

Perspective

Road map for research on responsible artificial intelligence for development (AI4D) in African countries: The case study of agriculture

Arthur Gwagwa,^{1,*} Emre Kazim,¹ Patti Kachidza,^{1,2} Airlie Hilliard,³ Kathleen Siminyu,⁴ Matthew Smith,⁵ and John Shawe-Taylor^{1,6}

¹Utrecht University, Department of Philosophy, Heidelberglaan 8, 3584 Utrecht, the Netherlands

²Axiom Global, 159-173 St John St, London EC1V 4QJ, UK

³Institute of Management Studies, Goldsmiths, University of London, New Cross, London SE14 6NW, UK

⁴Mozilla, 331 East Evelyn Avenue, Mountain View, CA 94041, USA

⁵International Development Research Centre, 150 Kent Street, Ottawa, ON K1P 0B2, Canada

⁶UNESCO, 7 Place de Fontenoy, 75007 Paris, France

*Correspondence: e.a.gwagwa@uu.nl

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THE BIGGER PICTURE Artificial intelligence (AI) is an area of computer science devoted to developing systems that can be taught or can learn to make decisions and predictions within specific contexts. This paper discusses the way AI applications may profoundly affect African countries, both positively and negatively. The impact on each country will depend on a number of factors, in particular, how each country is ready the emergence of AI, and this includes the level of preparedness in other technologies, such as the availability of Internet, and powerful computers connected to Cloud and data. Among several sectors where AI could potentially benefit Africa is agriculture, as most Africans are not just employed in this sector but the sector best reflects African cultural values and customs, such as the collective and communal approach to life and work. The benefits AI could bring to African countries include the automation of farms, which can reduce labor costs, or detecting diseases on crops early enough before they spread. However, as with other technologies, AI is also likely to marginalize the poor and disadvantaged, who will not be able to take advantage of rapid technological advancement and innovation designed for a world more modern than the one they live in. As an example, the widespread automation of farms may destroy African ways of life, including the environment and ecosystems, and at the same time the profits AI generates may go to the large corporations that own the technology. If those invested in the research and development of AI on the continent continue blindly forward, we should expect to see increased inequality alongside economic disruption, social unrest, and, in some cases, political instability, with the technologically disadvantaged and underrepresented faring the worst. They need to ask questions—and relevant ones—before coming up with a road map for the responsible research and development of AI in African countries. This is exactly what this paper does. It provides context and asks key provocative questions for consideration.



Concept: Basic principles of a new data science output observed and reported

SUMMARY

Individuals from a diverse range of backgrounds are increasingly engaging in research and development in the field of artificial intelligence (AI). The main activities, although still nascent, are coalescing around three core activities: innovation, policy, and capacity building. Within agriculture, which is the focus of this paper, AI is working with converging technologies, particularly data optimization, to add value along the entire agricultural value chain, including procurement, farm automation, and market access. Our key takeaway is that, despite the promising opportunities for development, there are actual and potential challenges that African countries need to consider in deciding whether to scale up or down the application of AI in agriculture. Input from African innovators, policymakers, and academics is essential to ensure that AI solutions are aligned with African needs and priorities. This paper proposes questions that can be used to form a road map to inform research and development in this area.



INTRODUCTION

In 2019, the authors published a paper on the state of play in AI R&D that would guide Africa to position itself to better harness responsible AI technologies. The paper recommended an R&D road map for each key sector in Africa, starting with agriculture. It resulted in the current paper. This paper's findings tease out key issues and ask questions on responsible AI R&D in agriculture. These are meant to guide all relevant stakeholders to formulate road maps relevant to their own country's contexts.

Artificial intelligence (AI) has the potential to help solve many of Africa's most pressing and perennial problems, particularly the problem of food security. Applying AI to agriculture would, in theory, have the benefit of creating an Africa that is less challenged in terms of food scarcity and, at the same time, would contribute to environmental and agricultural justice. However, as with other technologies, AI is also likely to marginalize the poor and disadvantaged, who will not be able to take advantage of rapid technological advancement and innovation¹ designed for a world more modern than the one they live in. The impact of these technologies on marginalized populations is likely to be greatest in the agricultural sector given that approximately 54% of all workers in sub-Saharan Africa are in the agricultural sector, a figure that surpasses 70% in some countries.² This is very high compared with the United States, where agriculture and the food sector accounts for 10.9% of total US employment, with direct on-farm employment accounting for 1.3%.³ The figure also drops in the United Kingdom, where 1% of the population is employed in the agricultural sector.⁴

The current world economic order has, for many years, been criticized for its failure to address the needs of the Global South and its lack of optimization of opportunities to allow the Global South to develop in tandem with the Global North.⁵ Machine learning and other disruptive technologies offer an opportunity to address this imbalance and give realistic prospects of upending the economic order while creating new sources of value for the benefit of all.^{6,7} However, the shake-up that can conceivably be borne from the application of these technologies to real-life environmental and industrial problems is not without its risks and adverse consequences; each technology raises issues of concern, and regulators and governments will be required to create or adapt new policies and protocols to ensure that the adverse consequences are addressed.⁸

By adopting Smith and Neupane's definition of AI as "an area of computer science devoted to developing systems that can be taught or learn to make decisions and predictions within specific contexts,"⁸ this paper examines the actual and potential impacts of AI in areas like selective breeding, automatic plant management, identifying biological anomalies, spatial planning, and analyzing soil and weather conditions for precision farming. The paper begins with a concise outline of the current landscape in AI innovation, capacity building, and policy initiatives in Africa. An overview of several fields of AI technology that are poised to have an impact on Africans will be given, with a particular focus on the positive implications of AI and the steps African countries are taking to ready themselves for the fourth industrial revolution (4IR).

