes, contributing to the protection of a fundamental human right (health) while fostering economic prosperity and sustainable development.

The 4IR offers efficient and effective ways to carry out public health measures to both improve health care outcomes and overcome crises such as COVID-19, Ebola, and other widespread diseases at various levels of cost, scope, and scalability. AI and mobile technology, for example, offer data-collecting tools to aid in contact tracing, symptom checking, outbreak prediction, vulnerability tracking, as well as communication platforms for doctor-patient interaction and public health information campaigns, while blockchain solutions can protect privacy during macro analysis of these crises by anonymizing collected data. Cloud-based platforms make it easier for workers and students to practice social distancing, as do drones and robots that deliver medicine, medical supplies, and meals to health facilities and infected patients. Advanced materials and nanotechnologies are also playing critical roles in rapid diagnostics, therapeutics, surveillance and monitoring, vaccines, and new, more effective forms of personal protective equipment. Quantum computing enables quick calculations, which enhances the functionality of applications that can accelerate drug discovery, optimize hospital and health care system logistics, and speed up vaccine validation. 3D printing allows for the scalable production of crucial medical supplies like testing kits, face masks, safety eyewear, and ventilator components, especially if the digital designs are accessible to the public. Mobile money allows vendors to go cashless, and thermal imaging allows for fast, non-contact fever screening.

A healthy society is essential for stability and economic improvement: Indeed, improved health outcomes lead increased productivity and better educational performance, and, of course, greater life expectancy, African governments should, therefore, capitalize on the Fourth Industrial Revolution in the health care sector and facilitate the development and adoption of relevant disruptive and scalable innovations needed for tackling challenges such as medical human capital shortages, medical supply and facility shortages, weak infrastructure and logistics, poor patient experience, efficiency of care, and organizational effectiveness. While policy solutions differ across individual countries, fixing health care challenges is a shared goal and is central to Africa's achievement of the Sustainable Development Goals and the African Union's Agenda 2063.

This report first discusses the key trends in health in Africa. Second, it explores recurring challenges and policy constraints to effective health care. Third, it provides trends and illustrations of emerging technologies and innovation of the Fourth Industrial Revolution in healthcare in Africa. Fourth, it presents seven effective strategies and policy options for bridging the gap between the promise and delivery in Africa's health care with the Fourth Industrial Revolution:

1. Commission a national 4IR or Digital Health Strategy task force that will develop (and help successfully implement) vertical and horizontal strategies and mechanisms adapted to local and national contexts, while benefiting from international innovations and experiences, to deliver on health care promise;

2. Engage in “public-private-philanthropic partnerships” (4P) to foster risk pooling and increase access to capital for smaller, local health organizations and innovators;
3. Capitalize on e-learning strategies to train both clinical and managerial medical personnel and them on and prepare them to properly use more complex technologies;
4. Leverage technological platforms and networks to face the shortage of human capital through a “digital brain gain” from the diaspora and friends of Africa;
5. Leverage fintech and digital health innovations to improve financial access to care and achieve universal health coverage;
6. Engage local communities and “community health care leaders” in order to accelerate 4IR technology adoption, usage, and efficiency;
7. Invest in health facility electrification, developing digital infrastructure, and universal access to broadband internet.

The successful implementation of effective 4IR and digital health strategies in Africa will also require initial and/or accelerating conditions for advancing technology more broadly, such as substantial investments to develop digital infrastructure and universal access to broadband internet, and a systematic and synergistic integration of digital technologies across actors and sectors beyond health care. Ultimately, multi-stakeholder collaboration and agile governance should be accelerated to reinforce preparedness and response for both infectious and non-communicable diseases, regional and international collaborations for effective health care delivery in the Fourth Industrial Revolution context.

Contents

I. Introduction

Recent studies have demonstrated the positive relationship between improved health care and economic performance,[1] including the importance of the Fourth Industrial Revolution in transforming health care, human capital, and economic development.[2] Indeed, experts estimate that additional investments in health care in Africa (an average of $21 to $36 per capita per year over the next five years) could save 3.1 million lives and generate economic gains of more than $100 billion over that time period.[3]

Improved health leads to longer life expectancy, better educational performance, increased savings and investment, decreased debt and health care expenditure, and increased productivity. In fact, the World Health Organization (WHO) estimates that, for every 10 percent increase in life expectancy at birth, annual economic growth increases by 0.4 percent.[4] Thus, beyond enhancing human life, investing in a healthy population is also critical for Africa's development.

Despite substantial progress across health care indicators, though, Africa, especially francophone Africa,[5] lags behind the rest of world when it comes to achieving United Nations Sustainable Development Goal (SDG) 3: "ensure healthy lives and promote well-being for all at all ages."[6] African countries face numerous health care challenges that require short- and long-term innovative solutions, including disruptive technologies and massive investment in the overall system. The emergence of epidemics like Ebola and COVID-19, but also the high incidence and mortality rates of diseases like HIV/AIDS, tuberculosis, cholera, typhoid, malaria, meningitis, viral hemorrhagic fevers, and avian influenza demonstrate the need for immediate, long-term, and complementary public and private coordination and investment for effective service delivery. As the majority of deaths in Africa are caused by communicable diseases, poor nutrition, or maternal and perinatal challenges, it is critical to capitalize on technologies that offer unique solutions for addressing these poor health outcomes (including delivery, accessibility, quality, affordability, effectiveness, personnel, facilities, infrastructures, systems, etc.). Furthermore, recent upticks in economic growth suggest a corresponding increase in noncommunicable diseases,[7] such as cardiovascular disease, diabetes, and cancer for which disruptive innovations can make a difference.[8]

The continent now carries 24 percent of the global disease burden, despite hosting only 17 percent of the world's population.[9] Health systems have low capacity: In general, there is a dearth of health care workers, with only 1.3 health workers per 1,000 people in 2015 (the target of Sustainable Development Goals is 4.5 health workers per 1,000 people).[10] To successfully address these shortcomings, African countries need sustainable investments in health care infrastructure and education to bolster their domestic capacity to provide medical services. In this way, African economies, investors and firms, public health systems, and, most importantly, citizens can benefit

[1] Weil (2014). Bloom, et al. (2019). UNECA, GBCHealth and Aliko Dangote Foundation (2019).
[2] Ndung'u and Signé (2020).
[3] UNECA, GBCHealth and Aliko Dangote Foundation (2019) referring to WHO work.
[4] World Health Organization (2014, p. 6).
[5] Yap Boum and Yvonne Mburu (2020) highlight the triple penalty for Francophone Africa in terms of burden of disease, when compared to Anglophone Africa: Francophone African countries bear the highest burden of diseases on the continent; they receive the lowest funds globally (ratio share of burden and funding received is 29:1 for west Africa compared to 3:1 for southern African countries); they are unequally served as English language dominates global health, which affect their ability to publish and tell their own stories
[6] The SDG 3 particularly focuses on reproductive, maternal, newborn, and child health; infectious diseases; noncommunicable diseases (NCDs), mental health and environmental risks, and health systems and funding.
[7] NCDs are becoming the leading cause of death in anglophone Africa while infectious are still the main in francophone (Boum and Mburu 2020).
[8] Frost and Sullivan (2016).
[9] United Nations (2019).
[10] World Health Organization (2017a).

greatly from the increased participation of private sector actors and their ability to provide that financing in the health sector.

Similarly, the Fourth Industrial Revolution, "characterized by the fusion of the digital, biological, and physical worlds"[11] and its groundbreaking technologies could make a difference in improving health care delivery. 4IR innovations promise not only new avenues for development of the health care industry, but also for transformative, life-saving social impacts. Innovations in biology and technology, such as biometric sensors, have the potential to entirely transform the health care and patient-caretaker systems. (Appendix 1 discusses the applications and benefits of key 4IR technologies in Africa—including artificial intelligence, big data, Internet of Things, blockchain technologies, digital health, 3D printing, automated vehicles and drones.) Furthermore, with an intentional, coordinated, and systematic multi-stakeholder approach to the entire health care system, the benefits of the 4IR could go further than just the technologies themselves.

Already, mobile technology has become a platform for improving medical data and service delivery. For example, Uganda uses mTrac in its public health system for data reporting, verification, and analysis, as well as communication among its workforce.[12] The SMS for Life program, a public-private partnership between the pharmaceutical company Novartis and eight African countries, has reduced medicine shortages in primary health care facilities by using mobile phones to track and manage stock levels of malaria treatments and other essential drugs.[13]

Another example is the Matiscope. Building from the Internet of Things, the Matiscope is a tool created by Ugandan company Matibabu that fits onto the index finger and, without drawing blood, can detect the presence of malaria-causing parasites. In just a few minutes, the Matiscope determines the results and sends them to a smartphone or computer application.

Urgent care and disaster response has been revolutionized by technology as well. In 2016, Rwanda, through a contract with Zipline, became the world's first country to incorporate drones into its health care system, using autonomous air vehicles to deliver blood transfusions to remote regions,.[14] The California company, now also operating in Ghana and Nigeria,[15] designed a drone capable of flying 100 miles round-trip in all-weather conditions while carrying several pounds of supplies, including COVID-19 vaccines requiring cold-temperature storage, personal protective equipment, and test kits.[16] During the Ebola outbreak in West Africa in 2014 as well as the COVID-19 crisis, for example, WhatsApp became an easy, reliable method of dispersing information, checking symptoms, and communicating under quarantine,[17] although, like other social platforms, it was not immune to the circulation of misinformation.

During the pandemic, Kenyan 3D printing company Ultra Red filled supply shortages by producing personal protective equipment as well as adapters that allowed ventilators to serve more than one patient at a time.[18] Entrepreneurs in Nigeria adapted their telehealth platform, Wellvis, to serve as a triage tool for users to obtain information, assess their COVID-19 risk, and make a doctor's appointment, alleviating the heavy call volume experienced by disease control centers.[19]

[11] Ndung'u and Signé (2020).
[12] UNICEF. "mTrac: Using innovations to improve healthcare."
[13] Access to Medicine Foundation (2016, p. 16).
[14] Matchaba (2018).
[15] Boudway (2021). Zipline plans to begin operations in Nigeria in April 2021.
[16] Ibid. De León (2020).
[17] Atieno (2017).
[18] Wadekar (2020).
[19] Rao (2020).

Similarly, artificial intelligence (AI) is already being used to increase efficiency, diagnosis accuracy, and quality of care: For example, a company in Nigeria has utilized AI technology and machine learning in a user-friendly app called Ubenwa, which can analyze the cries of a baby and detect child-birth asphyxiation, a major cause of child mortality, without the presence of a health care provider.[20] In Uganda, medical researcher Agnes Kiragga has developed a machine learning system that uses an HIV database to analyze retention rates of at-risk and infected female populations.[21] AI is also being implemented in Ethiopia to help medical professionals accurately diagnose cervical cancer and medical irregularities during checkups.[22] IBM Research Africa is using AI to determine optimal methods for eradicating malaria in specific locations and using game theory and deep-learning data analytics to diagnose pathological diseases and birth asphyxia.[23] Many 4IR advancements go even further with medical records increasingly and safely ensured and shared among doctors using blockchain, as well as expanded access to medical advice through the application of artificial intelligence algorithms mimicking human intelligence and analysis.[24]

Many African countries have been working to scale their infrastructure and institutional systems to better address persistent health care challenges. Some reforms take a "vertical" approach, which targets specific disease outcomes and intentionally addresses the factors that spread those diseases and create impediments to their treatment.[25] Other governments and health care practitioners implement "horizontal" programs that are intended to improve the entire health system, from the factors that increase disease prevalence to interventions that can prevent future illness. As the sector grows, it is vital to structure the approach to health care development using both vertical and horizontal mechanisms in order to properly address the severe and complex challenges we see in high-risk areas. With its diverse disruptive technologies, velocity, scope, and system impact, the Fourth Industrial Revolution offers a new and unique set of options that foster both vertical and horizontal mechanisms to deliver on health care promise.

