Artificial intelligence in Africa: challenges and opportunities

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Abstract

The developments in artificial intelligence (AI) have the potential to disrupt and transform socio-economic activities across industries. While evidence is emerging that businesses and governments across the world are positioning themselves to maximise these potentials, evidence also indicates that countries in the Global North are better prepared to reap the benefits of AI even though a significant number of jobs that could be displaced in the process are in the Global South. Therefore, we posit that countries in the Global South such as those in Africa need to tackle governance issues and lack of institutional capacity to establish the building blocks to allow AI to flourish. It is important to also examine the roles of international communities' in bridging the technological gaps in Africa by adopting a problem-driven approach where local needs and problems are contextualised into AI policy formulation rather than a blanket 'copy-and-paste' practice that has limited the advancement of development policies in Africa. A problem-driven approach would help African countries to formulate robust AI policies that are relevant to their unique circumstances.

Keywords: Africa, Artificial intelligence, Challenges, Digital divide, Opportunities.

1. Introduction

Developments in artificial intelligence (AI) have attracted both academic and public attention to analyse and understand its potential to transform our societies and its disruptive impact on a range of industries. While the definition of AI varies across literature, the definitions are underpinned by the idea of AI as a "non-human intelligence programmed to perform specific tasks" [1]. We draw on existing literature [2, 3,4] to posit that AI is a collection of information and communication technologies (ICTs) that mimic human intelligence to enable machines to facilitate our jobs better, create greater efficiencies and drive economic growth. Thus, various definitions of AI point to the capacity of machine to "perform specific roles and tasks currently performed by humans within the workplace and society in general" [1]. Although AI was first coined in 1956 by John McCarthy, the concept predates the 1950s [5, 6, 7,8]. Accordingly, while AI has existed for centuries and morphed from the first[1] to second[2] and third[3] industrial revolutions with limited attention, the emergence of the fourth[4] industrial revolution (4IR) has heightened attention due to the critical role of ICTs in accelerating socio-economic development. AI is accelerating the speed and scope of the 4IR at an unprecedented and exponential pace relative to the linear process of previous industrial revolutions [9]. From agriculture to banking, education to healthcare, the reach and usefulness of AI is still unfolding. It is estimated that by 2030, AI could contribute over $15 trillion to the global economy with more than 20% increase in the GDP of local economies as humans and robots 'work' in harmony to engineer solutions to challenging world problems [10, 3].

While governments and businesses across the world are beginning to position themselves to reap the opportunities of AI [4, 11], the development and deployment of AI technologies are uneven globally with a considerable gap between developed and developing countries [12]. Furthermore, it is argued that the increasing

[1] First industrial revolution adopted water and steam engine to mechanise and advance production process.
[2] Second industrial revolution adopted the power of electricity to advance mass production.
[3] Third industrial revolution (3IR) adopted electronics and information technology to automate production.
[4] Fourth industrial revolution adopts a fusion of digital technologies to further advance production automation.

use of AI can have a negative impact on developing countries that host a significant number of jobs that could be displaced through automation. Therefore, it is vital that we investigate the readiness of developing countries by exploring the opportunities and challenges that AI can bring to these economies. To achieve this feat, we focus on African countries. The overarching aim here is to provide insights into the African context – a region of the world that has not maximised the benefit of the previous industrial revolutions and often under-researched when it comes to the development of ICTs relative to the Global North [12, 13]. This chapter is organised as follows: we first take stock of recent developments in AI in Africa, followed by an examination of the potential economic, governance and social opportunities that it can provide to African nations. We then point out some of the challenges that policymakers need to be aware of as a result of AI deployment. We conclude by underscoring the need for policy initiatives to support the development of AI capabilities in the African context.