Examples are drawn from different agricultural sectors in specific African countries to demonstrate how AI can be applied along the entire agricultural value chain to address concerns like genetic sequencing, conservation, and climate change. This section will highlight the problems, opportunities, challenges, and social concerns, at both micro and macro levels, that AI could give rise to. We note that some of the key opportunities of AI relate to the ability to augment human capabilities and improve the access of African farmers to new markets through enhanced global value chains. We highlight how the innovations that allow these developments to take place are often used in tandem with other 4IR technologies such as biotechnology, nanotechnology, and blockchain. We discuss the impact of these technologies on policymakers, innovators, and academics/trainers in the agriculture sector, including how ownership and access rights to big and high-value data can have implications for genetic modification, automation, and value chains. We also address several key issues that stakeholders, especially governments, should prioritize: the disenfranchisement of African farm workers due to automation, concerns about data and privacy, application of algorithms in government procurement and distribution of agricultural inputs, and the need for agricultural and environmental justice to respect the rights of historically marginalized populations.

The discussions presented in the section "AI in agriculture: Theory, current progress, opportunities, and challenges" are followed by the questions that they have raised, which form the basis of the section "agriculture R&D questions and road map" in the African agricultural sector. Given the varying stages of adoption of AI in different African countries and the peculiarities of each country, the paper does not prescribe a template for the actions to be taken to address the challenges. Rather, this section focuses on providing guidelines and parameters to assist in the planning and formulation of an R&D agenda. Taking this approach enables the paper to provide context and direction for further exploration and research to those invested in the subject. It is our hope that this work will stimulate further discussions on how research should be conducted with the broader intention of development in mind. Our interest in developing this road map is precisely in creating and participating in a communal and collective engagement with fellow African scholars about common African issues in the same manner Europeans engage on European and European Union (EU) issues. As demonstrated in the section "agriculture R&D questions and road map," this paper teases out key issues and asks questions at a general level; it is limited in how it delves into specific country case studies as it is a road map and not the road itself. Constructing the detailed road is beyond this paper's purview. While the scope of this article is limited to agriculture, we anticipate that it is the first in a series of future papers that will examine the applications of AI to other sectors, including health-care, languages, and governance.

AI IN AGRICULTURE: THEORY, CURRENT PROGRESS, OPPORTUNITIES, AND CHALLENGES

Although AI-powered innovations bring powerful potential to improve agriculture, it is not sufficient to simply create a

technological solution to perennial problems, such as poor crop yields, without taking a holistic approach that addresses the problem and monitors and counters any negative effects of the technology. For example, while developers of a technology to improve crop yields may not be concerned with issues surrounding the collection, processing, and storage of data or the rights of the data subjects, it is imperative that they are aware of monopolies over data, seeds, and pesticides to ensure that the solution can be applied effectively. Having this awareness avoids the potential widening of the gap between the rich countries that have the monopolies and the poor countries that do not own their agricultural and data technology. Such a holistic approach allows agriculture to benefit from greater efficiency, particularly when AI decision-making technologies are applied to life-dependent food and water systems, ecosystems, and even the genetic foundations of life on the planet.⁹ However, it is also important to take into account the risks of collateral damage to these fundamental and delicately balanced areas; for example, genetic modification has ethical implications, and many argue that the focus of modifications should solely be on addressing the primary problem, namely the poor crop yields in this example.

Innovation

Agriculture is the backbone of many economies, with 54% of all workers in sub-Saharan Africa being employed in the agricultural sector, a figure that increases to over 70% in some countries.² However, the continent experiences huge challenges affecting a number of sectors within the agricultural industry, including food production, animal husbandry, and wildlife conservation, with 65% of Africa's land being affected by degradation caused by mining, poor farming practices, and illegal logging, reducing the resilience of communities to drought, flood, and other effects of climate change.¹⁰

Demand for food often exceeds supply and, as a result, countless people around the world suffer from chronic hunger, according to the International Fund for Agricultural Development, World Food Program, and Food and Agriculture Organization of the United Nations. In sub-Saharan Africa, the number of individuals suffering from a lack of food increases dramatically.¹¹ As the global population increases, the demand for food will naturally increase, with the global food demand expected to be at least 60% higher in 2050 compared with 2006.¹² This is likely to be accelerated by the coronavirus disease 2019 (COVID-19) pandemic, which has already exacerbated hunger and affected globalization and the free movement of people, goods, and capital.¹³ Many African countries also face additional challenges as they grow and urbanize; deforestation has left countless African communities struggling to establish new forest plantations due to financial restrictions.¹⁴

To meet these demands and economically develop, African countries must unlock their vast agricultural potential to enable the development of sustainable and inclusive agri-food innovation systems and to find ways to scale up smallholder forestry projects. Such innovation could, for example, take the form of restoring unused, degraded portions of smallholder farming plots and providing climate-resilient long-term savings and diversification to farmers.¹⁰ According to an agricultural specialist at the 2019 Skoll World Forum on Social Entrepreneurship in Oxford, as climate change makes farming more difficult

and young people around the world are rejecting farming as a career, these technological innovations are particularly important in making agricultural work more appealing and secure.¹⁵

Sub-Saharan Africa has already started to make progress toward developing these innovation systems, with nine of the 17 so-called innovation achievers coming from sub-Saharan Africa. Indeed, a growing number of developing countries are performing significantly better on innovation, as determined by the Global Innovation Index 2017, than their current level of development would predict. Low-income countries, led by Rwanda, Uganda, and Malawi, are continuing to gain ground on middle-income economies, closing the gap in innovation between high-, middle-, and low-income countries.

