Inclusively Advancing Agri-Food Systems through AI and Automation

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This document presents a subset of the full study on Inclusively Advancing Agri-Food Systems Through AI and Automation, focusing on **the impacts of AI and automation in agri-food systems in low and middle-income countries.**

INTRODUCTION

The Age of Artificial Intelligence (AI) is upon us - driven by unprecedented rates of innovation and adoption. Interest in AI has exploded as ChatGPT continues to capture the imaginations of the world. This AI technology - able to perform a wide range of language tasks at accuracies not seen before - was touted as the next frontier of AI capabilities until being achieved by OpenAI's GPT4 model. This step-change in the capability and accessibility of technology is the latest in a growing trend over the last century. In the early 1900s, the innovation and adoption of advanced agronomic practices and technologies such as high yield seed varieties, chemical inputs and mechanization led to the green revolution. The rapid growth in the capabilities of AI over the past decade is creating a new revolution in how every industry and sector around the world operates and is structured, and agriculture is no exception.

This revolution occurs at a time when the demands of the 21st century require a step change in agri-food system capabilities. The United Nations estimates that the global population will reach almost 10 billion people by 2050, with the majority living in LMICs in Africa and Asia.[1] This anticipated population boom will require a 60-70% increase in global food production by 2050.[2] The pressure on agri-food systems to produce more food to meet growing demand is compounded by the significant risks that climate change imposes on farming systems, particularly through changes in temperature and rainfall, extreme weather events and the increase in the number of pests.[3]

SSPs in LMICs, and their engagement with technology, are at the heart of whether and how this step change can occur. Although SSPs generate around one third of the world's food, they provide the vast majority of food consumed in sub-Saharan Africa and Asia – the regions where the bulk of the world's growing population will reside.[4] SSPs in LMICs are also among the poorest people in the world, with many living on less than $2 per day.[5] Even if larger, commercially oriented farmers alone were able to meet rising demand for food by adopting smart technology solutions, this would serve to further disenfranchise SSPs and the rural communities that depend on them. Enhancing the ability of SSPs to become more productive and resilient is therefore crucial, not only to global food security but to the economic and social development of LMICs.

AI and automation technologies have potential to deliver this step change due to significant advancements in their capabilities and a reduction in their costs. Foundational digital applications in agriculture are already demonstrating impact among SSPs. These include advisory services delivered through ICT rather than in-person, digital value chain payments creating an electronic record of income to better access financial services, and e-commerce platforms to procure inputs and sell products, among many others. Rapid advancements over the last decade in the capabilities of AI and digital automation technologies, with lowering barriers to entry and use, can build off this base to deliver greater value to SSPs at a much larger scale.

Despite their potential contribution, the impact that these advanced technologies among SSPs in LMICs will have is unclear. Whether they will help SSPs to improve their productivity and resilience to the extent that is required depends greatly on which value chain players the solutions are designed for; the accuracy and relevance of the solutions for SSPs; the accessibility and affordability of AI and automation and the underlying technologies; and the commercial viability of the solution providers. As with any new technologies, there are likely to be unintended consequences and risks that may limit this impact agri-food value chains are disrupted.

The full study aims to provide a compass to stakeholders navigating the complexities of these issues. As the application of these technologies among SSPs is still in the early stages, it is difficult to predict what their net impact will be, and almost impossible to do this quantitatively without significant investment in primary impact data collection.

This document provides a framework for considering the varied and sometimes contradictory impacts that specific AI and automation use cases may have in different contexts, and the trade-offs that need to be navigated by those working in agricultural and inclusive technology development.

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[1] United Nations, 2021, *World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100,* available here
[2] GSM Association, 2022, *Assessment of smart farming solutions for smallholder farmers in low and middle-income countries,* available here
[3] Mbow et al., 2019, *Food Security, Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*, available here
[4] Fanzo, 2017, *From big to small: the significance of smallholder farms in the global food system*, available here
[5] World Bank, 2016, *A year in the lives of smallholder farmers*, available here

METHODOLOGY

The study began with a comprehensive landscaping of AI and automation solutions in LMICs. This involved collecting information on current examples of AI and automation in agri-food systems in the twenty-three priority counties identified by the Bill and Melinda Gates Foundation (BMGF) and the US Agency for International Development (USAID).[6] Common types of applications – and their underlying AI and automation technologies – were identified in order to develop a taxonomy of use cases depending on where in the value chain they were being applied and what the core function of the technology was. This taxonomy was then used to select eight priority use cases with the greatest prevalence and potential for impacting on SSPs. The remainder of the study focused on these cases.