This report first discusses the key trends in health inputs and outcomes in sub-Saharan Africa (Section II). Second, it explores the recurring challenges and policy constraints to effective health care in Africa that must be addressed to successfully overcome crises like COVID-19, Ebola, and others (Section III). Third, it provides illustration of emerging technologies and innovation of the Fourth Industrial Revolution in healthcare in Africa (Section IV). Fourth, it presents effective strategies and policy options for bridging the gap between the promise and delivery of Africa's health care by capitalizing on the Fourth Industrial Revolution (Section V), before providing final considerations on how to reinforce preparedness and response, regional and international collaborations for effective health care delivery in the Fourth Industrial Revolution context (Section VI).

II. Recent trends in health care in Africa

Efforts to improve health outcomes and responded to health crises in Africa have increasingly regionalized: In 2017, as a response to the Ebola epidemic, the African Union launched the Africa Centers for Disease Control and Prevention (Africa CDC) for member states to coordinate strategic public health initiatives, including emergency preparedness and response, disease surveillance, and technical support. Since the beginning of the COVID-19 pandemic, the Africa CDC's COVID-19 task force has led the region's response to the crisis by creating a response fund, providing testing and research capacity, spearheading education and prevention campaigns, deploying health workers, and

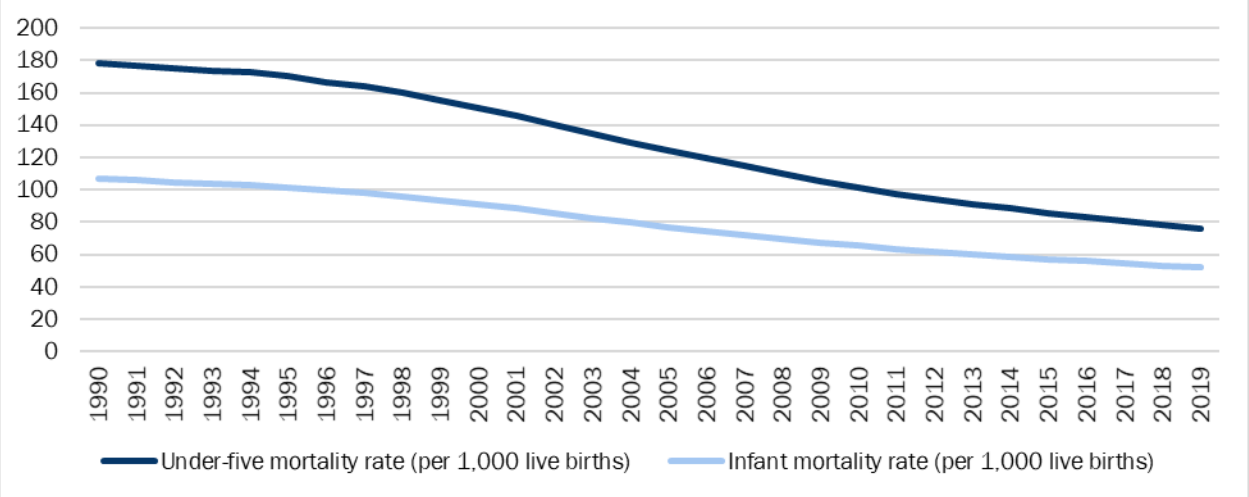
[20] Akileswaran and Hutchinson (2019, p. 11).
[21] Quartz staff (2019).
[22] Champlin et al. (2017).
[23] Akinwande (2018).
[24] IBM (2017).
[25] Bryan et al. (2010).

procuring donations from international partners. Because Africa has very little vaccine manufacturing capacity on the continent, the African Union partnered with the Africa CDC and the African Export-Import Bank to establish the African Vaccine Acquisition Trust initiative, which sources the majority of Africa's vaccines bilaterally or through COVAX, a global multilateral partnership.[26] The Africa CDC and the African Union created an initiative to foster the development of manufacturing hubs to help lift Africa's overdependence on vaccine imports.[27] However, the Africa CDC needs more autonomy to fully carry out its mission, as well as the cooperation of member states to fulfill national budget obligations.[28] More than 15 years ago, in the Abuja Declaration, African Union member states committed themselves to raising government spending on health to 15 percent of the national budget, but most countries still fall short of this target, with many allocating less than 5 percent prior to the pandemic. As a result, health care access in Africa is heavily dependent on assistance from international donors and aid agencies, along with out-of-pocket payments for services, which places significant strain on low-income households. Meanwhile, nearly half of the population in sub-Saharan Africa lacks access to clean water or sanitation services—a pressing concern especially considering the rapidly expanding population in the region's slums.

Furthermore, Africa's burgeoning health sector hosts too few medical professionals proportional to the size of the population in most countries. As of 2015, the African region had an average of 1.3 health workers per 1,000 people, far fewer than the Sustainable Development Goal target of 4.5 per 1,000 people.[29] Relatedly, many African countries are also susceptible to "brain drain" of medical professionals, a trend in which African-trained health professionals move abroad, leaving African countries with a shortage of qualified health care workers.

Then again, despite these challenges and common perceptions about health outcomes in Africa, the region has made substantial progress on many health indicators over the past 50 years. For example, the World Bank reports that, between 2005 and 2012, the number of hospital beds in Africa increased by 7.1 percent, the number of doctors by 3.3 percent, and the number of nurses by 5.1 percent. The infant and the under-five mortality rates in sub-Saharan Africa decreased by more than half between 1990 and 2019 (Figure 1).[30]

Figure 1: Declining infant and child mortality rates in sub-Saharan Africa



Data source: World Bank: https://data.worldbank.org/.

[26] World Health Organization (2021e).
[27] Africa CDC (2021).
[28] Uche Ordu (2020).
[29] World Health Organization (2017a).
[30] World Bank (2020a). World Bank (2020b).

The burden of communicable diseases in the region has similarly dropped. For example, there has been substantial progress in combatting the HIV/AIDS epidemic over the past decade: There was a 42 percent decrease in AIDS-related deaths in the WHO's Africa region from 2010 to 2017.[31] By 2019, at least nine sub-Saharan African countries had achieved more than 80 percent coverage in antiretroviral treatment,[32] with the region exhibiting a 20 percent reduction in disease prevalence from 2000 to 2019.[33]

The incidence of malaria in Africa has decreased by 22 percent since 2010, with the malaria mortality rate decreasing by roughly 30 percent during that period. The tuberculosis mortality rate has fallen by one-third since 2000.[34] Many other preventable and tropical diseases like polio, leprosy, guinea worm, and river blindness have been all but eliminated. Moreover, in response to the 2013/2016 Ebola outbreak in Sierra Leone, Guinea, and Liberia that shocked the world in its intensity and spread, the WHO has implemented a regional-level Integrated Disease Surveillance and Response strategy across Africa in order to improve the detection, reporting, and coordinated response to emergency diseases.[35]

Although Africa's health outcomes continue to improve rapidly, the continent still lags far behind other world regions, including other developing ones, across a range of indicators. The African region, in particular, accounts for roughly one-quarter of the world's disease burden, but just 3 percent of the world's health workforce,[36] with only 2.3 physicians and 10 nurses or midwives per 10,000 people.[37] Today, Africa is the only world region in which the ratio of deaths caused by communicable diseases continues to surpass that of noncommunicable diseases (NCDs). The 2016 incidence rate of HIV in Africa was 1.2 per 1000 people, a significant drop from 2.1 in 2011.[38] The antiretroviral coverage rate for people on the continent with HIV is about 70 percent, compared to about 66 percent globally, as a result of long-term development efforts.[39]

Average life expectancy at birth in Africa is now 64.5 years,[40] an increase from just 38 years in 1950 and 50 years in 1990[41]—yet significantly lower than the global mean of 73.3 years.[42] Notably, the vast majority of improvements in Africa's life expectancy rates over the past 50 years are attributed to improvements in infant and childhood mortality ratios.[43]

Much of the global comparison masks variation within Africa. Regional averages tend to be pulled down by poor performers where mortality rates are actually increasing and places where progress has lagged substantially due to the heavy disease burden.[44] For example, the region's adult female mortality rate is roughly double the world average, but in some countries—such as Lesotho and Central African Republic—the rate is over three times as high.[45] Africa also exhibits some of the lowest numbers in the world in terms of life expectancy: Just 53 years in the Central African Republic, 54 in Chad, 55 in Nigeria, and 59 in Cameroon.[46] In contrast, people born in North Africa and the island nations of

[31] WHO Regional Office for Africa (2019).
[32] World Bank (2019h).
[33] World Bank (2019i).
[34] WHO Regional Office for Africa (2018, p. 51, 53, 64).
[35] World Health Organization (2014, p. 67).
[36] Kamineni (2019).
[37] Zeufack et al. (2020).
[38] World Health Organization (2018, p.41).
[39] World Health Organization (2021d, p. ix d 71).
[40] World Health Organization (2019a, p.16). f
[41] World Health Organization (2016, p. 9); World Health Organization (2019a, p. 6).
[42] World Health Organization (2021c, p. 16)
[43] World Health Organization (2016, p. 26).
[44] World Health Organization (2016, p. 44).
[45] World Bank (2019e).
[46] World Bank (2019f).

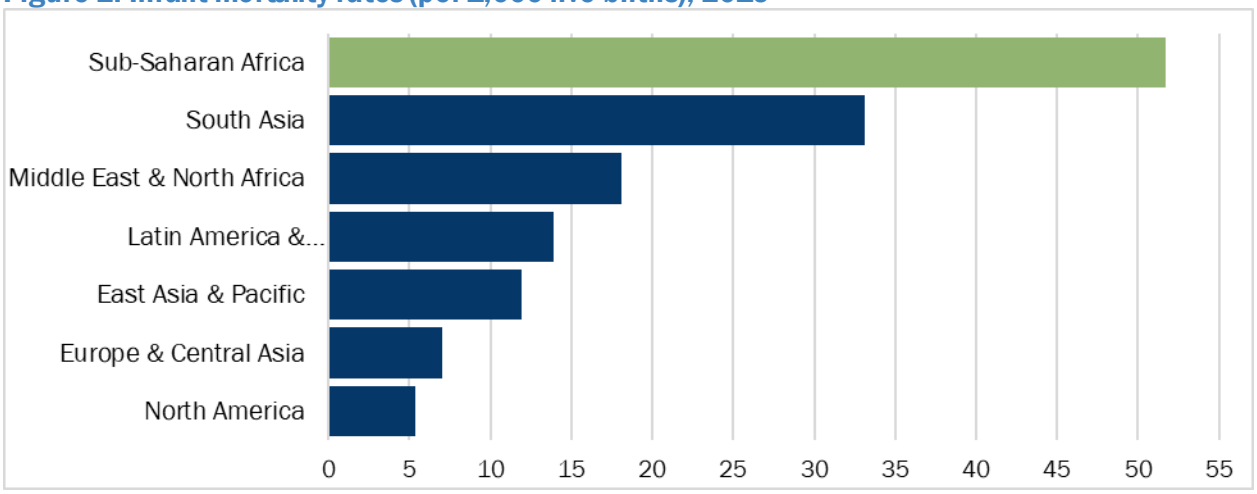
Mauritius, Seychelles, and Cabo Verde can expect to live more than 70 years—approximately equal to the global average.[47]

In fact, within Africa, the most significant progress in health to date has been made in North Africa. Over the last two decades, North Africa's maternal mortality rate has decreased by 54 percent, compared to a 39 percent decrease in sub-Saharan Africa,[48] while the under-5 mortality rate has decreased by about 50 percent.[49] Several North African countries have also exhibited the continent's most impressive reduction in infant mortality since 2000: 53 percent in Egypt, 42 percent in Tunisia, 59 percent in Libya, and 57 percent in Morocco.[50]

Other impressive performers in Africa include Sierra Leone, where the maternal mortality rate decreased by more than half between 2000 and 2017, from 2,480 per 100,000 live births to 1,120; and Eritrea and Mozambique, where maternal mortality declined by roughly 63 percent over the same period.[51] In Angola, the maternal mortality rate has fallen by almost 71 percent since 2000, from 827 deaths per 100,000 live births to 241.[52]

Despite the overall progress in health care outcomes, sub-Saharan Africa still underperforms compared to the rest of the world in major indicators such as infant mortality, the number of physicians, or the number of nurses and midwives (per 1,000 people) as illustrated in Figures 2, 3, and 4. The next section discusses some of the recurrent challenges and policy constraints responsible for Africa's continuing poor performance in such indicators.