Within these less developed countries, these innovations, some of which are complementary to AI, include smartphone applications that connect farmers with other rural entrepreneurs who invest in labor-saving machinery like wheat-combine harvesters and offer them for hire.¹⁶ This is beneficial both to farmers, who can gain access to technologies that make harvesting more efficient, and to the entrepreneurs, who receive a return on their investment. Additionally, AI has been applied in Rwanda to predict harvest yield based on farm size and to create satellite-based "predictive analytics" for harvests in 10 additional African countries through a partnership between the Alliance for a Green Revolution in Africa and the Silicon Valley AI firm Atlas AI.¹⁵

Logistical services

AI-based algorithms can be used to facilitate the detailed organization and implementation of agriculture, especially complex farm operations. An example of an emerging technology aimed at improving the yields and profits of African farmers is the provision of low-cost agricultural machinery through AI-enabled or digital platforms like IBM's Hello Tractor, an open-source mobile platform that enables farmers to access tractor services on demand.¹⁶ Technologies like this will enable farmers who cannot afford to buy the equipment to react to the uncertainty caused by climate change in a quicker and more cost-effective way.

Africa's agricultural input schemes can also leverage AI both for efficiency and accountability. The AI and algorithmic decision-making (ADM) systems used in agriculture can be applied to improve efficiency in various sectors and have been used in the implementation of complex public-sector procurement, a major source of business for many companies. These systems can also help reduce fraud and corruption and do away with excessive and limiting bureaucracy.

Important questions to address surrounding how AI can affect logistics are:

- How are AI-based algorithms being used to facilitate the detailed organization and implementation of complex operations, and, if they are not, how could this be implemented?
- How can African governments rely on ADMs in agriculture administration, logistics, and supply chains, including the inputs programs?

Animal and crop disease diagnosis

Google's AI open-source library, TensorFlow, is already being used in Africa to monitor crops for disease as the capability of AI to recognize disease from images surpasses that of humans. This technology, which makes the process more accurate and

less time consuming than manual methods, has been applied by a start-up in Kenya that is using TensorFlow to recognize species and diseases in crop leaves using a convolutional neural network model that is trained to validate each step of the process, obtaining 94% accuracy after 10 epochs, a figure that can be improved to more than 99% after fine-tuning.¹⁷ Similar innovation is also occurring within African start-ups that leverage machine learning to create solutions to real-world problems,¹⁸ with young people in Ghana's hubs using mobile phones to create innovative machine-learning-based solutions for diagnosing crop diseases. Such technologies can be advantageous through early detection before disease can spread throughout the crop and allows farmers to promptly treat diseases before they have progressed to a severe stage. However, Nyalleng Moorosi, a Software Engineer at Google AI, revealed during the UN Global Pulse consultations that Google Ghana believes that AI technology in Africa is still in the early phase of implementation. Moorosi suggests that, rather than simply adopting ready-made AI products that are exported to Africa, the continent has opportunities to innovate: "We have interesting problems so we can expect our innovations and solutions [to be unique]."¹⁹

Further, this solution is not limited to crops but is also applicable to animal diseases. According to examples from other continents, machine-learning applications could also be adapted to animal health monitoring, with Aquabyte working toward a system that uses a network of Edge AI-powered cameras to monitor the size, health, and behavior of gigantic schools of salmon. Similarly, machine-learning applications used for human disease diagnosis could be adapted to animals. In Nigeria, the start-up Aajoh uses AI to diagnose medical conditions based on symptoms submitted by users in the form of text, audio, and photographs,²⁰ and, in Ghana, the app Diagnosify uses AI to provide solutions and diagnoses for skin diseases.²¹ Adaptations of these technologies could allow animal disease to be diagnosed based on symptoms given by farmers, allowing quicker action to be taken.

Questions raised by the use of AI in disease diagnosis are:

- Apart from crop disease diagnosis, what other range of tasks can machine learning, especially dataflow and differentiable programming, be applied to? For instance, how effective are these on animal disease diagnosis? What data exist that can be used?