2. Artificial intelligence in Africa: distilling the story so far

As the development of AI continues to expand across the world, an ecosystem of AI is also emerging across Africa. According to Leila Janah, the founder and CEO of Samasource[5], *"if you use a mobile phone or laptop's facial recognition features, drive a car, or shop online, there's a good chance that a person in East Africa helped train the algorithm that makes your technology work."* [14]. Similarly, several local and international AI research hubs have been established. For example, the University of Cape Town (South Africa) established the Robotics and Agent Lab (RAL) in 2007 to focus the development of robotics and computational intelligence as well as building the capacity of children from low-income households by supporting their annual participation in RoboCup Junior – an annual international robotics competition [15, 16]. Data Science Africa (DSA), which has been operating since 2013, is a non-governmental organisation based in Kenya with a focus on promoting affordability, wider deployability and the suitability of AI solutions in Africa [17]. DSA provides a platform for AI practitioners and researchers across Africa to discuss and share knowledge of the development and usefulness of AI via summer schools and workshops, which have been held in Ethiopia, Ghana, Kenya, Nigeria, Tanzania and Uganda. Part of DSA achievements includes the training of over 200 people in machine learning techniques and data science applications using the internet of things (IoT) and social media data analytics. The outcomes of these trainings have resulted in the development of applications that facilitate agriculture, disaster management and healthcare [17].

Women in Machine Learning & Data Science (WiMLDS) also have chapters in Algeria, Botswana, Kenya, Morocco, Nigeria and Uganda to engage with and promote women participation in AI. WiMLDS is critical in amplifying the voice and input of women in the advancement of AI given the concerns raised on the lack of diversity and gender bias in AI [18]. Furthermore, IBM Research opened AI labs in Nairobi (Kenya) and Johannesburg (South Africa) in 2013 and 2016 respectively [19]. Google followed in 2019 and opened its AI lab in Accra (Ghana) [19]. Both Google and IBM labs have engineered AI solutions to improve food production and healthcare across Africa as outlined in Section 3. Given that majority of the academic and industry research hubs that focus on AI are predominantly located in advanced and wealthy locations such as Silicon Valley in California and Zhogguancun in Beijing, a recent shift to African countries is encouraging and has led to the emergence of around 100 AI start-ups across various regions in Africa, examples of which are presented in Table 1.

[5] Samasource is an AI data training company headquartered in San Francisco with operations in East Africa.

Table 1: Examples of AI start-ups across Africa

Country	Government AI readiness index ranking (out of 194 countries)	Number of AI start-ups	Start-up example	Year founded	Sector application	Description
Algeria	141	1	Monadim	2017	Marketing	Monadim combines data analytics and machine learning algorithms to provide a 'one-stop' digital platform for firms to manage business activities such as accounting, customer relationship management, purchasing, payroll, project management and inventory
Cameroon	119	1	Agrix Tech	2018	Agriculture	Agrix Tech uses data analytics and AI imaging techniques to detect crop diseases at early stages and propose viable treatments to farmers in local languages
Cote d'Ivoire	104	1	WeFlyAgri	2016	Agriculture	WeFlyAgri provides drone technologies and virtual reality services that are user-friendly for farmers to remotely monitor crop production from the sky
Egypt	111	5	WideBot	2016	Business service	WideBot provides a segmentation platform that focuses on over 400 million Arabic speakers using a customised chatbot to understand different Arabic dialects for targeted broadcast
			Niotek	2017	Manufacturing	Niotek combines hardware and software to power an IoT platform that relays real-time visibility and actionable insights to facilitates efficient and fast decision making for manufacturing operations
Ghana	75	5	Curacel	2016	Fintech	Curacel provides an automated platform that helps insurers to facilitate claims and fraud detection using algorithms that can detect fraud and errors in customer data
Kenya	52	9	PesaKit	2018	Fintech	PesaKit combines a chatbot with other AI techniques to provide a last-mile agent network to accelerate financial inclusion for the unbanked
Nigeria	107	20	Gradely	2017	Education	Gradely uses AI to study the learning pattern and output of students to engineer a personalised learning toolkit that helps schools and parents to intervene in real-time and plug the gaps in students learning
			Aajoh	2015	Health	Aajoh provides a platform that uses predictive analytics to improve healthcare access via mobile phones – where people can remotely receive medical diagnosis and treatment, and mitigate the lack of healthcare in various parts of Africa
South Africa	68	26	Accrad	2020	Health	Accrad developed an AI deep learning algorithm application called CheXRad to concurrently detect coronavirus (Covid-19) and up to 14 clinical diseases in chest radiography

Source: created by the authors using data from a variety of sources including Alliance4AI.org and Oxford Insights