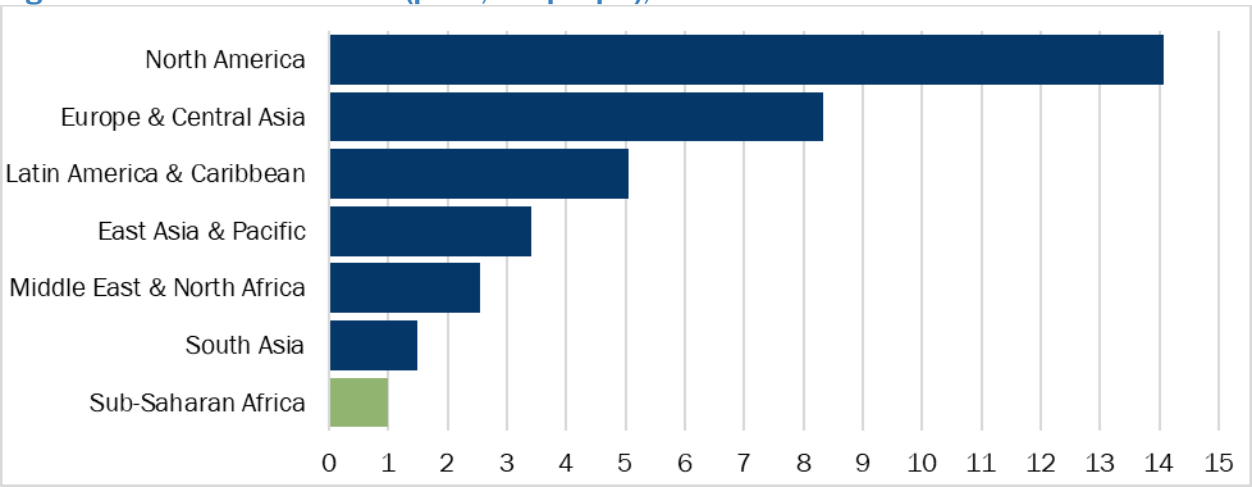
Figure 2: Infant mortality rates (per 1,000 live births), 2019



Source: World Health Organization, extracted from World Bank data.

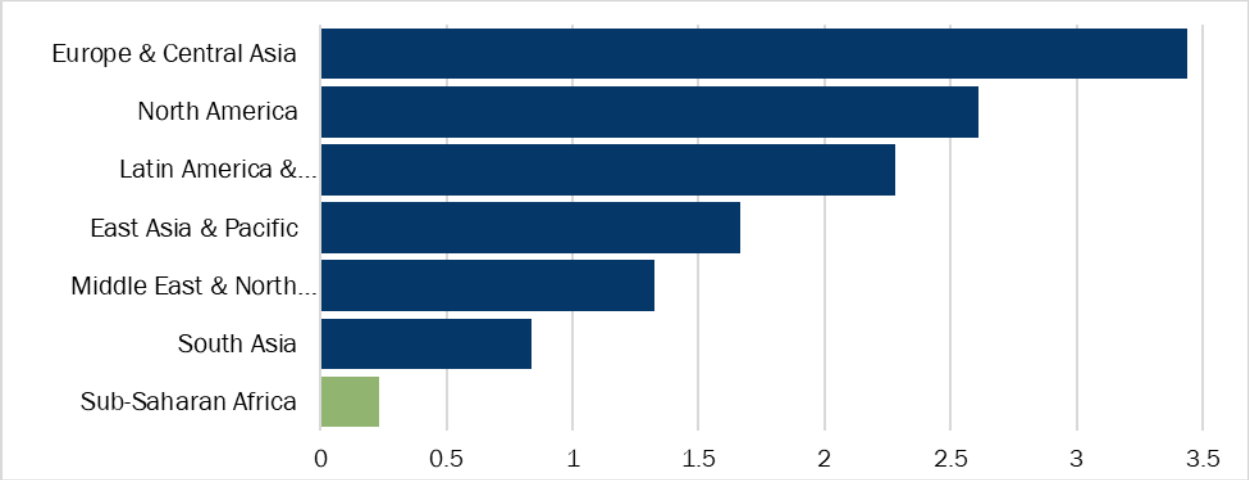
[47] Ibid.
[48] UNFPA et al.(2019). Borgen Project (2020).
[49] World Bank (2019a).
[50] World Bank (2019b).
[51] UNFPA et al. (2019).
[52] Ibid.

Figure 3: Nurses and midwives (per 1,000 people), 2018



Source: World Health Organization, extracted from World Bank data.

Figure 4: Physicians (per 1,000 people), 2017



Source: World Health Organization, extracted from World Bank data.

III. Recurrent challenges and policy constraints to health care in Africa

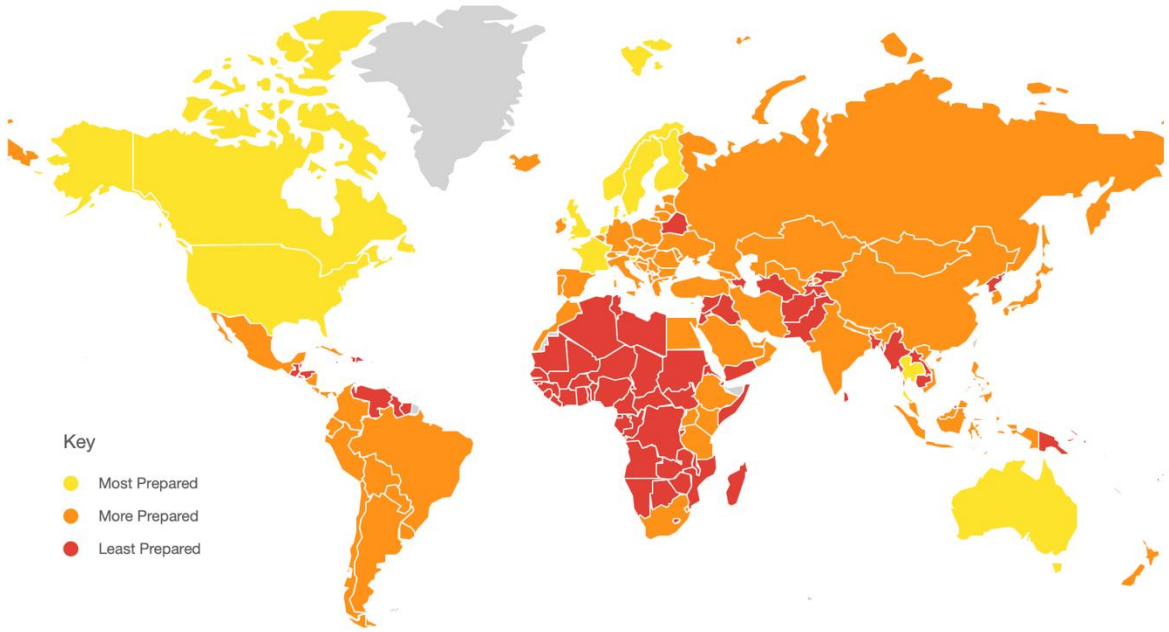
African citizens have some of the lowest rates of satisfaction with their health care systems of any region in the world.[53] Despite heavy investment by both foreign donors and local governments over the past two decades, the sector is still characterized by lack of access and infrastructural gaps, shortages of medications and medical staff, and corruption. In combination with poor access to clean water and sanitation, as a result, health outcomes on the continent are among the worst in the world. Furthermore, many African policymakers have not succeeded in prioritizing health care and do not devote sufficient resources. If these challenges are not adequately addressed, and without increased private sector participation in the health sector, especially around technology, the continent's current demographic patterns will only add greater stress to an already overburdened and underdeveloped system.

[53] Deaton and Tortura (2015).

Limited preparedness for epidemics and pandemics

Africa is the least-prepared region when it comes to preventing the emergence or release of pathogens, according to the Global Health Security Index 2019 (Figure 5), meaning its ability to detect and respond to epidemics is very low. This low performance can be explained by a series of challenges. The first challenge is the limited disease detection ability, given the lack of qualified personnel and quality laboratories, timely surveillance and reporting, and effective data sharing among stakeholders. The second challenge is the weak preparedness and, consequently, often slow response and mitigation in case of epidemic take-off. Contributing factors include the scarcity of trained health care professionals (including epidemiologists to investigate when the outbreak occurs) combined with the limited availability of equipment and medication, whether for detection, prevention, deployment, or treatment. And even when countries have the resources, they are not necessarily effectively prepared to face disruptive epidemics and pandemics. Finally, limited social protection initiatives for the most vulnerable complicate the ability to contain any disease, and in the quest for economic survival, citizens may adopt behaviors that contribute to worsening the epidemics.

Figure 5. "Preventing the emergence or release of pathogens" indicator from the Global Health Security Index 2019



Source: www.ghsindex.org

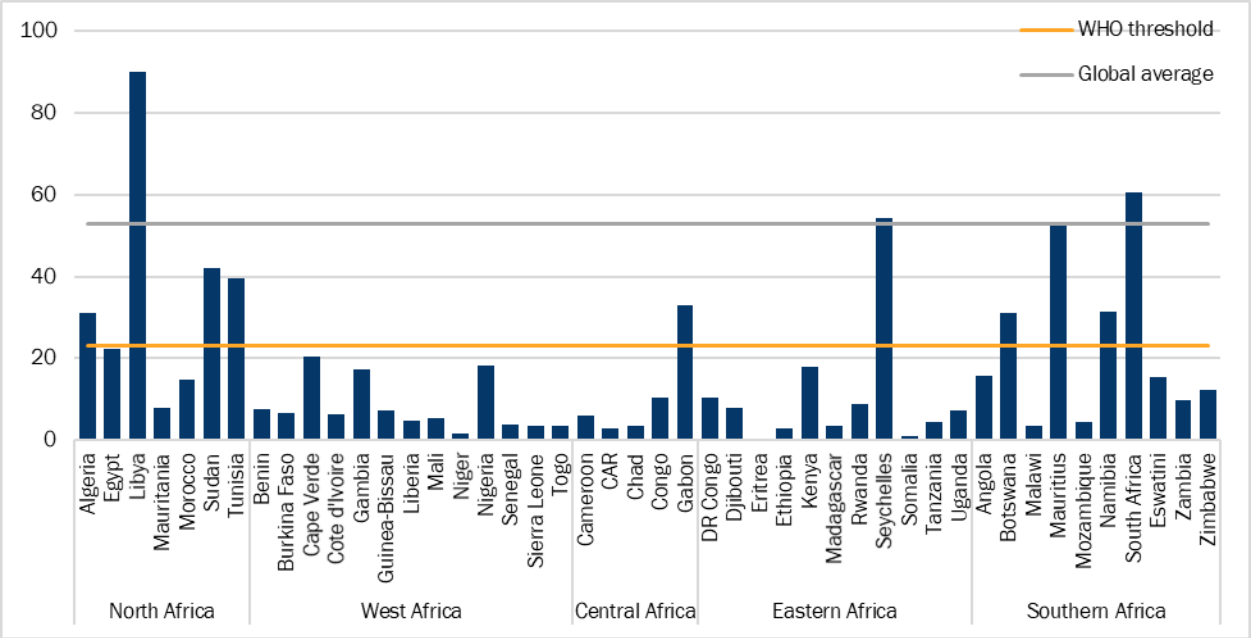
Human capital and brain drain

Africa's shortage of trained medical professionals is a significant contributor to the gap between supply and demand in the health sector, as well as to the poor management of health care facilities. The WHO estimates that Africa will have a shortage of 6.1 million health workers by 2030, a 45 percent increase from the estimated 2013 shortage of 4.2 million.[54] In 20 African countries,[55] there is fewer than one

[54] World Health Organization (2020b, p. 44).
[55] Malawi, Liberia, Niger, Chad, United Republic of Tanzania, Benin, Lesotho, Central African Republic, Sierra Leone, Ethiopia, Togo, Eritrea, Guinea, Mozambique, Senegal, Cameroon, DRC, Zambia, Burkina Faso, and Eswatini.

doctor for every 10,000 people. In fact, the sub-Saharan African region as a whole has just 2.1 physicians per 10,000 people (less than 12 percent of the world average)—the lowest ratio in the world.[56] Similarly, the average sub-Saharan African country has just 9.94 nurses and midwives per 10,000 people (less than one-third of the world average)—and in 12 countries,[57] fewer than five.[58] Figure 6 illustrates the low density of skilled health professional by sub-region, showing not only the overall low performance of African countries, but also the disparities within and across sub-regions.