Geospatial data

Farmers can use data to support their decision-making processes to decrease their inputs and increase their outputs, something that is particularly important for modern, precision agricultural methods. Farmers using these practices can benefit from increasing the accuracy of operational spatial data by using spatial statistics methods to determine the different soil types in a field, Global Positioning System (GPS) technology to create soil maps, and geographic information systems technologies to predict weather patterns. These technologies encompass an Internet of Things (IoT) ecosystem comprising networks of advanced sensors, auto-guided driving tractors that harvest both crops and data, servers and drones, and satellite imagery, which is often purchased by farmers.²² The geospatial technologies used in Africa, however, vary by country:

- In South Africa, the information-analytical company Aerobotics utilizes aerial imagery and machine-learning algorithms across several industries, including insurance and agriculture, for example, to solve specific problems like detecting early pest disease.²³ In May 2019, Aerobotics signed an agreement with Agri SA to offer this as a free service for all South African farmers.²⁴
- Ethiopia launched its first observatory satellite into space in 2019 for agricultural, climate, mining, and environmental observations, allowing the Horn of Africa to collect data and improve its ability to plan for changing weather patterns, for example, by using such data to decide on when and what to plant. Developments in Ethiopia follow the introduction by the African Union of an African space policy, which calls for the development of a continental outer-space program and the adoption of a framework to use satellite communication for economic progress.
- The Kenyan company Apollo Agriculture uses AI to interpret satellite data, soil data, farmer behavior, and crop yield models. The data interpretation algorithms are targeted at detecting plant pests and diseases and give farmers access to customized financing, seed, and fertilizer packages. Additionally, Fastagger, a Kenya-based start-up's AI-as-a-Service platform, offers picture annotation to AI-driven companies in several sectors, including healthcare, power, industry, and agriculture. There is still a need, however, to ensure that these technologies are accessible to a wide array of farmers and that they are developed as inclusively as possible to include the views of and to benefit all sub-populations.

The UN World Data Forum mandated that the collection of data and monitoring of progress toward achieving economic, social, and environmental sustainability was the responsibility of individual countries. Sessions have since been held to enable the sharing of sound Earth observation methods and geospatial data products.²⁵ Further, academics, including Patrick MacSharry at the Carnegie Mellon University campus in Rwanda, have called for the improvement of the quantity and quality of data and the encouragement of wider and more effective use of big data in agriculture.

An important question on the use of geospatial data is:

- How can we ensure data from geospatial technologies in Africa's space are benefitting African farmers, especially smallholders?

Climate change and air quality prediction

Climate change is an impending crisis that the world has barely begun to prepare for.²⁶ While there are potential benefits of climate change, like increases in crop yields as temperature and carbon dioxide levels rise, these benefits are limited to particular regions, and optimal levels of soil nutrients and water are needed to capitalize on these benefits. Further, detrimental effects of climate change, like increases in the frequency and severity of floods, which can diminish food security,²⁷ are most likely to be felt in developing countries. By 2050, it is predicted that hundreds of millions of people are likely to have to leave their homes, particularly those whose livelihoods are in the agricultural sector if their land is no longer viable due to drought or

floods, resulting in a mass displacement that will place already vulnerable populations in more precarious and unpredictable positions and impose heavy burdens on the communities that absorb them.

International organizations, such as the United Nations, as well as industry and society, are exploring technological solutions that capitalize on the convergence of technologies like AI, robotics, drones, sensors, and networks to monitor the effects of climate change. While it may be argued that these technologies are taking over roles that are more suited to humans, which can conflict with the centrality of humanitarian principles, adoption of these technologies, particularly machine learning, has the potential to allow Africa to be in a better position to mitigate and adapt to the effects of climate change. Such solutions include the development of tools and technologies that leverage data sources from radio content, social media, mobile phones, and satellite imagery to develop technology toolkits. For instance, the network of Pulse Labs in Indonesia and Uganda and at the UN Headquarters (New York) collaborated on 20 innovation projects with over one dozen UN agencies and development partners to develop such toolkits. By leveraging data sources, they can enhance decision making by providing real-time situational awareness for project and policy implementation to mitigate climate change.²⁸ Projects that have applied AI to climate change include Omdena, who is using it to predict climate change through supervised learning support-vector machine (SVM) classifiers;²⁹ the Makerere University's Artificial Intelligence Research Group (AIR Lab) AirQo project;³⁰ and the IBM Green Horizons initiative.

Climate change innovations raise a number of questions:

- What climate change adaptation, mitigation, and resilience policies and practices are appropriate for the African context?
- Are there good practices that can balance the benefits and threats of greenhouse gases like carbon dioxide?
- How can Africa distribute the responsibility and impact of climate change with the developed world? For example, can AI be used to scale up collaboration on scaling up natural carbon capture globally to offset carbon emissions?

Infrastructure and data

The explosion in big data and better analytical tools is giving rise to new opportunities for innovation, some of which are already affecting agriculture or could potentially do so. These innovation patterns do not necessarily rely on cutting-edge technology; augmenting products to generate data, digitizing physical assets, combining data within and across industries, trading data, and codifying a distinct capability can all be carried out without state-of-the-art technology. Advances in the development of sensors, wireless communications, and big data have meant that it is now feasible to collate and crunch huge amounts of data in a variety of settings, ranging from kitchen appliances to intelligent surgical equipment in medical treatments. Within agriculture, the most relevant approach is the augmentation of products to generate data, with tractors and wind turbines being fitted with sensors that improve input and improve accuracy. The datasets can then be applied to improve the design, operation, maintenance, and repair of assets or to enhance the performance of activities. In turn, new and better services and business models are created based on these developments.