About 100 AI start-ups have emerged across Africa, raising over $140 million of seed-funding with the majority going into fintech in Nigeria. For example, Cellulant[6] have raised $47.5 million followed by Mines.IO[7] with $17.2 million [20]. While Nigeria has attracted the largest amount of seed-funding, South Africa has the highest number of AI start-ups (26) in Africa followed by Nigeria (20) and Kenya (9). Further, Tunisia and Zimbabwe have 6 AI start-ups apiece while Egypt and Ghana have 5 each. It is somewhat surprising that while Nigeria has attracted the largest AI seed-funding, Kenya, Tunisia, Mauritius, South Africa and Ghana rank higher (respectively) when it comes to government AI readiness in Africa [see 12 for details]. It is also interesting to note that while the fintech sector has attracted the largest amount of seed-funding, the healthcare sector has the highest number of AI start-ups (21) followed by agriculture (14) and manufacturing (5) sectors. What is more, most of the AI start-ups were founded about a decade after the advent of the 4IR, which began in 2000 [21]. An indication that African countries are already lagging behind the rest of the world. This is consistent with the 2019 government AI readiness index, which indicates that there is no African country in the top 50 from the 194 countries analysed [12]. This is reflective of [10] projection that Asia (especially China) and North America would have the largest economic gains from AI - nearly 70% of the projected $15.7 trillion estimated for AI contribution by 2030.

In order to avoid a repeat of the missed opportunities from the previous industrial revolutions that have left a negative legacy for African countries, governments must create an enabling environment for these AI start-ups to flourish and accelerate the socio-economic development of Africa. These AI start-ups have taken the first step to overcome the infrastructure and resource constraints prevalent across Africa to engineer local solutions [20, 22]. Strong political will and government leadership are now needed to complement and sustain the gains made so far. Specifically, AI funding is needed to help local start-ups expand capacity and reach because if one compares the $140 million that has been raised in Africa thus far to the projected $79.2 billion global AI spending for 2022 [23], one could see a huge AI funding gap between Africa and the rest of the world.

3. Opportunities

AI-powered 4IR has the capacity to improve various aspects of socio-economic development across the world. AI has the potential to improve employment, the advancement of medicine and the quality of lives, improve productivity and efficiency of global supply chains as well as raise global incomes [9]. Many of these opportunities are already emerging across Africa. Take **employment**, for example. Samasource has employed youth across Kenya and Uganda to 'train' data and transmit human intelligence to AI for big tech companies including Google, Microsoft and Yahoo [14, 24]. Over 11,00 youth are working on various projects across Kenya and Uganda with incomes that support, for example, the education of their siblings and overall living condition of their families so much so that a network of over 50,000 people are now benefitting from this process [25]. The dependable income generated in the process also increases the purchasing power of people, which then helps them to gradually break the endemic cycle of poverty. For a country like Kenya with disproportionately high levels of youth unemployment of over 30% despite a growing literacy rate [25, 26], the jobs created by Samasource are critical to improving the quality of lives and maintaining social cohesion in Kenya.

In terms of promoting **food security**, Google AI lab has collaborated with farmers in rural Tanzania to create a machine-learning application called 'Nuru' (meaning light in Swahili) to diagnose early stages of cassava plant diseases for the advancement of the production of a common staple crop that provides food for over 500 million people [27]. Nuru works directly on farmers' cellphone even without internet connectivity and warns them to take early intervention by quickly identifying and managing cassava plant diseases, which, in turn, helps to maintain consistent food production. From the Sahel region to the Horn and Southern Africa, food insecurity is a major concern across the continent [28]. In 2018 alone, over 230 million people in sub-Saharan Africa (SSA) suffered from food insecurity [29]. While about 65% of global arable uncultivated land is situated in Africa, its governments collectively spend nearly $65 billion importing food in 2017 [30]. Furthermore, the locust outbreak in the Horn of Africa in 2020 is estimated to destroy over $8 billion worth of food and livestock [55]. The impact of food insecurity in Africa could be mitigated with the use of AI applications like Nuru and others in Table 1, crop diseases and disasters can be predicted, and farmers forewarned for better preparation. It is also useful to bear in mind that over 60% of Africa's employment comes from the agricultural sector [30]. Therefore, agriculture is a strategic sector that needs improvement across Africa and AI should be a critical part of the solution going forward.