Figure 6: Skilled health professional density (per 10,000) by African sub-region, various years



Note: The WHO threshold is the minimum density of skilled health professional per 10,000 people required to provide the most basic health coverage.
Source: World Health Organization, Global Health Observatory data repository (2018).

Due to limited domestic capacity for medical education and training, many African countries pay for doctors and nurses to be trained abroad. However, once accredited, better working conditions and higher salaries abroad incentivize those newly trained professionals to stay there—resulting in a "brain drain" away from Africa's health sector.[59] In fact, according to data collected by the Center for Global Development, Liberia, Angola, and Mozambique have more doctors working in foreign countries than in their home country. In fact, in 2008, in Liberia, there were two doctors working abroad for every one working at home.[60]

More broadly, a study published in 2008 stated that approximately 65,000 African-born physicians (one-fifth of African-born physicians globally) and 70,000 African-born professional nurses (about one-tenth of African-born professional nurses) were working in a developed country in 2000,[61] and these

[56] World Health Organization Global Health Observatory data (various years). https://www.who.int/data/gho/data/indicators/indicator-details/GHO/medical-doctors-(per-10-000-population)
[57] Cameroon, Guinea, Chad, Central African Republic, Niger, Madagascar, Benin, Angola, Malawi, Mali, Togo, and Mozambique
[58] World Health Organization Global Health Observatory data (various years). https://www.who.int/data/gho/data/indicators/indicator-details/GHO/nursing-and-midwifery-personnel-(per-10-000-population)
[59] Oxford Business Group (2017).
[60] Clemens and Pettersson (2008).
[61] Clemens and Pettersson (2008).

numbers have continued to increase substantially, as in the United States alone, the inflow of African-educated physicians increased by 27.1 percent between 2005 (10,684) and 2015 (13,584).[62]

While there is no doubt Africa desperately needs more trained providers, technology itself can also be part of the solution. In 2015, for example, Uganda had only 12 technicians in 10 locations certified to make plaster prostheses, a job in which it takes at least three years to become certified. Demand for such medical equipment and specialized care far outstrips the supply, as children outgrow prosthetics in six months, and the traditional process to properly design, produce, and fit the prosthetic takes weeks and multiple patient visits. That year, Comprehensive Rehabilitation Services Uganda partnered with the University of Toronto to make 3D printed prosthetics. The 3D printing process they used cut the time it took to complete the process by 75 percent, and allowed technicians to see five more patients per week.[63] That efficiency, in addition to the lower cost, drastically increased accessibility of protheses for poor, rural patients.

Weak infrastructure

One of the greatest current challenges to health care delivery in Africa is access, especially due to the low numbers of health facilities and gaps in pharmaceutical availability and affordability. The hospital-to-patient ratio is exceptionally low in sub-Saharan Africa, where fewer than 50 percent of people have access to a quality health facility. The health facilities that do exist tend to lack diagnostic equipment—such as x-ray machines, ultrasounds, and chemistry analyzers—causing medical staff to rely on alternative diagnostics and often delaying diagnosis until diseases are more advanced and difficult to treat. Similarly, in April 2020, *The New York Times* reported that the CAR, DRC, Liberia, Mali, Madagascar, and South Sudan all had fewer than 10 ventilators each; Somalia had none.[64] Where such technologies do exist, they have usually been donated by an NGO for communities that lack skilled technicians for maintenance and upgrading. Moreover, many vital preventative medications are not available in numerous health centers, including dispensaries and government clinics. Given there are few pharmaceutical manufacturing facilities in sub-Saharan Africa, most countries import 70 to 90 percent of their drugs, resulting in high prices and low preparedness.[65]

Beyond the deficiency of staff, facilities, and equipment, the health system is threatened by broader infrastructural gaps that threaten all economic sectors in Africa, such as those in basic utilities and ICTs, further complicating and even hindering potential uptake of 4IR technologies. For example, only 28 percent of the rural population in sub-Saharan Africa has access to electricity; hospitals and clinics—particularly those in rural areas—often face power outages, which pose a significant risk to surgical patients and limit clinics' ability to store vaccines and other pharmaceuticals.[66,67] Roughly two-thirds of the population lack access to basic sanitation services, and nearly 40 percent lack basic drinking water services,[68] exacerbating the incidence of communicable diseases that have been all but eradicated in other regions, especially cholera and dysentery.[69]

Finally, the absence of mass internet connectivity severely limits the capacity of national health management and information systems to generate, coordinate, store, analyze, and disseminate data relevant to health crises, as well as data relevant to patients' long-term health.[70] Providers and

[62] Duvivier et al. (2017).
[63] Burpee (2015).
[64] Maclean and Marks (2020).
[65] Conway et al. (2019).
[66] Today, utility infrastructure must not only be reliable and sustainable, but also invulnerable to cybersecurity breaches, which are becoming increasingly common in Africa and globally. (Power Africa (2020)).
[67] World Bank (2019d).
[68] World Bank (2017c and 2017d).
[69] World Health Organization (2014, p. 94).
[70] Kirigia and Barry (2008).

patients need access to a reliable internet connection to benefit from the myriad of digital health solutions, from cloud-based electronic medical records to telemedicine to IoT devices. While most African countries have been trying to solve some of the above-mentioned challenges, the continent still lags in terms of the quality of health care systems and overall health care outcomes.

Investment gaps in health care

Feeding into the challenges listed above is a lack of financing for improved health outcomes. UNECA, GBCHealth, and Aliko Dangote Foundation (2019) estimate Africa's health financing gap at $66 billion per year, as the required financing is at about $114 billion.[71] By combining indicators such as the "domestic government health expenditure, out-of-pocket expenditure, density of skilled health workers, average disease burden, government debt, and the annual GDP growth rate" among others, the authors posit that a total of 20 countries are either very health-stressed[72] (Benin, Cameroon, Central African Republic, Democratic Republic of the Congo, Republic of the Congo, Côte d'Ivoire, Guinea, Guinea-Bissau, Mali, Mozambique, Niger, and Zambia) or severely health-stressed (Angola, Chad, Mauritania, Nigeria, Sierra Leone, South Sudan, Togo, and Zimbabwe), given their vulnerability.[73]

The limited investment in health care on the continent also contributes to other problems, for example, the widespread circulation of counterfeit drugs. Between 2013 and 2017, 40 percent of reported fake medicine seizures in the world were in Africa,[74] and fake medication in circulation could actually represent up to 70 percent of the total pharmaceuticals on the continent.[75] Counterfeit pills are estimated to result in about 450,000 preventable malaria deaths globally,[76] and disproportionately affect Africa, which accounted for 94 percent of malaria deaths worldwide in 2019.[77] Without investment in quality and affordable drug production as well as technology such as mPedigree (Ghana) for the detection of fake pharmaceuticals, the continent will be left behind, especially its poorest citizens.

Low government spending

As noted above, in the Abuja Declaration in 2001, leaders of African Union member states committed to increasing health-related spending to 15 percent of their national budgets.[78] However, while the average share of government expenditure on health increased markedly between 1995 and 2004, it has remained relatively constant at around 11 percent since then.[79] Just seven countries—Uganda, Rwanda, eSwatini, Ethiopia, Malawi, Central African Republic, and Togo—currently meet the 15 percent benchmark, while 10 countries allocate less than half that amount.[80] In per capita terms, however, government health expenditure has continued to increase steadily since the mid-1990s, with the average African country now spending roughly $110 per person every year, compared to just $40 in 1995 (considering purchasing power parity). Some countries spend $400 per capita or more, as shown in the table below. Although out-of-pocket expenditure as a percentage of current health expenditure decreased by nearly 7 percent from 2000 to 2018 in all of Africa, sub-Saharan African countries still

[71] UNECA, GBCHealth and Aliko Dangote Foundation (2019, p. vi).
[72] The report determines health-stress by evaluating the thresholds of domestic government health expenditure, out-of-pocket expenditure, density of skilled health workers, average disease burden, government debt and the annual GDP growth rate indicators.
[73] UNECA, GBCHealth and Aliko Dangote Foundation (2019, p. xvi).
[74] World Health Organization (2017b).
[75] PwC (2017).
[76] Ibid.
[77] World Health Organization (2020c, p. xiv).
[78] Kaseje (2006, p. 4).
[79] It is worth noting that this ratio is higher than some other WHO developing regions, including Southeast Asia and Eastern Mediterranean.
[80] World Health Organization (2016, p. 62).

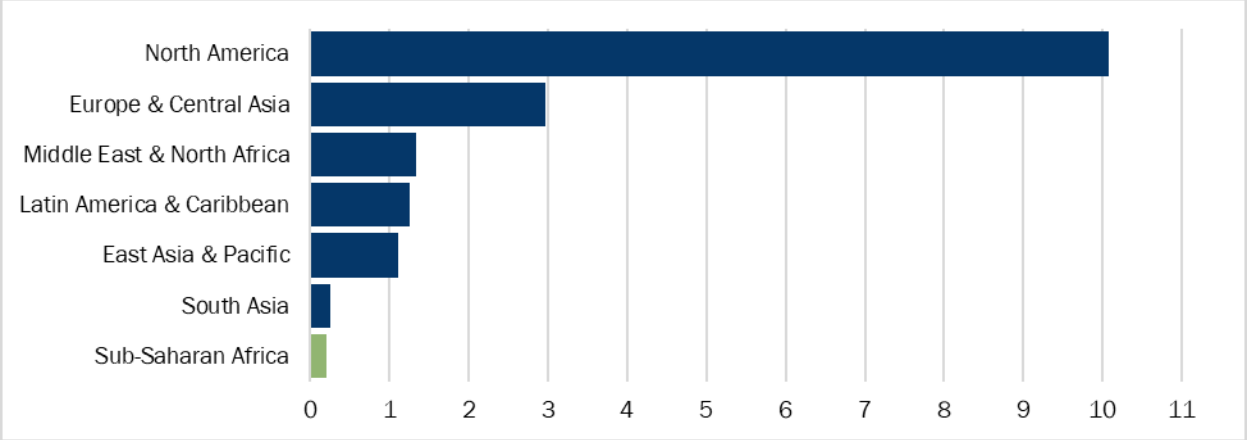
have the highest out-of-pocket expenditure per capita in the world (Figure 9), resulting in a major financial burden on their own citizens.[81]

Table 1: Per capita government health expenditure in the WHO Africa Region

Domestic general government health expenditure (GGHE-D) per capita, 2018	African countries
High (> $100)	Mauritius, Namibia, Botswana, South Africa, Algeria, Seychelles, Gabon, Cape Verde
Medium-high (between $30 and $100)	Eswatini, Equatorial Guinea, São Tomé and Principe, Ghana, Lesotho, Angola, Kenya, Zimbabwe
Medium-low (between $10 and $30)	Niger, Malawi, Liberia, Nigeria, Senegal, Tanzania, Burkina Faso, Congo, Rwanda, Mauritania, Côte d'Ivoire, Zambia
Low (<$10)	Democratic Republic of the Congo, South Sudan, Cameroon, Central African Republic, Eritrea, Guinea-Bissau, Chad, Ethiopia, Burundi, Comoros, Benin, Guinea, Gambia, Uganda, Togo, Madagascar, Sierra Leone, Mozambique, Mali

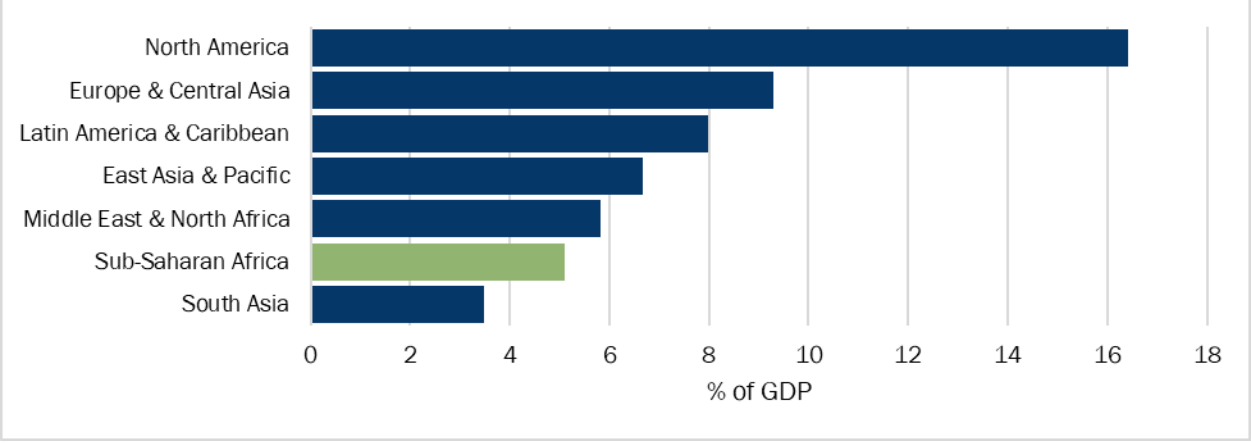
Source: The Global Health Observatory (World Health Organization) 2018.