Despite the importance of big and high-value data, there are constraints to the use of such data; not only are these data often unavailable in emerging economies but the relevant stakeholders may also lack the capacity (technical and otherwise) to make use of them.³¹ Additionally, many countries in the Global South are not being given the necessary access to their own data that would allow them to apply and benefit from them due to contract rules that limit the ability of public citizens to access the data.³² In the context of AI in agriculture, a good example of exclusive data ownership rights and their implications comes from the use of digital sequence information, which, at a micro-level, applies DNA data to agricultural practices.³³ These advances have already been seen to transform genomics and gene editing, which could be ground-breaking for agriculture and animal husbandry, although more attention has been paid to the implications for human health. AI sequencing of DNA is faster, cheaper, and more accurate compared with conventional methods and allows researchers to gain perspective on the genetic blueprint that orchestrates all activities of that organism. With this insight, they can make decisions about care and determine what an organism might be susceptible to in the future, what mutations might cause different diseases, and how to prepare for the future.³³ Similarly, digital sequence information is relevant for aspects such as farm, landscape, and market-level data. Companies that already have a monopoly on the seed and pesticide industry, like Bayer-Monsanto or John Deere, possess a comparative advantage in the AI era; the merger of Monsanto and Bayer and John Deere's bid to merge its big data expertise with Monsanto-owned Precision Planting LLD can only increase their access to the big data necessary for the development of machine-learning algorithms in farm automation.³⁴

At the macro-level, however, a contemporary issue relates to the flow of information and the governance of digital sequence information. There is an ongoing difficult debate among party countries of the Convention of Biodiversity and the United Nations Convention on the Law of the Sea about access and benefit sharing for use of digital sequence information. While African countries are pushing for regulations that impede the flow of information, the European Seed Association offers a different view.³⁵ Thus, while big data and AI technology will provide excellent new business models, the precondition for these business models to be implemented on a large scale, particularly in Africa, would be to ensure the privacy of their users.

The use of AI in African infrastructure raises some important questions:

- How can we promote the use of data such that they can be exploited for African agricultural innovations?
- How can farmers and agriculture-based businesses create value for their customers using data and analytic tools they own or could have access to?
- Who should own the data? If the data are collected on farms, should they not be farmer data?

Inclusion and respect

Inclusion and future of work

The impact of AI automation has already begun to be felt.³⁶ Analysis of more than 200,000 jobs in 29 countries by PricewaterhouseCoopers³⁷ revealed the potential impact of automation:

- By the early 2020s, 3% of jobs will be at risk of automation, rising to almost 20% by the late 2020s.
- By the mid-2030s, 30% of jobs will be at risk of automation. For unskilled workers or those without higher education, this figure rises to 44%.

To fully anticipate the impact of AI on jobs in Africa's agricultural sector, it is important to consider the distribution of the labor force. In the agricultural sector, AI has two primary uses that are, or are expected to be, of significant impact and value:³⁸

- AI-powered agricultural bots (robots) that can exceed human capabilities for harvesting crops and picking weeds.
- Data analysis to predict the weather, optimize planting/harvesting schedules, and calculate fertilizer requirements.

The introduction of automation to harvesting and weeding would see AI, at least in part, competing with human labor. However, when AI technology is applied to predict important factors like weather conditions and the optimal farming practices, this can increase yields and the productivity or efficiency of the land without having a significant negative impact on the African agricultural labor force. Indeed, by improving the ability to predict floods and drought, optimize land usage, and increase yields, AI may increase the need for human workers in the agricultural sector. The use of AI is, therefore, not necessarily competitive with human labor but could complement it, depending on how it is used.

However, the reality of African agricultural practices reduces the overall impact that AI is likely to have. As small farms that occupy less than 2 ha account for 40% of farmland in sub-Saharan Africa, they make a substantially larger contribution to farmland than small farms do in rich countries,³⁹ and the daily wages for farm laborers in sub-Saharan Africa are substantially below those of highly developed countries. As a result, there is less of an economic incentive to invest in agricultural bots in Africa compared with developed countries. Accordingly, and notwithstanding the concerns about the potential of agricultural workers becoming redundant due to AI, the above factors suggest that the negative impact of AI on farm labor could, therefore, be substantially less in sub-Saharan Africa compared with developed countries. Further, the effectiveness of technologies is likely to increase if combined with other, complementary technologies; if technologies to predict floods could be combined with technologies to protect the farm from the floods, this is likely to maximize the effectiveness of both tools.

This discussion about the future of work raises an important question:

- What assessments of social justice issues, such as social mobility, lifestyle, and labor rights should be carried out before deciding which parts of the agriculture value chain should be automated?

Community values

Decisions about which technologies to apply or upscale in the context of agriculture should also consider which processes would benefit from being descaled or left as a human procedure. While automation can bring benefits like improved efficiency, the introduction of this automation can threaten the values, realities,

and aspirations of the communities that they affect by bringing disruption to families, their homes, and their living world. This poignant point has been made by Jim Thomas of the ETC Group, which monitors the impact of emerging technologies on biodiversity, agriculture, and human rights: 'When I contemplate Bayer-Monsanto or John Deere's harnessing of machine learning to further improve the productive "efficiency" of industrial agriculture I imagine them that way — forcing already depleted soils and farm economies into a metaphorical corner of the ring and pummeling them more efficiently.'⁹ Likewise, social media is awash with content questioning the true motivation of the benevolence of the external actors who seek to bring AI and other developmental tools to African agriculture, with many branding these initiatives as a danger to African self-determination and sovereignty. Such perceptions of AI as a poisoned chalice would limit the benefits of automation in Africa if they became the hallmark of these efforts. Open and honest dialogue involving all stakeholders must be established and maintained to ensure that these negative connotations are addressed and dispelled to allow the life-enhancing benefits of AI to be brought to the fore, even if this requires stakeholders to make compromises and modifications to their initiatives.