Healthcare improvement is also not exempted. Following the delay in the reporting process of cancer diagnosis in South Africa as a result of the manual and unstructured pathology process, IBM Research pioneered a machine-learning system to automate the process and cut the reporting time from four to two years [19, 31]. The

[6] Cellulant is a fintech start-up located in Nigeria. It uses AI to facilitate digital payments and transfers

[7] Mines.IO is a fintech start-up located in Nigeria. Mines provides a platform that uses financial analytics to develop credit rating and fraud detection.

reduction of the reporting process offers invaluable information for the government to formulate national health policy and take timely decisions that would save lives. While South Africa is among the two countries in Africa (the other being Mauritius) that meets the minimum World Health Organisation's recommendation of 23 healthcare workers per 10,000 people [32], the country is still struggling to provide adequate healthcare to its citizens. Overall, access to healthcare in many African countries is acute. AI solutions like those engineered by IBM Research and other AI start-ups in Africa could be a 'game-changer' as the use of machine-learning systems and mobile phones can facilitate remote diagnosis and treatment for millions across Africa, particularly those living in remote and rural areas. Accordingly, from agriculture to banking, education to employment, healthcare to manufacturing, Table 1 is indicative of the opportunities and transformation offered by AI in Africa. But while there are several opportunities to be reaped from the development of AI in Africa, scholars have also pointed out several challenges and implications concerning, for example, structural inequalities and ethical concerns that policymakers need to take seriously [1].

Our country analysis in Section 2 indicates that the Fintech sector has attracted the highest investment in AI start-ups in Africa. **Financial inclusion** has thus been boosted by the advancement of technology in general and AI in particular. For example, it has been established that two-thirds of the over 1 billion people in Africa do not have access to traditional financial services [33]. The implication of this is that many people living across Africa are unbanked and excluded from the benefits of financial services, including the improvement of income earning potential for millions of people affected by poverty. For example, it has been found that an increase in financial inclusion by mobile money in Kenya has lifted over 180,000 women from poverty by enabling them to move from farming to developing small businesses [34]. AI is now enabling Fintech platforms such as Curacel and PesaKit (see Table 1) to accelerate digital financial inclusion for millions of unbanked across Africa.

4. Challenges

AI scholars [11, 35] have expressed concerns that the evolution of AI and other technological advancements could result in a series of unintended consequences. Broadly speaking, these concerns include the amplification of existing *structural inequalities, governance and regulation, and business and work disruptions* [35, 36, 37]. While these concerns could endanger any country in the world, we offer a nuanced discourse that focuses on African countries.

Structural inequalities are the disproportionate levels of access to socio-economic and political resources such as education, employment, income, ICTs and healthcare. When it comes to access to such socio-economic resources, African countries are among the least developed in the world [38]. Since AI is powered by a fusion of ICTs, the lack thereof is not the only disadvantage to prospective AI users but also AI developers with the implication that those suffering from a structural inequality like digital divides[8] are more likely to miss out on the critical opportunities of AI. Similar to the disproportionate levels of structural inequalities, African countries also lag behind other parts of the world when it comes to digital divides albeit with varying degrees across regions. For example, while Northern African countries average 68% average mobile phone penetration, SSA have 45% [39]. Digital divides in Africa are linked to issues such as inadequate telecoms network, lack of supporting infrastructure like electricity, unaffordability of smartphones and lack of digital skills [40]. Therefore, the Digital divides in Africa is symptomatic of deeper issues so much so that existing inequalities are then transferred into the digital space with the implication of poor AI readiness and many Africans falling through the net as indicated in the 2019 AI government readiness index [12]. With high levels of structural inequalities and digital divides, [41] also highlights a high degree a lack of government preparedness for AI among African countries with no country in the continent among the top-ranked 50 positions. Therefore, there is a correlation between structural inequalities, digital divides and AI readiness so much so that the most disadvantaged would also miss out on AI opportunities such as employment, improvement in education and healthcare, and access to e-government services.