Figure 7: Current health expenditure per capita, PPP (current international $) in 2018



Source: World Health Organization, extracted from World Bank data.

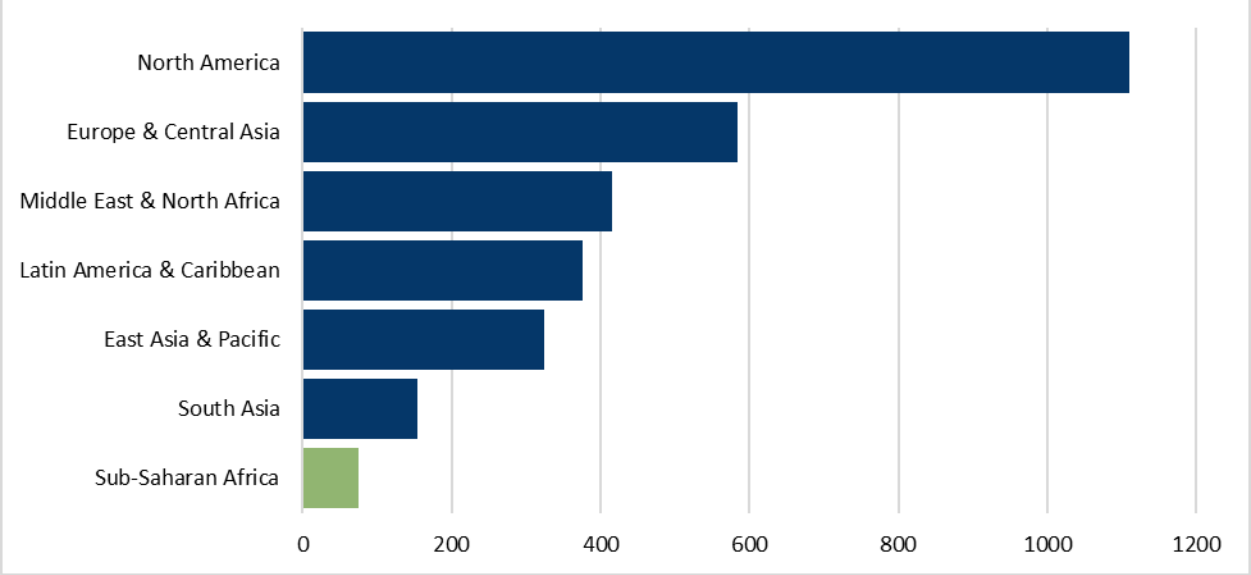
Figure 8: Current health expenditure (% of GDP), 2018



Source: World Health Organization, extracted from World Bank data.

[81] World Health Organization. (2021b).

Figure 9: Out-of-pocket expenditure per capita, PPP (current international $), 2018



Source: World Health Organization, extracted from World Bank data.

Regulatory environment and public inefficiencies

The public regulatory environment facing the health sector also tends to lack resources and coordination. In the DRC and Madagascar, public inspectors often go unpaid, and private clinics report not being inspected for years. Furthermore, only 1 in 5 African countries even have education requirements for medical staff working in private facilities.[82]

Moreover, corruption in the public health sector has led to inefficiencies and a loss of resources, reducing access and affordability for patients more broadly, and creating uncertainly in the sector overall. With bilateral and multilateral assistance flowing into Africa in an attempt to reduce the out-of-pocket payments facing households seeking health care, reports of public officials and medical staff directly diverting aid money, trading bribes for drug registration or health inspections, or selling medications meant to be provided for free have amassed over the past decades. In some countries, the tenure of health ministers has averaged just six months due to mismanagement of resources; in 2009 alone, Gambia had four health ministers in office.[83] Some countries are taking action: For example, health ministers in the DRC[84] have been jailed for misappropriation of health financial resources.

Furthermore, perceptions of corruption threaten official development assistance (ODA) toward health in Africa. At the same time, many observers have argued that the failure to meet public spending goals has itself been exacerbated by the large amount of donor funding flowing into the sector in order to fill resource gaps.[85] Indeed, governments have become highly reliant on donor aid, particularly in the area of disease control, such as for HIV/AIDS, tuberculosis, and malaria, which leaves the health system vulnerable to further decreases in ODA in the future.

[82] African Development Bank (2013, p. 14). According to the African Development Bank's 2013 report *Health in Africa over the Next 50 Years*, only 20 percent of African countries explicitly mandate Continuing Medical Education requirements for privately practicing health care workers.
[83] Ibid.
[84] Alfa Shaban (2020).
[85] Kaseje (2006, p. 4).

Future risks to African health systems

A 2013 evaluation of the 2008 Libreville Declaration on Health and Environment in Africa concluded that major changes taking place on the continent—for instance, climate change, unplanned and rapid urban migration, and uncontrolled population growth—are putting added strain on the continent's already delicate health systems.[86] While much of the current focus of health interventions is on communicable diseases, rising incomes on the continent are extending people's lives and causing lifestyle changes that will make NCDs—such as cancer, diabetes, and cardiovascular disease—much more prevalent in the coming years, especially in francophone Africa, as it is already the case in anglophone Africa.[87]

As in the developed world, Africans are consuming more processed, high-sodium foods, as well as alcohol and tobacco, and engaging in less physical activity.[88] Thus, there is a growing imbalance between general health services and disease control programs, and while the vast majority of donor funding has focused on infectious diseases, there has been little attention to other critical areas,[89] such as tropical diseases and injuries including snake bites that lack antivenoms.

Furthermore, as noted above, Boum and Mburu (2020) highlight the triple penalty for francophone—as compared to anglophone—Africa in terms of disease burden: Francophone African countries bear the highest burden of diseases on the continent; they receive the lowest funds globally (ratio share of burden and funding received is 29:1 for West Africa compared to 3:1 for Southern African countries); and they are unequally served, as the English language dominates global health, which affect the ability of scholars and institutions to publish and tell their own stories effectively.

IV. Emerging technologies and innovation of the Fourth Industrial Revolution in healthcare in Africa

The World Economic Forum's Insight Report[90] on health and healthcare in the Fourth Industrial Revolution identifies three broad key drivers of innovation in health care: unsustainable rise of costs, digitalization of health and healthcare, and rapid evolution of science and medicine.[91] In the African context, given the gap of health care professionals, infrastructure, equipment, facilities, spending, investment, and enabling policies, among others, "necessity is the mother of invention" in increasing healthcare effectiveness through the 4IR.[92] Numerous African entrepreneurs and innovators, including dynamic youth, are exploring affordable technological solutions to address their immediate health care challenges, benefiting from technology diffusion, transfer, adoption, adaptation, and when possible, innovation. This emerging dynamism offers the opportunity to African innovators, often in partnership with their international counterparts, to leapfrog in addressing some of the continent's persisting critical health care challenges. However, success can only occur if they can scale up, something that remains a true challenge. It is therefore important to explore some of the health care solutions associated with the 4IR technologies in Africa, discussing their relevance in addressing the continent's current healthcare challenges. In so doing, we are building on the classification of WEF's Insight Report[93], adapting it to the African context.

[86] World Health Organization (2014, p. 94).
[87] Boum and Mburu (2020).
[88] Clausen (2015).
[89] African Development Bank (2013, p. 14).
[90] World Economic Forum (2019).
[91] World Economic Forum (2019).
[92] Schwab (2016).
[93] World Economic Forum (2019).

Trends in "analytics and computing" that seek to improve diagnostics, treatment, storage, and security: Artificial intelligence (AI), machine learning, big data, and blockchain technology

Artificial intelligence systems are programmed using algorithms that allow for the practice of machine learning, which enables the system to recognize patterns and make predictions using data collection and analysis.[94] In healthcare, AI is often used for diagnostics and accelerated treatment strategies. Ilara Health, founded in Kenya, produces affordable diagnostic equipment using AI, including a portable ultrasound device and a diagnostic app that detects respiratory infections from the sound of a cough[95]. AI is often paired with blockchain, a secure transaction ledger database shared by a decentralized network of computers.[96] Blockchain is particularly useful in health document verification, secure data storage systems, and digital identification. In a public-private partnership, PanaBIOS (Kenya), Econet Group, the African Union, and the Africa CDC launched the Trusted Travel digital platform that uses blockchain to facilitate cross border health certificate verification (and prevent the use of false documents) between travelers, laboratories, and border agents and immigration officers.[97] Zimbabwean digital identity firm FlexFinTx provides a platform for medical providers to store licenses and credentials. License portability could be particularly useful in allowing healthcare workers to cross borders during a pandemic and work in areas with doctor shortages. Other companies integrating AI, blockchain, sensors, and machine learning include Afya Rekod (Kenya), which equips patients and providers with a decentralized, user-generated medical data storage platform, and mPedigree (Ghana), which prevents and detects counterfeit medicine, and other products, within supply chains.[98]

Trends in "modern machines" addressing the gap in infrastructure, equipment, and facilities in healthcare in Africa: 3D printing and drones

In the context of infrastructure deficits or medical supply scarcity, where traditional options are unavailable or too costly, African firms have pivoted to the adoption, adaption, or innovation of modern machines. 3D printing, also known as additive manufacturing, enables a computer to use a digital design to produce a 3D object layer by layer, using materials like plastics, metal, nylon, and ceramic. For example, when medical equipment was in high demand but low supply during the height of the pandemic, Kenyan 3D printing company Ultra Red Technologies printed face masks and ventilator components. Despite the extremely limited resources in Sierra Leone, a Dutch organization has established a 3D printing lab and training center for the manufacturing of prosthetic limbs.[99] Drones, or unmanned aerial vehicles (UAVs), provide life-saving solutions through on-demand last-mile delivery of crucial medical supplies. In cases of cold chain supply, where health centers are unable to store blood or vaccines at the proper temperature, whether because of unreliable electricity, poor road conditions inhibiting timely delivery, lack of access to cold chain supply trucks, or other factors that result in wastage, companies like Zipline (highlighted below) and Nigerian logistics and supply chain company Lifebank have had an important impact. Lifebank has saved 14,000 lives in Nigeria and Kenya using UAVs, among other transport methods; data analytics; AI; and blockchain to safely deliver over 40,000 affordable and trackable medical supplies, like blood, oxygen, COVID-19 tests, and medications.[100] Johnson & Johnson has started using drones to transport lab samples and HIV medication to 2,700 people per day on remote islands on Lake Victoria, where weather conditions have made boat deliveries difficult.[101] The project will allow the existing health workers more time to treat patients, and will create jobs for local Ugandans.