The best initiatives will be the ones that respect African values; some fear that technological responses to issues like climate change may technologize care, a vital component of the universal African concept of Ubuntu. In most African communities, agriculture is more than just a means of procuring food and livelihood; it is intertwined with culture and underpins many key events in villagers' lives, such as births, marriages, funerals, and celebrations. Given its dominance, AI initiatives should respect and avoid replacing the important aspects of Ubuntu to avoid creating a lacuna that would diminish and possibly render extinct the concept and values of Africanness.

This discussion on the potential impact of AI on African communities raises an important question:

- What social justice impact assessment, for example, environment damage and sentimental value of land, should be carried out before deciding which parts of the agriculture value chain should be automated, or where AI applications should be scaled up or descaled? For example, what would be the implication of deskilling in a certified profession like veterinary science?

Gender and exclusion

The ubiquitous challenges faced by women worldwide are particularly salient for African farmers, with women making up nearly half of all agricultural workers in Africa. Across many parts of Africa, these female farmers typically do not have equal ownership of the land on which they work, even at a subsistence level, are often ineligible for loans, and lack capital and access to training and agricultural inputs. These barriers, along with culturally sponsored gender discrimination, result in women being excluded from information that would enable them to adopt innovative agricultural practices to improve their crop yields and management systems. Consequently, there is a lack of female representation in higher-productivity agricultural sectors like commercial farming due to the reliance on social networks, infrastructure, and technology to which women do not have

access. They can also be restricted by laws that limit their access to agricultural inputs and other resources, preventing them from having equal participation in agricultural value chains. As a consequence, women's access to and control of income or seed capital for expansion projects becomes diluted, creating a cycle of exclusion and disempowerment.⁴⁰

This pattern of discrimination against female farmers could be further exacerbated by AI algorithms, which typically disfavor women as they are trained on biased data, resulting in them reflecting and amplifying the inequalities that already exist. The impact of these biased algorithms is particularly salient when inequality is multilayered,⁴⁰ since many women in African countries are already unable to afford to fulfill their basic needs.⁴¹ However, when used responsibly, innovation can make agriculture more accessible to women and mitigate some of the inequality; Twiga Foods, a start-up working with IBM to apply AI, big data, and blockchain, has allowed women who apply for unsecured loans for their micro-enterprises to build a credit score, allowing them to access funding for their businesses, something that would not be possible without this technology.⁴²

A number of questions are raised concerning the impact AI might have on female farmers:

- How will AI contribute to gender parity in agriculture participation? For example, will it improve the terms on which women participate in agriculture given the current shifts within markets and agricultural value chains, and, if so, how?
- In what ways are the current disfavoring of women by data and algorithm biases reflected in agriculture? What policies are needed for the intentional inclusion of women to redress discriminatory anomalies and provide safety nets, while utilizing AI technologies to include them in new forms of work, entrepreneurship, and innovation?

AGRICULTURE R&D QUESTIONS AND ROAD MAP

The road map provided in this section will set out the key issues of policy, innovation, capacity, and infrastructure for individuals and institutions to give readers who are unfamiliar with Africa-related issues in AI and agriculture—whether from government, industry, media, academia, or otherwise—a general sense of the kinds of questions the community is, or could be, asking and why. In formulating this road map, the authors avoid two pitfalls to ensure that the road map is not characterized by the long-foretold promise of a workless future or a cynical pipe dream obfuscating and reifying age-old power differentials.⁴³ We propose a road map that urges keen travelers to keep asking questions that will facilitate the creation of inclusive AI in Africa to ensure that there is power equality among AI stakeholders along with empowerment of the weak to prevent particular groups in Africa from being alienated from each other, their environment, or their culture.⁴⁴ While this paper teases out key issues and ask questions at a general level, it is limited in how it delves into specific country case studies as it is a road map and not the road itself. Constructing the detailed road is beyond this paper's purview.

Innovation

Agriculture logistics

- How are AI-based algorithms being used to facilitate the detailed organization and implementation of complex operations, and, if they are not, how can this be done?
- How can African governments rely on ADM systems in agriculture administration, including in the popular government or donor-funded agriculture inputs programs? Are there examples of public, private, and public/private logistical services?
- How can ADMs be deployed in a manner that includes and empowers the weakest members of society who have previously been excluded?

Research could collate information about the logistical services, their numbers and locations, capabilities, challenges and benefits, opportunities for scaling, and the role of government as an enabler within agriculture. It would also be important to examine extant regulatory frameworks that can be applied to public infrastructures such as satellites and technologies that pose huge capacity benefits, as well as safety and security challenges. Further, assessing how ADMs can improve efficiency, eliminate or reduce corruption, and contribute to more inclusive and fair schemes would also be valuable.

Food production

- Apart from crop disease diagnosis, what other range of machine-learning tasks can TensorFlow library (especially dataflow and differentiable programming), and related technologies be applied to? For instance, can it be applied in animal husbandry? If so, what would be the implication of deskilling certified professions, like veterinary science?
- What are the implications for the training of future crop and animal science professionals?