Challenges also abound for AI **governance and regulation**. The fusion of multiple technologies underpins the architecture of AI and its ability to drive the 4IR. This fusion is accelerating technology convergence in a manner that poses a new challenge to governments, particularly in the realms of regulation. It is argued that the institutional capacity (i.e., skills and financial resources) of governments to regulate previous industrial revolutions, was less challenging given the propinquity between the speed of public policy decision-making and the linear-mechanistic process that existed [9]. Accordingly, governments had more time to formulate relevant regulatory framework to set the rules of engagement using limited capacity to govern the industry [36]. However, with the fast-moving pace of modern technology coupled with constant convergence, regulation becomes increasingly challenging, complex and expensive for governments [42]. Therefore, relevant legal and regulatory frameworks to guide the rules of the game are difficult to formulate and could quickly become obsolete as

[8] Digital divides here refer to the lack of access and skills to and affordability of ICTs.

technologies are becoming a moving target. The complexity that comes with the 4IR also requires a higher degree of institutional capacity, which is disproportionately lacking in African countries along with a fragile legal and regulatory framework [40, 43]. For example, only 19 of the 55 countries in Africa had enacted data security and privacy laws as of 2018 [44]. The headline figure is far meagre when it comes to AI - of all the 46 SSA countries, "only Kenya has an AI task force that is working towards a national strategy" [45].

The general lack of institutional capacity and AI regulatory framework across Africa could result in unintended consequences, including the inability of governments to guarantee the data security and privacy of citizens as well as mitigating the impact of cyber and national security. While the threat of cybersecurity has been around since the 3IR, the advancement that comes with AI and IoT further complexify personal and national security as critical and life-saving devices are wirelessly tethered together [46]. One implication of this is that state or individual actors could cripple critical infrastructure in a manner that threatens the existence of a nation. As technological advancement like AI develops, it heightens the threat levels of cybersecurity – this should also shift how governments respond to safeguard societies. Therefore, the paucity of comprehensive AI policy frameworks that are relevant to the African context is deeply concerning. While some have suggested that African countries should adopt the Convention on Cyber Security and Personal Data Protection of the African Union [45], we argue that such blanket 'copy-and-paste' practice has not helped the advancement of policies in the continent. From mimicking the tenets of wider economic reforms like the 'Washington consensus' [47] to telecoms liberalisation [48], copying-and-pasting policies have left much to be desired in developing economies such as those Africa [40, 49]. Instead of a copy-and-paste approach, African governments should adopt a problem-driven approach where local needs and problems are contextualised into policy formulation [50]. This approach would move AI policy in Africa beyond *institutional form* (how policy should look like) to *institutional function* (what policy should actually do) [51]. This, in turn, would help African countries to formulated robust AI policies that are relevant to their unique circumstances. However, African governments need stakeholder engagement to help reflect the inputs of relevant and a much broader community to build an agile institutional capacity capable of governing AI.

What about **Business and work disruptions?** According to Klaus Schwab, who introduced the 4IR concept, a common concern among business executives is that *"the acceleration of innovation and the velocity of disruption* [in the 4IR] *are hard to comprehend… even for the best connected and most well informed"* [9]. Similarly, there is evidence across Africa that the advancement of AI is beginning to challenge and underpin business models and processes. For example, over 70% of CEOs in South Africa have acknowledged the need to increase AI investment to boost competitiveness and productivity [3]. However, *"only about a third of these organisations are planning significant AI investments…"* [3]. This further underlines the huge AI funding gap between Africa and the rest of the world previously highlighted in Section 2. Low levels of AI investment would result in low adoption for businesses operating across Africa, making it very challenging to leverage on the opportunities offered by AI. Further, the evolution of AI could lead to the displacement of workers as automation could become substitutes for human labour [3, 36]. This would lead to wage stagnation and/or increase unemployment as the importance and negotiating power of labour becomes weak. This could increase the income gaps between the high-skilled and low-skilled workers, which could exacerbate structural inequalities. For example, [9] found that as the 4IR continues to emerge, the demand for high-skilled workers has increased while that of low-skilled workers, including those with less education, has decreased. Scholars [52] have highlighted the dangers of automation to the erosion of labour market and industrial policies in SSA and called for stronger institutions to enforce and protect workers' rights.

Another way to mitigate the displacement of workers in the face of automation is by reskilling the existing workforce on the one hand and repositioning the educational systems to cater for the needs of emerging digital opportunities on the other hand. The study of AI could be taken to the grassroots level and embedded in the curricula of primary and secondary schools so that people could learn about the usefulness of AI while also equipping young people with skills that are relevant to the 4IR. If such practice becomes widespread across Africa, this would help to mitigate the concerns around AI entrenching inequalities as more people would become knowledgeable of AI opportunities, increase its adoption, and create a pipeline of skills to compete in the emerging future of work.