[94] World Economic Forum (2019).
[95] Jackson (2020a).
[96] Kaushal and Tyle (2015).
[97] African Union and Africa CDC (2021).
[98] Salient (2021).
[99] Van der Stelt, et al. (2020).
[100] Retief (2021).
[101] Goad (2021).

Trends in the capitalization of digitalization to address the shortage in human capital and limited access to financing of healthcare: Telemedicine, the Internet of Things (IoT), cloud computing and fintech

The digital health industry continues to leverage the high mobile penetration in many African markets to facilitate telemedicine, including remote doctor consultations and inventory shortages. Addressing the gap in digital infrastructure are mobile health (mHealth) companies like Zuri Health, whose offerings include SMS-based telehealth services to patients who lack access to internet. In Uganda, where many patients had previously travelled long distances to reach clinics only to find that the needed medications were unavailable, a mobile health (m-health) system called mTRAC now provides information about medicine stocks in clinics across the country.

Telemedicine platforms are adding direct-to-consumer product distribution services, and vice versa, often through partnerships with other startups.[102] A 2021 Salient study of over sixty health tech companies showed that nearly half are actively targeting markets in both urban and rural areas, and some are even pursuing strategies to facilitate cost-savings at pharmacies in low-income communities.[103] The eHealth company mPharma (Ghana), has branched beyond pharmacy inventory and operational software to several other sectors, including fintech (technology-driven financial services. mPharma's newest product in Ethiopia is Mutti, a mobile money membership program that offers healthcare financing services to help patients, especially uninsured patients, pay for healthcare costs.[104] Maisha Meds, a point-of-sale and operations management software used by over 300 pharmacies in East Africa, has built a digital reimbursement feature that utilizes mobile money to lower drug costs for patients, who often cannot afford to buy the quantity or quality of medicine their doctor has prescribed.[105] Innovative fintech companies like MicroEnsure, Jamii Africa, and M-Tiba are bringing affordable health insurance policies to Africans as well, including microinsurance and cellular plan add-ons.[106]

Specific devices utilizing sensors, the Internet of Things, and other 4IR technologies target facilitate diagnoses of specific health conditions. For example, the Matiscope is a tool created by Ugandan company Matibabu that fits onto the index finger and, without drawing blood, can detect the presence of malaria causing parasites. In just a few minutes, the Matiscope determines the results and sends them to a user-friendly smartphone or computer application.[107] Many digital health applications and devices use cloud computing to store and manage data on a network of remote servers. Such is the case with RxAll's RxScanner, a device that uses AI and cloud computing to rapidly detect counterfeit drugs.[108]

However, there are immense challenges when integrating emerging technologies into healthcare systems, particularly when firms pursue new markets across borders. For example, African telemedicine startups have incredible momentum, but expansion across borders requires adapting to a country's unique regulatory policies internally as well as demonstrating that understanding and preparedness to investors.[109]

[102] Mureithi (2021b).
[103] Salient (2021, p. 20).
[104] Jackson (2021).
[105] Maisha Meds (2020).
[106] Signé (2021).
[107] Lewis (2019).
[108] Kene-Okafor (2021).
[109] Mureithi (2021).

Medical discoveries and biotechnologies providing innovative treatments, preparedness, and responses in the African context

Biotechnology has been recognized as contributing to medical breakthroughs, and although breakthroughs do not happen often, even incremental discoveries can make a difference. Despite the challenges in human resources and infrastructure on the continent, Africa has been home to some discoveries, and hosts small, yet evolving, genetic engineering activities that have the potential to reshape global public health and reduce the burden of disease. In fact, early in the pandemic, scientists at the Africa Higher Education Center of Excellence for Genomics of Infectious Diseases (ACEGID), in partnership with the Nigerian Center for Disease Control, contributed to the understanding of SARS-CoV-2 by identifying multiple viral lineages through genome sequencing.[110] ACEGID, with funding from the World Bank, USAID, private foundations, and others, trains hundreds of students in genomics, and has COVID-19 knowledge-sharing and skill-transfer programs for established scientists.[111] Other active biotechnology hubs exist in Mauritius, Kenya, Uganda, and South Africa.[112]

Biotechnology has a particularly important role driving malaria research.[113] The Target Malaria research alliance had encouraging results from a release of genetically modified mosquitos in 2019 in Burkina Faso, driving forward their goal of bioengineering to eradicate the disease[114] CRISPR, a gene-editing tool, is recommended by scholars for use in pursuing the development of a malaria vaccine, or outright malaria eradication, in Sub-Saharan mosquito populations. Furthermore, CRISPR application has been identified as a tool to correct the genetic mutation that causes sickle-cell anemia, for which 8 out of 10 cases occur in sub-Saharan Africa.[115]

Africans are drastically underrepresented in the data that fuels genomics research and is used for precision medicine, a medical model that provides individual patient treatment based on genetics, environment, and lifestyle.[116] The mission of Nigerian company 54Gene is to close that data gap by building a biobank through global partnerships with public and private institutions and glean insights that positively impact the future accessibility and equity of precision medicine.[117] Similarly, Kenya-based IndyGenUS is using partnerships to build a blockchain-enabled indigenous and diasporic genomics database for use in disease and drug research.[118] These examples demonstrate that major investment in African biotechnology initiatives have the potential to lead to discoveries that drastically reduce the burden of diseases and improve lives both on the continent and globally.

Agile governance and policy: The experience of Rwanda

Agile governance is integral to the optimization of life-saving technologies for improved health outcomes. In 2016, Rwanda faced a major barrier to reducing maternal mortality: rural hospitals had poor access to cold chain blood supply.[119] Capitalizing on drone technology, the government worked with Zipline, then a U.S. startup, to implement a blood delivery program that has since scaled across Rwanda and into Ghana, Nigeria, and other areas. Rwanda's approach to drone regulation provides a rich case study of the benefits of agile frameworks through mechanisms like regulatory sandboxes, stakeholder engagement, and cross-sectoral partnerships.

[110] Happi (2020); World Bank (2021).
[111] World Bank (2021). Ikegbune (2021).
[112] Bitok (2016).
[113] According to the WHO, 94 percent of 2019 malaria cases occurred in Africa. (2020c).
[114] Diabaté (2021).
[115] Ogaugwu et al. (2019).
[116] World Economic Forum (2019).
[117] Jackson (2020b).
[118] IndyGeneUS AI (2021).
[119] Russo and Wolf (2019).

Approaching the project holistically, Rwanda's Ministry of Health created the Drone Advisory Council, a taskforce that included representatives from the ICT, agriculture, and transportation ministries, among others. Zipline forged partnerships with local and global institutions, like Rwanda's Civil Aviation Authority and the World Economic Forum, fostering knowledge sharing, mutual understanding, and training opportunities.[120] Both Rwanda and Zipline prioritized continuous stakeholder engagement in capacity-building and market research, approaching the project from the perspective of healthcare delivery, rather than the common association of drones as a military or surveillance tool.[121] Instead of spending years building a complex and comprehensive air traffic control system before launching the program, Rwanda used a regulatory sandbox to test a basic, functional, and flexible framework. Regulations were built on a mission-based use of airspace, with scalability in mind, requiring operators to prove they meet safety and quality-control standards before receiving clearance to fly.[122]

The program was successfully and scaled nationally, and today Zipline's drones are providing the majority of blood supply outside of Rwanda's capital city. They are delivering lifesaving medical supplies, including COVID-19 vaccines, in several countries, reaching a population of 25 million, with a plan to serve 40 million people by the end of 2021.[123] Rwanda's use of drones has been replicated by other African countries: Ghana and Nigeria have contracts with Zipline. Notably, Zipline's CEO says the business model is proving to be self-sustaining, attracting investors and accelerating expansion.[124]

Despite some efforts, like those of Rwanda explained here, African governments and regional institutions continue to face similar challenges, such as those discussed in WEF's Insight report: "workforce," "regulation," "ethics, equity, and social considerations," "norms, standards, responsible conduct," "data ownership, privacy, and sharing," "biosecurity and biosafety," and "cybersecurity."[125] It is critical for such governments and regional institutions to adopt a broader and cohesive digital and 4IR strategy that confronts the barriers to scale both nationally and regionally, like poor infrastructure (internet connection and electricity), financial access, technology adoption, and regulation of the broader business environment. The next section discusses broader strategies and recommendations to address those challenges and capitalize on the 4IR in healthcare.

V. Strategies for effective health care delivery in Africa with the Fourth Industrial Revolution

Given these challenges, African governments should capitalize on the Fourth Industrial Revolution in the health care sector and facilitate the development and adoption of disruptive and scalable innovations capable of addressing the obstacles discussed above—leading to better health service delivery more broadly. This section discusses some of the strategies necessary for bridging the gap between the promise and delivery in Africa's health care during the Fourth Industrial Revolution. Although a number of countries are making progress in specific areas, an intentional, coordinated, and systematic approach or strategy to the entire health care system, combining vertical and horizontal approaches would greatly multiply the benefits of the 4IR. Even as 4IR technologies are increasingly adopted, they are not sufficiently scaled across the continent. For the continent to reap the full benefits, additional investment will be needed in the most effective innovations, as well as Africa's human capital and infrastructure. One opportunity that may benefit Africa in the coming years is the $400 million health care fund established by Quantum Global Group to invest in private medical

[120] World Economic Forum (2018).
[121] World Economic Forum (2018).
[122] World Economic Forum (2018).
[123] Duffy (2021).
[124] Duffy (2021).
[125] World Economic Forum (2019).

centers, pharmaceuticals, biotechnology, medical equipment, and medical support services across the continent. Over 40 African e-health startups received funding in 2020, compared to 7 in 2015.[126]

Commission a national 4IR or Digital Health Strategy task force that will develop (and help successfully implement) vertical and horizontal strategies and mechanisms adapted to local and national contexts, while benefiting from international innovations and experiences, to deliver on health care promise

A dedicated section of the national government should be created to focus directly on how to improve country readiness and proactivity for implementing 4IR technologies in the health sector, including timely adoption of the most effective tools during crises such as COVID-19. A task force could build on multi-stakeholder collaboration (public and private sectors, academia, civil society, etc.) and agile governance (including flexibility, rapidity, adaptability, inclusiveness) to face the complexity of disruptive challenges such as COVID-19, simplify emergency regulatory processes, and capitalize on the strengths of key actors that could react quickly and with agility, innovate, and test and implement timely, effective options, whether originating from local, national, continental, or global spheres.

Regulatory issues like data privacy, cybersecurity, unregulated airspace (drones), and health system integration and interoperability will need to be evaluated, as will workforce capacity, emergency response systems, and budget constraints so that the overall strategy is adapted to the local reality. Such an approach will help policymakers better bridge the gap between the promise and delivery. The task force will need to identify gaps in digital infrastructure and health care delivery, as well as opportunities to partner with international organizations and the private sector for financing and scaling.[127] Most importantly, it will need to design a sustainable digital health strategy framework with a roadmap outlining timelines and goals, including monitoring mechanisms. There should be dedicated government officials engaging with the private sector throughout the process, as well as official liaisons to work with lawmakers on potential policy initiatives that attract local and regional tech entrepreneurs and innovators, educate and retain health professionals (reverse brain drain), and provide incentive for foreign investors.[128]

Engage in "public-private-philanthropic partnerships" (4P) to foster risk pooling and increase access to capital for smaller, local health organizations and innovators

A number of African countries are beginning to offer incentives for private investment in health, as well as vital sectors that bolster the health system, such as infrastructure and education.[129] While ministries of health are likely to maintain their central role in managing and coordinating health policy, the need for funding signals an opportunity for private industry to use its expertise to assist African governments in areas such as facilities, logistics, and distribution and production of pharmaceutical products, so that prioritized programs are best able to reach target populations, especially in rural and remote locations.[130] From a risk management perspective, public-private coordination through government national payment schemes or commercial insurance can foster higher-quality health care and better organization among private health actors.