Evidence from other sectors has shown that AI can have an impact on environmental and social justice. In the context of agriculture, machine-learning tasks can be used to increase food production,⁴⁵ analyze images to discriminate against weeds and crops,⁴⁵ and automate harvesting and pest detection.⁴⁶ The sustainability of these technologies, however, has been questioned by concerns about soil depletion, which would result in subsistence farmers being unable to use these areas. This has the potential to cause disruption to urban facilities and services, which would be forced to accommodate the in-country migrants who were driven out of their rural homes. Consequently, the complex infrastructural problems that would result from this would be costly to resolve, thus diminishing the potential benefits of AI. However, if AI technology was applied to monitor soil quality as well as increase the quality and volume of yields, this could help to mitigate these potential issues.

Geospatial data

- What regulatory frameworks are in place to make sure data from geospatial technologies in Africa's space is benefiting African farmers, especially smallholders?

It is important to understand the role of the government in providing the regulatory frameworks used to determine the

boundaries surrounding the use of public infrastructures like satellites and GPS-driven technologies. Regulators would also likely benefit from considering who owns the data that are harvested by these technologies, and how local populations and smallholder farmers benefit from these data, which include high-value datasets used in weather prediction and drought mitigation.

Climate change and air quality prediction

- How can African farmers have access to timely, summarized climate and agricultural information for specific localities to help detect and prevent or respond to perennial catastrophes such as drought and floods?
- How can predictive analytics and AI technology be used on a range of other projects, such as harvest prediction?

The massive and intensive use of digital technologies around the globe is causing a colossal increase in energy consumption and greenhouse gas emissions. “Internet protocol traffic is much higher than estimated, and all cars and machines, robots and artificial intelligence are being digitalized, producing huge amounts of data which is stored in data centers.”⁴⁷ As a result, digital technology alone is expected to consume 20% of the world’s electricity by 2025 and account for 14% of greenhouse gas emissions by 2040. The electricity required to store vast amounts of data significantly contributes to climate change, the consequences of which are already disproportionately felt in African countries.⁴⁸ In response to this, Google Ghana is experimenting with compressing algorithms so that the computing power of mobile phones will be sufficient to run them, reducing the need for costly and energy-intensive computers and data farms.¹⁷ However, efforts to mitigate the effects of climate change typically emerge slower and are less of a priority in Africa than other countries as they are preoccupied with more immediate issues like hunger, drought, and political instability. The question of how AI and data projects can help African countries to cope with the effects of climate change is a key research topic and should remain firmly on the list of priorities for R&D agenda.

Community impact

Ethical and social impact

- What new and complex questions does AI raise regarding ethics and social impact in agriculture, and which entities should research these?
- What human rights, environmental, sustainability, cultural, and agricultural justice impact assessments should be carried out before deciding which parts of the agriculture value chain should be automated, or where AI applications should be scaled up or descaled?

AI has the potential to address challenges in agriculture, improve socioeconomic development, increase adoption, and reduce alienation and disempowerment. However, any adverse effects of the use of AI-driven technologies will be most felt by historically marginalized groups, meaning that it is important to explore historical issues such as natural resource exploitation, concerns about sustainability, and measures to protect the country’s biodiversity when introducing these technologies. Canada has already set an example for this in its use of AI models to understand how ecosystems⁴⁹ might respond to possible dis-

ruptions caused by various interventions or natural occurrences,⁵⁰ a project that has huge potential benefits for Canada.⁵¹

These considerations should be considered not only by the companies building and deploying the technology but also by independent academic research institutions in the region that are best equipped to pursue localized and innovative interdisciplinary research for the benefit of the African continent. This would make the consultation process more inclusive, likely resulting in local stakeholders being more cooperative.

Gender

- In what ways is the current disfavoring of women by data and algorithm biases reflected in agriculture?
- How will AI contribute to gender parity in agriculture participation? For example, how will it improve the terms on which women participate in agriculture given the current shifts within markets and agricultural value chains?
- What policies are needed for women to benefit? For example, could they benefit from policies that address these anomalies, provide safety nets, but also utilize AI technologies for including women and sexual minorities in new forms of work, entrepreneurship, and innovation?

AI technology is prone to bias due to implicit bias in the data used to train the algorithms, resulting in AI in agriculture disfavoring female farmers due to the long-standing discrimination against them. Research into how the bias in these algorithms could be mitigated and regulatory frameworks to enforce this will be an important step toward making automation in agriculture more beneficial to all.

Logistical issues

Scaling or descaling automation and its impact on the labor force

- As it has been argued that excessive automation by firms may lead to stagnating labor demand, declining labor share in national income, rising inequality, and lower productivity growth,⁵² how true does this hold for agriculture?
- What human rights, environmental, sustainability, cultural, and agricultural justice impact assessments should be carried out before deciding which parts of the agriculture value chain should be automated, or where AI applications should be scaled up or descaled?
- How is the deployment of AI in agriculture changing the ratio between capital and labor and how is Africa readying itself for the tension between labor and capital?
- How is the agriculture sector generally preparing for automation?

AI, particularly automation, is going to transform the way we work, with research revealing that AI technologies in the workplace tend to exacerbate tensions between the objectives of capital and labor. However, if organizations that are single-minded and purposeful in their development and deployment of AI undergo a cultural shift to be more considerate of its potential negative impacts, this will allow Africans to embrace the opportunities AI provides and apply it in a way that benefits them and reduces negative consequences³⁶ like the decimation of rural employment opportunities. Fortunately, this is not just an

African-led desire as impact assessment has become a standard consideration in the development and introduction of virtually any product or service in organizations. This is just one of the many ways in which organizations will have to adapt to the intelligence revolution.