5. Conclusion and the way forward

AI technologies have now become a central concern of academic and public discourse as they continue to disrupt industries and several aspects of our societies and daily life. Due to the forecasted contribution and impact of AI on future economies, academics, practitioners, and governments around the world are attempting to understand its implications and the ways through which its development can be nurtured. There remains however a huge gap between developed and developing countries when it comes to AI development and deployment which if not closed can lead to further inequalities between the Global North and South. Accordingly, several African

countries such as Algeria, Egypt, Ghana, Kenya, Nigeria, and South Africa have established governmental ministries and agencies that are tasked with building national AI strategies to ensure that AI implementations are driving technological changes in businesses, economy, education, agriculture, and infrastructure [53]. However, most African countries are still faced with governance issues and lack of institutional capacity which limits their ability for building supporting institutional and technological infrastructure for AI development and deployment. This leadership challenge raises the question of what institutional development policies and models should be adopted to support AI start-ups in Africa. It is important to also examine the roles of international communities' in bridging the technological gap in Africa which is increasing the social divide [1].

The role of governments in nurturing a conducive environment for start-ups is well established in the innovation eco-system literature. As the innovation literature points out, "innovation, like regional competitiveness, will not be achieved by fiat but rather through a combination of public and private initiatives" [54]. A national innovation ecosystem is composed of complex linkages between a variety of actors including entrepreneurs, large corporations, universities, governments, and users. The system must provide the right incentives for actors to encourage them to engage in innovative activities. These incentives can take the form of funds and seed capital for entrepreneurs and universities research centres engaged in developing AI technologies; encouragement of collaboration between universities and the private sector; and provision of tax policies that rewards innovation in AI. It is important, however, that such policies are not "copy and pasted" by African countries from the west, or imposed by international organisations, rather they should be developed contextually to fit with the needs of their local contexts [50].

While there are considerable opportunities to be gained from AI in Africa, there are also several challenges and unintended consequences that might arise that policymakers need to take seriously. These challenges range from structural inequalities due to digital divides and the lack of digital skills among a large proportion of the African population, to the dangers of automation and the displacement of jobs that might affect many industries. Therefore, due diligence is needed to account for these challenges - for example, by focusing on AI technologies that can empower rather than displace workers as well as developing schemes that focus on bridging the digital divides in African economies. Furthermore, underpinning AI developments is the need for a digitally skilled workforce, as such, bridging the digital divides is vital for African countries to be better placed to benefit from advances in AI.

References

1. Dwivedi, Y. K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., . . . Williams, M. (2019). Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*.

2. Kok, J. N., Boers, E. J., Kosters, W. A., Van der Putten, P., & Poel, M. (2009). *Artificial Intelligence: Definitions, Trends, Techniques, and Cases.* Paris: UNESCO & Encyclopedia of Life Support Systems.

3. Schoeman, W., Moore, R., Seedat, Y., & Chen, J. Y.-J. (2017). *Artificial intelligence: Is South Africa ready?* Pretoria: Accenture and the University of Pretoria's Gordon Institute of Business Science.

4. Singh, J. A. (2019). Artificial Intelligence and global health: opportunities and challenges. *Emerging Topics in Life Sciences, 3*, 741-746.

5. Anyoha, R. (2017). The History of Artificial Intelligence. *Science in the News - Harvard University*, 1-19.

6. Plant, R. (2012). An introduction to artificial intelligence. *American Institute of Aeronautics and Astronautics*.

7. Smith, C. (2006). The History of Artificial Intelligence. *History of Computing - CSEP 590A*, 1-27.

8. Spector, L. (2006). Evolution of artificial intelligence. *Artificial Intelligence, 170*, 1251-1253.

9. Schwab, K. (2016, January 14). *The Fourth Industrial Revolution: what it means, how to respond*. Retrieved from World Economic Forum: https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

10. PWC. (2017). *Sizing the prize: What's the real value of AI for your business and how can you capitalise?* London: PricewaterhouseCoopers (PWC).

11. Xu, M., David, J. M., & Kim, S. H. (2018). The Fourth Industrial Revolution: Opportunities and Challenges. *International Journal of Financial Research, 9*(22), 90-95.