Investments are critical to the emergence and scaling up of disruptive innovations and support of public initiatives as local businesses often have a wealth of knowledge about specific patients, public, or private needs and demands, as well as existing recognition and development opportunities, but

[126] Disrupt Africa (2020).
[127] Knapp et al. (2010).
[128] Stroetmann (2018, p. 19 and 27); Akileswaran and Hutchinson (2019, p. 42-43).
[129] Bastos de Morais (2017).
[129] Breedon and Brufal (2016).
[130] Kaseje (2006, p. 10-11).

tend to lack technical capacity and capital.[131] This strategy has already been used by some health-industry companies in Africa. In Nigeria and Kenya, for example, GSK works with pharmaceutical production and packaging companies to offer products that range in size and price in order to be competitive in a wide variety of markets. In partnership with the Africa CDC, the Mastercard Foundation committed over one billion dollars towards initiatives including the development of the vaccine manufacturing sector as well human capital.[132] Both organizations, along with Zain Verjee Group and NAMU Communications, launched the COVIDHQ digital platform, attracting users through storytelling while also serving as a COVID-19 public health resource with accurate information and data from the WHO and Africa CDC.[133]

As illustrated in the appendix, most of the 4IR innovations aiming at addressing Africa's health care challenges are driven by small- to medium-sized enterprises (SMEs), if not individual entrepreneurs, and are often not scaled enough—suggesting the need for improved access to capital for small entrepreneurs and businesses in sub-Saharan Africa that are often unable to innovate and scale due to limited financing opportunities. Governments can support this effort by providing local banks with more information on the risks involved with the health sector or by developing equity-based financing mechanisms for health care SMEs.[134]

Capitalize on e-learning strategies to train both clinical and managerial medical personnel and prepare them to properly use more complex technologies

E-learning strategies for medical personnel foster collaboration across the world. In this way, improving physical and digital infrastructure will allow Africa to confront another major challenge that accompanies the eHealth transition: the shortage of medical personnel and skilled health care workers. There is an urgent need to increase access to medical education in order to grow the health care workforce.

Many of the existing eLearning programs serve existing networks of community health workers, a crucial part of health systems. As of February 2021, Amref Health Africa had used its mobile learning platform to deliver free COVID-19 training to 60,000 community health workers in 47 Kenyan counties.[135] Early in the pandemic, UNICEF's Somalia nutrition and health sections generating learning materials in less than a week and leveraged their existing networks to deliver COVID-19 training webinars to hundreds of Somalia's community health workers.[136] Nigeria's health ministry trained thousands of its program managers on COVID-19 using e—learning, reducing costs by over 80 percent, and equipping them to transfer knowledge to health workers they manage.[137] While this training is crucial, especially in the short term to prevent COVID-19 cases and deaths, more can be done to use eLearning more effectively to grow the workforce beyond the community level, particularly skilled health professionals.

While there is enormous potential for success, e-learning medical education programs in sub-Saharan Africa have repeatedly failed to move beyond the pilot stage due to flaws in scope, scalability, and structure. Furthermore, academia has not produced a widely accepted framework for evaluating the effectiveness of medical e-learning programs in low-to-middle income countries. Most publications attempting to evaluate effectiveness conclude with mixed or unclear results, leaving e-learning advocates without the scientific body of knowledge they need to incentivize investment in new

[131] Breedon and Brufal (2016).
[132] Mastercard Foundation (2021a).
[133] Mastercard Foundation (2021b).
[134] International Finance Corporation (2008, p. 33).
[135] Amref Health Africa (2021).
[136] UNICEF (2020).
[137] Dele-Olowu, et al. (2020).

programs.[138] In order to achieve an optimal outcome, experts must play a role in developing the pedagogy to adopt within a digital training strategy rooted in local universities but also driven by national governments.

Furthermore, health care providers may find ICT solutions overly expensive or complicated or may have liability concerns regarding the use of new technologies. As eHealth systems are implemented and the sector becomes more reliant on technology, existing workers must be equipped with e-learning platforms to improve their digital competencies.[139] A Finnish study on Tanzanian private sector urban health care workers published in the *Journal of Health Informatics in Developing Countries* found that although many workers lacked the necessary level of digital literacy to successfully transition to an eHealth system, most personnel had positive attitudes toward job training for eHealth technologies.[140] The public and private sectors should therefore seize this opportunity to increase the e-learning offering for the medical personnel, whether for clinical, managerial, and digital trainings, or to prepare them to properly use technologies for remote health care delivery, among others. Special attention should be paid towards rural health care workers, who are likely to be less digitally literate, and perhaps even less comfortable with the concept of e-learning.

Leverage technological platforms and networks to face the shortage of human capital through a "digital brain gain" from the diaspora and friends of Africa

To address brain drain in the health sector, African countries could develop a more effective digital strategy to better use its large medical diaspora. About one-fifth of all African-born physicians practice outside of Africa in developed countries.[141] In numerous advanced economies such as the United States, the United Kingdom, and Canada, the African medical diaspora (Nigeria, Egypt, Sudan, Cameroon, etc.) is already organized, including with the goal of supporting their home countries through health care services and training, including distance learning, but remains under-utilized.[142]

Digital innovations could help build communities of knowledge, consisting of professional Africans at home and abroad, as well as provide critical channels through which African professionals abroad can contribute more directly to the growth of the health and science ecosystem in Africa. These interdisciplinary knowledge communities can span multiple countries and regions, thereby contributing more effectively to regional integration and the building of knowledge-based economies in Africa. This is, for example, the case of Nexakili, a network of African and African diaspora health professionals, scientists, and engineers, which aims to promote the global collaboration of African professionals and the transfer of knowledge to Africa; promote the circulation of scientific and medical knowledge in Africa; take advantage of the latest digital and technological innovations to develop innovative algorithms that mobilize the collective intelligence of medical and scientific experts; and to accelerate the availability of innovative medicine in Africa. Governments and the private sector should scale up such types of initiatives, including in the case of epidemics and pandemics such as COVID-19.

Leverage fintech and digital health innovations to improve financial access to care and so achieve universal health coverage

Out-of-pocket expenditures represent about 36 percent of health care spending in Africa, putting a huge burden on the people living below the poverty line.[143] In fact, one study found that as many as

[138] Barteit, et al. (2019).
[139] Stroetmann (2018, p. 16).
[140] Laitinen, et al. (2019, p. 16).
[141] Duvivier et al. (2017, p. 2).
[142] Frehywot et al. (2019).
[143] UNECA, GBCHealth and Aliko Dangote Foundation (2019).

38 percent of low-income Kenyan households will delay or refuse health care treatments due to the unbearable cost.[144] Innovations to increase financial access are therefore critical for increasing health care access and coverage, especially for those working in the informal economy and often not participating in the formal banking system. Some of the most prominent solutions could facilitate savings for health, contribute to voluntary pooling of resources or insurance, or in some cases, facilitate participation in the broader mandatory universal health coverage. Health-specific mobile or online payment platforms can encourage patients and caretakers to save up for health care expenses. For example, M-TIBA in Kenya,[145] is a mobile health payment platform that enables its members to save money for health care or collect it from others, constituting a medical savings account. People can contribute money for their children, siblings, or extended family members without handling cash or having formal bank operations. Funds can also be deposited from abroad, facilitating the mobilization of remittances for health purposes. M-TIBA has over 4 million users, more than 1200 active providers, and has handled 1.5 million transactions.[146]

Other solutions involving pooling of funds include mobile or online platforms offering voluntary insurance packages to households. For example, Jamii[147] is a human-centered innovation offering mobile micro-health insurance products, especially for the informal sector in Tanzania. Mobile health-saving and mobile or online micro-health insurance are not mutually exclusive, but they are both limited as not mandatory and universal, resulting in a significant number of people without coverage. Digital technologies provide sufficient innovations to facilitate the achievement of universal health coverage, from patient identification and public health data management to the facilitation of targeted interventions, effective health service delivery, quick reimbursement, and evaluation of patient experience.

Engage local communities and "community health care leaders" in order to accelerate 4IR technology adoption, usage, and efficiency

One of the primary criticisms of previous health interventions in Africa is the failure to incorporate local communities in the processes of implementation, monitoring, and evaluation. The success and sustainability of all health programs are intrinsically tied to local ownership, such as through local volunteers and community health workers, but also through specialized training in order to build the supply of medical staff at the local level.[148] Pharmaceutical companies, for example, can work to overcome the deficiency of skilled and educated workers in Africa by building in-house, mobile, and online training capabilities.

For example, in Uganda, Kenya, and Zambia, Living Goods is a network of health entrepreneurs that leverage social capital from their local communities. Through the help of local female leaders, Living Goods facilitates the provision of collateral and technical training on health and business to develop local product distribution chains and channels for knowledge sharing. Over time, this work has reached approximately 5 million people, and an evaluation of the program found that its community relationship-building approach was associated with a 27 percent decrease in child mortality in the regions of interest.[149] Living Goods demonstrates how micro-engagement through training and dissemination of information to local people and communities can have a large effect on health outcomes, access, and innovation across Africa. Such initiatives could be supported and replicated across the continent.

[144] Ogbuoji et al. (2019).
[145] Seo (2019).
[146] Ibid.
[147] Jamiiafrica. (2017) (www.jamiiafrica.com).
[148] Kaseje (2006, p. 11).
[149] McHugh (2017).

Moreover, trust and uptake of health programs, especially in remote villages, is often dependent on the incorporation of "community health care leaders," who are integral to many African cultures in various ways. Since these community health care leaders are often more available in rural areas than most health care professionals, policymakers should encourage capacity-building, possibly through e-learning, if available, so that they could be tapped for non-vital, preventative procedures in areas where there is a shortage of doctors,[150] provided that they receive the appropriate training and resources, and would immediately refer to the closest doctor when the situation imposes. This strategy could also result in a better regulation of community health care leader activities, helping to distinguish between the accredited or recognized community health care leaders that could serve as health auxiliaries while ending unauthorized local practices. For example, the engagement of "community health care leaders," for preventive procedures has proven highly effective in combatting the HIV/AIDS epidemic in Uganda, where trained "community health care leaders" proved willing to translate and implement national-level health policies in ways that included local beliefs and practices. Similarly, the Bajenu Gox Initiative in Senegal has contributed to maternal and child health by creating a community support for women, training women to be leaders in reproductive health, and providing advice from the prenatal period until the children reach the age of 5.[151] Ethiopia has recruited a "health army" network of community leaders and respected mothers trained with basic information to improve maternal and child health.[152] As illustrated in Appendix 1 and discussed above in regards to COVID-19, e-learning, m-learning, m-health, and e-health can facilitate the coordination of networks, as well as improve patient experience, learning, and outcomes.

Invest in health facility electrification, developing digital infrastructure, and universal access to broadband internet

For any of the above strategies to be successful, bottlenecks to the 4IR must be addressed by encouraging substantial investments for electrification, digital infrastructure, and universal access to broadband internet as well as a systematic and synergistic integration of digital technologies across actors and sectors beyond health (as they are mutually reinforcing).

To take advantage of the many healthcare solutions the 4IR has to offer, national governments must capitalize on existing multilateral initiatives and public-private partnerships to accelerate powering health facilities with reliable energy. In many cases, off-grid, renewable energy resources are being used to provide power to the three-fifths of sub-Saharan healthcare facilities that currently lack reliable access to electricity.[153]

Since nearly all 4IR technologies rely on internet access, investment in the development of physical and digital infrastructure as well as universal and affordable access to broadband internet is critical for the broader adoption of 4IR for health care in Africa. Indeed, in Africa, although the number of broadband connections exceeded 400 million in 2018, the average broadband penetration was only about 25 percent.[154] Internet penetration varies wildly among countries—from (as of 2017) 4 percent of the population in the CAR, 6 percent in Chad, and 8 percent in South Sudan to 56 percent in South Africa, and (as of 2019) 59 percent in the Seychelles, 59 percent in Mauritius, 67 percent in Tunisia, and 74 percent in Morocco.[155] The Broadband Commission Working Group on Broadband for All published a report estimating that to achieve affordable and universal broadband in Africa by 2030, [156]

[150] Chatora (2003); Kasilo (2003); Kaseje (2006, p. 10-11).
[151] IDRC.
[152] VOA (2011).
[153] Sustainable Energy for All (2021).
[154] Broadband Commission Working Group on Broadband for All (2019).
[155] World Bank (2017-2018). In sub-Saharan Africa, approximately 25% of individuals used internet in 2017.
[156] About 80% of the investments are related to infrastructure (about 250,000 new 4G base stations and at least 250,000 kilometers of fiber, Wi-Fi based solutions for remote rural areas, etc.), about 20% related to building skills and local content, and 2-4% for policy framework.

investments of $100 billion are required. Such investments will help achieve affordable and universal broadband in Africa by 2030, connecting an additional 1.1 billion people.