Capacity

- What factors are enhancing or hindering interdisciplinary working; for example, engineers and technologists collaborating with lawyers and media practitioners?
- Why are the funding channels being built around or in collaboration with academic institutions and which universities and departments are taking part in which streams of work?
- What funding streams are available, which AI sectors are being funded, what are the current budgets?

Capacity has long been a challenge in African countries that are suffering from the restrictions of colonialism and lagging development and brain drain. Greater awareness of research and funding sources, investors, and policymakers would create and enable capacity building frameworks and conditions.

Accessing global value chains

- What are the governance (legal, ethical, and regulatory) considerations Africa needs to access global value chains in the AI era?

Technology, including AI, “can create significant new value through innovations for food systems.”⁴⁷ However, for this to happen, the current inequities in the global agriculture value chains need addressing, otherwise AI will simply reify the age-old power differentials.

Data

- What set of legal, technological, and social rules are needed to protect the ownership of data and make it clear where the data can or cannot be used?

Rules surrounding data usage and ownership should consider the explosion of big and high-value data, including that from geographic information systems (GSI) and satellite imagery. Research in this area should focus on how open data architectures that advance economic and social activities could be created and used in a way that balances access and privacy, cross-border data flows, data ownership, and equity to enable farmers to access markets and scientific knowledge fairly and securely. This would ensure that big technology companies using big data, new technologies, and new analytical approaches in their partnerships with big corporations in the agriculture sector do not consolidate their power to limit democratic oversight in the public interest. African policy owners could explore how they could learn from the new EU Open Data Directive, which reins in the corporate monopoly over high-value data and is more stringent and open to protecting public values in its provisions.

CONCLUSIONS

The ability to enhance the performance and sustainability of agricultural food production systems globally depends on developing a deeper understanding of the linkages between innovation inputs

and outputs and diffusion pathways in the sector. AI can play a key role in helping us understand these diffusion pathways, not only in the agricultural sector but also in the crucial process of connecting African farmers to new markets, as well as to new sources of knowledge from other sectors. Only then will it be possible to fully leverage the potential of agricultural innovation, reverse persistently low levels of agricultural productivity, and ensure a sustainable global food supply.⁵¹ In this regard, AI is an invention in the methods of invention that can fundamentally increase the productivity of scientific R&D and generate important spillovers for the sectors using that knowledge.⁵³

As observed above, to diffuse successfully, AI can leverage the current convergence of biology, agronomy, plant and animal science, digitization, and robotics that is transforming the global agri-food value chain. Sub-Saharan African countries will be able to capitalize on these advancements if they omit the earlier stages of innovation, which they did not participate in or benefit from, and, to do this, Africa must enhance its data infrastructural capacity to be able to handle the big data required to train the machine-learning algorithms. Failure to make these enhancements would result in the forced adoption of obsolete and rudimentary AI solutions that would not be adequate for Africa’s developmental goals and the needs of its populations, leading to the perpetuation of Africa’s slow uptake of current technology and the potential of AI to solve some of the perennial problems referred to in this paper being limited. For Africa to be fully integrated into the global supply chain and new markets, advancements need to be made: the negotiation of trade rules and multilateralism at forums like the World Trade Organization, the introduction of new trading rights addressing the monopoly on the seed and pesticide industry, the strengthening of government regulation in the public interest, and workers in these developing countries being protected from being kept at the lowest levels of the global value chains and labor disruption due to automation.

However, this integration into the global supply chain also raises some ethical questions. Although, throughout most of history, there has been a limited range of actions available to agricultural workers and the consequences of these actions have been constrained in scope and impact through dispersed power structures and slow trade, in today’s globalized and networked world, farmers can easily access new markets through enhanced global value chains. Algorithmic decisions, therefore, can affect billions of people instantaneously and have tremendously complex repercussions, posing questions like:

- How do we decide how machine-learning algorithms and their designers should act?
- What ethics apply today and what will they be in the future?

These questions cannot be addressed by policymakers and technologists alone as they are in the realm of ethics, or the philosophy of human conduct,⁵⁴ something that is difficult to replicate artificially. AI R&D in Africa should, therefore, consider legal, ethical, and regulatory governance along the entire value chain but should, more importantly, reflect African cultural values and customs such as the collective and communal approach to life and work. Particular attention should also be paid to Africa’s historical peculiarities, such as the colonial practices that resulted in the displacement of families from productive

agricultural land to dry, unproductive lands, as well as the impact on subsistence and social cohesion. AI application, especially the automation of tasks and the reconfiguration of global value chains, should not cause a second wave of displacement but should instead be anchored in the values, realities, and aspirations, including the families, homes, and the living world, of the communities that are to benefit from the technologies.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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Arthur Gwagwa is in Utrecht University Ethics Institute, where his research interests include ethics of autonomous intelligent systems with a particular focus on Africa. He has held research associateships with University College London, Strathmore, and University of Cape Town and currently guest edits for Springer Nature and for the Stanford Internet Observatory. He has authored key papers in AI ethics, including for the We Robot Conference, Columbia, and Data & Society. <https://orcid.org/0000-0001-9287-3025>