12. Oxford Insights. (2019). *Government Artificial Intelligence Readiness Index 2019.* Oxford: Oxford Insights and the International Development Research Centre (IDRC). Retrieved from Oxford Insights and the International Development Research Centre.

13. Amankwah-Amoah, J. (2019). Technological revolution, sustainability, and development in Africa: Overview, emerging issues, and challenges. *Sustainable Development, 27*(5), 910-922.

14. Janah, L. (2018, December 05). *How East Africa Trains AI*. Retrieved from Linkedin: https://www.linkedin.com/pulse/how-east-africa-trains-ai-leila-janah/

15. Ferrein, A., & Meyer, T. (2012). A Brief Overview of Artificial Intelligence in South Africa. *Association for the Advancement of Artificial Intelligence*, 99-103.

16. RoboCupJunior. (2019). *What is RoboCupJunior?* Retrieved from RoboCupJunior: https://junior.robocup.org/about/

17. DSA. (2020). *About Data Science Africa*. Retrieved from Data Science Africa: http://www.datascienceafrica.org/

18. Feast, J. (2019). 4 Ways to Address Gender Bias in AI. *Harvard Business Review*.

19. Hao, K. (2019). The future of AI research is in Africa. *MIT Technology Review*. Retrieved from https://www.technologyreview.com/2019/06/21/134820/ai-africa-machine-learning-ibm-google/

20. Tsado, A., Litombe, N., Leta, E., & Giuliani, D. (2019, September 13). *AI Generation: Learnings from Alliance4AI's First 100 Startups in Africa*. Retrieved from Medium: https://medium.com/alliance4ai/ai-generation-learnings-from-alliance4ais-first-100-startups-in-africa-acfba0f753d1

21. Prisecaru, P. (2016). Challenges of the fourth industrial revolution. *Knowledge Horizons - Economics, 8*(1), 57-62.

22. Travaly, Y., & Muvunyi, K. (2020). The future is intelligent: Harnessing the potential of artificial intelligence in Africa. In *Foresight Africa 2020: Top priorities for the continent 2020-2030* (pp. 69-71). Washington, D.C.: The Brookings Institution.

23. International Data Corporation. (2019, March 11). *Worldwide Spending on Artificial Intelligence Systems Will Grow to Nearly $35.8 Billion in 2019, According to New IDC Spending Guide*. Retrieved from International Data Corporation: https://www.idc.com/getdoc.jsp?containerId=prUS44911419

24. Lee, D. (2018, November 03). *Why Big Tech pays poor Kenyans to teach self-driving cars*. Retrieved from BBC: https://www.bbc.co.uk/news/technology-46055595

25. CNBC Africa. (2020, January 16). *Artificial Intelligence: What opportunities and challenges does it bring to East Africa?* Retrieved from CNBC Africa: https://www.cnbcafrica.com/east-africa/2020/01/15/artificial-intelligence-what-opportunities-and-challenges-does-it-bring-to-east-africa/

26. Statista. (2020). *Kenya: Youth unemployment rate from 1999 to 2019*. Retrieved from Statista: https://www.statista.com/statistics/812147/youth-unemployment-rate-in-kenya/

27. Alcober, F. (2018, June 20). *AI takes root, helping farmers identify diseased plants*. Retrieved from Google: https://www.blog.google/technology/ai/ai-takes-root-helping-farmers-identity-diseased-plants/

28. Ehui, S. (2020, May 14). *Protecting food security in Africa during COVID-19*. Retrieved from The Brookings Institution: https://www.brookings.edu/blog/africa-in-focus/2020/05/14/protecting-food-security-in-africa-during-covid-19/

29. Food and Agriculture Organization. (2019). *The state of food security and nutrition in the world: Safeguarding against economic slowdowns and downturns.* Rome: Food and Agriculture Organization of the United Nations.

30. Broom, D. (2019, July 12). *Millennials are transforming African farming*. Retrieved from World Economic Forum: https://www.weforum.org/agenda/2019/06/the-millennials-giving-african-farming-an-image-boost/

31. IBM Research-Africa. (2018, August 22). *Could you make a critical health policy decision using four-year-old data?* Retrieved from IBM Research-Africa: https://www.ibm.com/blogs/research/2018/08/cancer-machine-learning/

32. Jayaram, K., Leke, A., Ooko-Ombaka, A., & Sun, Y. S. (2020). *Finding Africa's path: Shaping bold solutions to save lives and livelihoods in the COVID-19 crisis.* Nairobi: McKinsey & Company.