Closing the current internet gap will better empower Africa to find sustainable 4IR solutions to its health care (and other) challenges,[157] fostering engagements among governments, the private sector, civil society, and individual citizens. Once connected, existing technologies can be implemented to address the lack of access to health care providers, limited preparedness for emergency health situations, insufficient medical equipment and supplies, among others.

Additional challenges may result from the apprehension from patients to use ICT-enabled health care platforms. Most ICT platforms, particularly those that improve the provision of information, still require patients to proactively engage with the technology, but many patients are unfamiliar, distrustful, or untrained. Civil society groups with the appropriate resources can position themselves to help ease the digital transition through localized support and training. Without investment in digital infrastructure, the Fourth Industrial Revolution may be limited in ushering in more efficient, effective health care.

VI. Final considerations: Reinforcing preparedness and capacity-building for effective health care delivery in the Fourth Industrial Revolution context

In the aftermath of the Ebola crisis and in the midst of the COVID-19 pandemic, it is crucial that African countries focus on integrating digital health into their preparedness strategy while prioritizing investments in local scientific and medical research, technological innovation, and regional collaboration. COVID-19 has shown Africa's overreliance on not only external scientific production, but also medical equipment and pharmaceutical products. Although international cooperation is extremely important, the persistence of low local capacity highlights its limits. African leaders should therefore act boldly to unlock the local preparedness potential at the continental level with the strengthening of institutions such as the Africa Center for Disease Control,[158] but also, most importantly, at the regional, national, and local levels.

There is a plethora of 4IR tools that health ministries can use to stay prepared and to react quickly in an emergency. Disaster-preparedness strategies should incorporate mHealth applications for nationwide alerts and information sharing. The strategic incorporation of these tools requires a focus on local and national needs to build resilience, agile governance, capable administration for quick deployment, and the creation of well-endowed specific emergency funds to support preparedness and response operations. Perhaps most importantly, African countries should focus on incorporating an interoperable health information system across public and private health facilities that use digital health apps and big data analytics for routine data collection. These 4IR technologies provide the resources for efficient disease reporting and data analysis, which would help increase accuracy and strengthen decisionmaking, especially in times of crisis. For example, in 2015 and 2016, Sierra Leone built its Electronic Integrated Disease Surveillance and Response (eIDSR) application in under a year. Over 95 percent of health facilities participated in weekly reporting after the implementation, as opposed to about a third of facilities when reporting was paper-based.[159] Additionally, the use of blockchain for personal medical records would protect a patient's information while still providing

[157] Broadband Commission Working Group on Broadband for All (2019).
[158] Specialized technical institution of the African Union which aims at creating "a safer, healthier, integrated and prosperous Africa, in which Member States can efficiently prevent disease transmission, implement surveillance and detection, and always be prepared to respond effectively to health threats and outbreaks." Africa CDC.
[159] Stroetmann (2018, p. 11).

accessibility to doctors in any health care facility provided it is integrated into the national health information systems. This will help facilitate more efficient and effective treatment no matter the location of the patient, especially when health systems are overwhelmed during a public health crisis. Furthermore, if medical professionals' licensing were stored on blockchain, the medical workforce would be freer to move across borders if needed during a disaster (assuming license portability). When clinics and hospitals are over capacity and experiencing shortages during a public health crisis, the government should have an existing implementation strategy that utilizes drones and 3D printing for crucial medical supplies. They should also focus on building up local medical supply and pharmaceutical manufacturing that can scale up and distribute across the continent during shortages. The African Continental Free Trade Area (AfCFTA) will make this easier by removing tariffs on intra-African trade, which is expected to increase by 52.3 percent once the AfCFTA goes into effect.[160] The AfCFTA will empower local SMEs to grow their businesses as supply chains develop and infrastructure improves.

Africa's health challenges require a coordinated approach by policymakers, business leaders, international institutional investors, philanthropists, local actors, and civil society. The strategies discussed in this report will be necessary to create a sustainable health care system with the capacity to handle both long-term illnesses and short-term disease outbreaks. The increase in technology available on the continent will only facilitate the expansion of health solutions to rural communities and regions still facing infrastructure challenges. Each stakeholder in the sector must tackle the technology, policy, institutional, and investment challenges that remain in order to create a sustainable health sector that can facilitate economic growth, encourage innovation, and contribute to Africa's achievement of the Sustainable Development Goals and the African Union's Agenda 2063.

[160] UNECA (2020) Signé and van der Ven (2019).

Appendix: The emerging role of the Fourth Industrial Revolution's disruptive technologies and solutions in addressing health care challenges in Africa

Health care providers throughout the continent have managed to capitalize on 4IR technology to address major threats. Illness detection and pharmaceutical production have most immediately benefited from digitization. Some of the prominent 4IR technologies that have increasingly been used in Africa include artificial intelligence, automated vehicles and drones, big data, the Internet of Things, 3D printing, blockchain technologies, and digital health (m-health and e-health).

This appendix illustrates recent developments on the continent for specific technological solutions to further illustrate the promise of the Fourth Industrial Revolution should the appropriate policies be adopted.

African entrepreneurship and key 4IR technologies		
4IR technologies	**Health care applications/benefits**	**Illustrative innovations/cases/stories in Africa**
Artificial intelligence (AI) systems are programmed using algorithms that allow for the practice of "machine learning," which enables the system to recognize patterns and make predictions using data collection and analysis.	Accelerated diagnostics; improved treatment strategies	**CareAI** (regional): Computer platform, supported by blockchain technology, using integrated sensors for autonomous patient monitoring **SOPHiA** (regional): Cloud based platform accelerating collaboration between 780 healthcare facilities through AI-powered analysis of genomic data and treatment **Ubenwa** (Nigeria): App that detects child-birth asphyxiation **Ilara Health** (Kenya): Affordable diagnostic equipment using AI, including a portable ultrasound device and a diagnostic app that detects respiratory infections from the sound of a cough.
Digital health (M-health and E-Health) is perhaps the most advanced 4IR tool in Africa to date. These mobile applications have a variety of uses, including connecting users virtually to doctors and providing public health information and alerts,	Improved access and delivery of health care and health information through remote patient-provider communication and monitoring, and immunization management	**HelloDoctor** (South Africa): Mobile app providing 24/7 communication with a doctor **eIDSR** (Sierra Leone): Mobile app for disease reporting by health facilities **Clinic Communicator** (Uganda): App facilitating email and SMS doctor-patient communication

and are especially crucial for remote areas where health care services are limited.		**mPedigree** (Ghana): Platform using cloud-based and mobile technologies to verify pharmaceutical authenticity **Gifted Mom** (Cameroon): Mobile health platform helping pregnant women and mothers to access medical advice **Chanjo Plus** (Kenya): Mobile technology used by health workers to register and track child vaccinations **Rocket Health** (Uganda): Telemedicine platform offering clinical and laboratory services and medicine delivery
Blockchain technology is a "secure transaction ledger database that is shared by all parties participating in an established, distributed network of computers. It records and stores every transaction that occurs in the network, essentially eliminating the need for "trusted" third parties."[161]	Secure medical record sharing between information systems; patient privacy; payment systems	**CareAI:** Patient monitoring platform using blockchain to protect its health data management system **Afya Rekod** (Kenya): Decentralized, user-generated medical data storage platform using blockchain and AI **PanaBIOS** (Kenya): Health document verification system powering, along with Econet Wireless, the AU and Africa CDC's Trusted Travel to facilitate cross-border travel within Africa.
Drones are unmanned aerial vehicles.	Faster delivery of needed blood and medical supplies	**Zipline** (Rwanda, Ghana, Nigeria): Drone delivery service to rural health facilities **Beat Drone** (Nigeria): Spraying disinfectant (coronavirus) and insecticide (malaria) **Lifebank** (Nigeria): AI and blockchain powered deliver traceable medical supplies
The Internet of Things (IoT) refers to interconnected devices able to send and receive data automatically. These types of technologies are commonly labeled as	Accelerated diagnostics, medication distribution; improved water management	**CardioPad** (Cameroon): Heart scanning device connecting rural patients' data with urban cardiologists for evaluation **Matibubu** (Uganda): Malaria diagnostic device **Pelebox** (South Africa): Smart locker for routine prescription medicine pickup

[161] Kaushal and Tyle (2015).

"wearables" or "smart" devices.		**MamaOpe** (Uganda): Biomedical smart jacket that screens for pneumonia symptoms in children
3D printing, also known as additive manufacturing, enables a computer to use a digital design to produce a 3D object layer by layer using materials like plastics, metal, nylon, and ceramic.	Faster production of medical equipment, prosthetic limbs, and organs	**Cameroonian – Israeli partnership:** The High Tech Centre of the National Advanced School of Engineering where students are manufacturing protheses **Ultra Red Technologies** (Kenya)**:** Printing plastic face shields using an open source Swedish design to fill gaps in supply chain during coronavirus pandemic
Big data analysis refers to the collection of large and complex data sets from a range of sources that is stored, processed, and analyzed using 4IR technologies.	Faster, more accurate identification of health care gaps, health patterns, and disease tracking	**Vantage** (regional): Analytics system for health program implementation **54gene** (Nigeria): African genomic data aggregator supporting clinical and academic researchers
Cloud computing is the storage and management of data using a network of remote servers.	Broader accessibility of health databases and software across health systems	**RxAll** (Nigeria): IoT scanning device using AI for drug authentication **MamaRescue** (Uganda): Mobile platform facilitating transportation for mothers in real time to health facilities with the current capacity to offer the care they need
Fintech is digital and mobile financial services, including mobile money and microinsurance	More accessible financing solutions for healthcare costs	**Maisha Meds** (East Africa): Software platform with a mobile money reimbursement and discount feature **Mutti** (Ethiopia): mPharma's mobile money membership program **MicroEnsure** (Ghana): Health insurance offered as a mobile plan add-on **Jamii Africa** (Tanzania): Low-cost health microinsurance plans **M-TIBA** (Kenya): Health insurance mobile manager and provider, including mobile money that can be transferred to friends and family for healthcare costs

Biotechnology is an applied science using living organisms	Medical discoveries (vaccines, genetic engineering, etc.) that prevent or eradicate disease	**IndyGenUS** (Kenya): Blockchain-enabled indigenous and diasporic genomics database for use in disease and drug research **TargetMalaria** (Burkina Faso, Ghana, Uganda, Mali): Alliance researching gene-editing in mosquitos **ACEGID** (Nigeria): Genomics research, education, and capacity-building center at Redeemer's University
Virtual reality uses hardware and software to create a 3D experience simulation	Treating mental health conditions and developmental disabilities, as well as educating health care providers	**VRapeutic** (Egypt): AI and biosensor powered tool for medical professionals to use in the therapeutic treatment of children with autism, ADHD, cerebral palsy, among others; Cloud-based, immersive learning modules targeting social and cognitive skill development

Source: Author's compilation of information from various sources.

All in all, as illustrated here and summarized in the table above, Africa's health care sector is one with the potential to benefit the most from the disruptive technologies of the Fourth Industrial Revolution. To further capitalize on it, policymakers have to address recurrent challenges and policy constraints, and adopt effective strategies for bridging the gap between the promise and delivery in Africa's health care during the Fourth Industrial Revolution.

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