33. Demirgüç-Kunt, A., Klapper, L., Singer, D., Ansar, S., & Hess, J. (2017, April 19). *The Global Findex Database 2017: Measuring Financial Inclusion and the Fintech Revolution.* Washington, DC: International Bank for Reconstruction and Development/The World Bank. Retrieved from The World Bank.

34. Suri, T. W. J. (2016). The long-run poverty and gender impacts of mobile money. *Science, 354*(6317), 1288-1292.

35. Brynjolfsson, E., MacAfee, A. (2014). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies.* London, New York: W. W. Norton & Company.

36. Schwab, K. (2017). *The Fourth Industrial Revolution.* New York: Crown Business.

37. World Economic Forum. (2020). *The Fourth Industrial Revolution, by Klaus Schwab*. Retrieved from World Economic Forum: https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab

38. UNHDR. (2018). *Human Development Indices and Indicators: 2018 Statistical Update.* New York: United Nations Human Rights Council.

39. GSMA Intelligence. (2020). *The Mobile Economy.* London: GSM Association.

40. Arakpogun, E. O., Wanjiru, R., & Whalley, J. (2017). Impediments to the implementation of universal service funds in Africa – A cross-country comparative analysis. *Telecommunications Policy, 41*(7-8), 617-630.

41. Rutenberg, I. (2019). Africa. In O. Insights, *Government Artificial Intelligence Readiness Index 2019* (pp. 9-11). Oxford: Oxford Insights and Canada's International Development Research Centre (IDRC).

42. Janssen, M., Brous, P., Estevez, E., Barbosa, L. S., & Janowski, T. (2020). Data governance: Organizing data for trustworthy Artificial Intelligence. *Government Information Quarterly*.

43. Fick, M., & Akwagyiram, A. (2018, April 04). *In Africa, scant data protection leaves internet users exposed*. Retrieved from Reuters: https://www.reuters.com/article/us-facebook-africa/in-africa-scant-data-protection-leaves-internet-users-exposed-idUSKCN1HB1SZ

44. Consumer International. (2018). *The state of data protection rules around the world: A briefing for consumer organisations.* London: Consumer International.

45. AI4D. (2019, May 08). *A roadmap for artificial intelligence for development in Africa*. Retrieved from Artificial Intelligence for Development in Africa: https://ai4d.ai/blog-africa-roadmap/

46. Wilner, A. S. (2018). Cybersecurity and its discontents: Artificial intelligence, the Internet of Things, and digital misinformation. *International Journal, 73*(2), 308-316.

47. Williamson, J. (1993). Democracy and the "Washington consensus". *World Development, 21*(8), 1329-1336.

48. Gillwald, A. (2005). Good intentions, poor outcomes: Telecommunications reform in South Africa. *Telecommunications Policy, 29*(7), 469-491.

49. Thomas, J. W., & Grindle, M. S. (1990). After the decision: Implementing policy reforms in developing countries. *World Development, 18*(8), 1163-1181.

50. Andrews, M. (2013). *The limits of institutional reform in development: Changing rules for realistic solutions.* Cambridge: Cambridge University.

51. Pritchett, L., Woolcock, M., & Andrews, M. (2013). Looking Like a State: Techniques of Persistent Failure in State Capability for Implementation. *The Journal of Development Studies, 49*(1), 1-18.

52. Gaus, A., & Hoxtell, W. (2019). *Automation and the Future of Work in Sub-Saharan Africa.* Berlin: Konrad-Adenauer-Stiftung.

53. Rudman, R., & Bruwer, R. (2016). Defining Web 3.0: opportunities and challenges. *The Electronic Library, 34*(1), 132-154.

54. Wessner, C. S. (2005). Entrepreneurship and the innovation ecosystem policy lessons from the United States. In *Local Heroes in the Global Village* (pp. 67-89). Boston, MA: Springer.

55. Kray, H., & Shetty, S. (2020, April 14). *The locust plague: Fighting a crisis within a crisis*. Retrieved from The World Bank: https://blogs.worldbank.org/voices/locust-plague-fighting-crisis-within-crisis?cid=ECR_TT_worldbank_EN_EXT