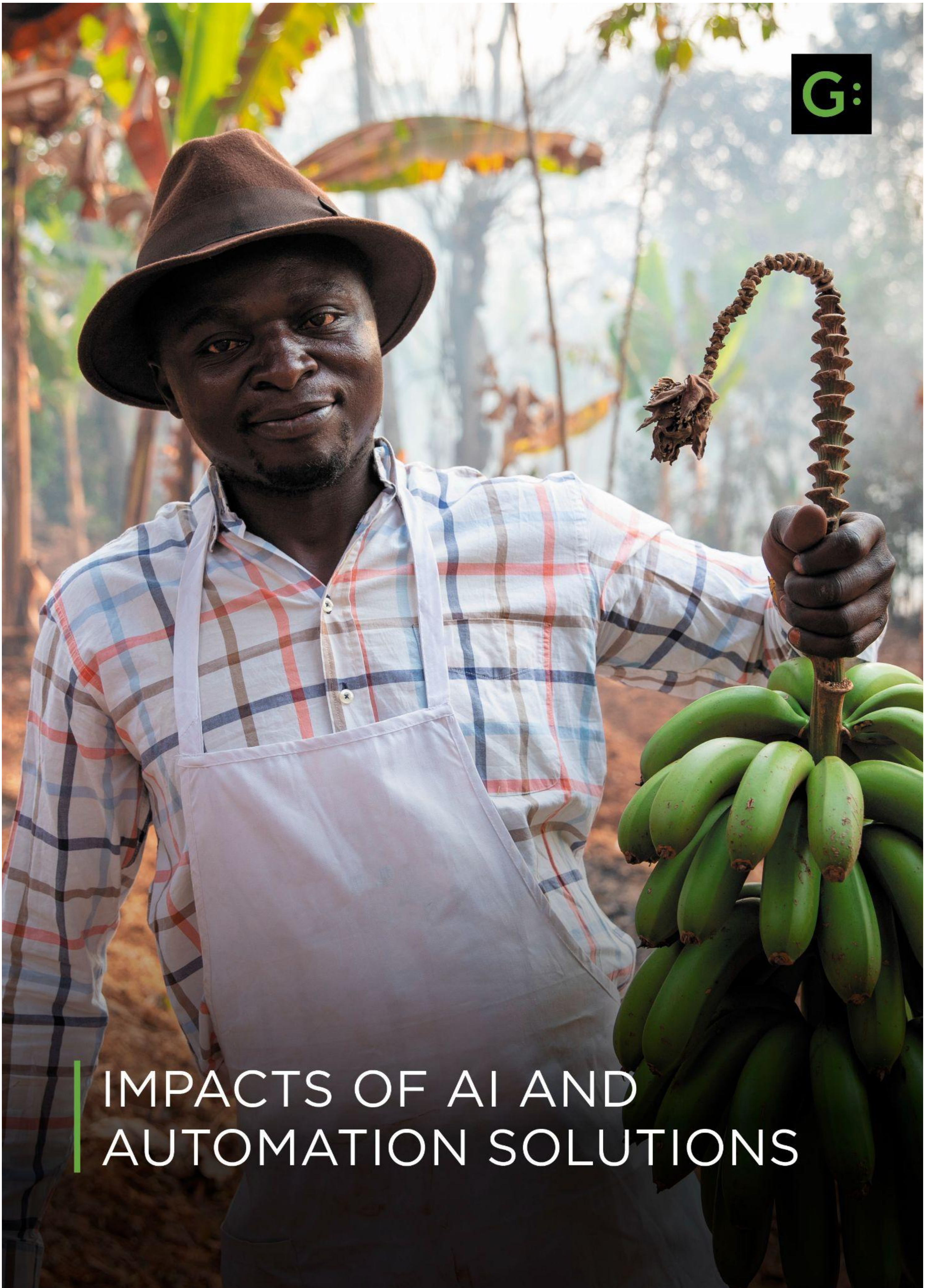
The stakeholder engagement phase collected information through targeted stakeholder interviews across the agri-food, technology and development ecosystem. These included interviews with agricultural policymakers and program officers, agricultural practitioners, impact investors, AgTech providers, and other agriculture and inclusive technology development experts. A full list of stakeholders is provided in Appendix 1. The purpose of the interviews was to uncover information on the technology requirements, delivery models and impacts of the prioritized use cases. A request for information was also issued to gauge a wider set of written responses to these questions.

The priority use cases were then analyzed through a framework that aimed to understand the potential impact channels – both positive and negative – and the factors likely to influence them. The framework components included economic, social, environmental and technological opportunities and risks. The most common opportunities and risks were synthesized into four key impact channels: productivity, cost saving, inclusion and climate resilience. This led to the identification of several cross-cutting trade-offs and considerations for solutioning, which need to be considered to maximize the opportunities and minimize the risks.

The cross cutting trade-offs and considerations for solutioning were then explored through several Joint Solutions workshops. The Joint Solutions methodology convenes small groups of diverse stakeholders, each of whom have a different perspective on a problem with diverse ideas on how to solve it. The purpose of the workshops was to validate the findings that emerged from our diagnostic assessment and identify potential solutions to the barriers preventing AI and automation innovation from supporting inclusive outcomes in agri-food systems.

The insights from the workshops were used to co-create policy, program and technology recommendations that can help overcome the barriers to achieving inclusive and impactful adoption of AI and automation in agrifood systems. The findings of our study, including the policy and program recommendations were presented in a public dissemination webinar on Tuesday the 4th of April 2023. The presentation outlined the key risks and opportunities of this tech-driven agricultural transformation, providing solutions to steer the ecosystem toward more inclusive outcomes.

[6] Bangladesh, Burkina Faso, DRC, Ethiopia, Ghana, Guatemala, Honduras, India, Kenya, Liberia, Mali, Madagascar, Malawi, Mozambique, Nepal, Niger, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Uganda and Zambia.



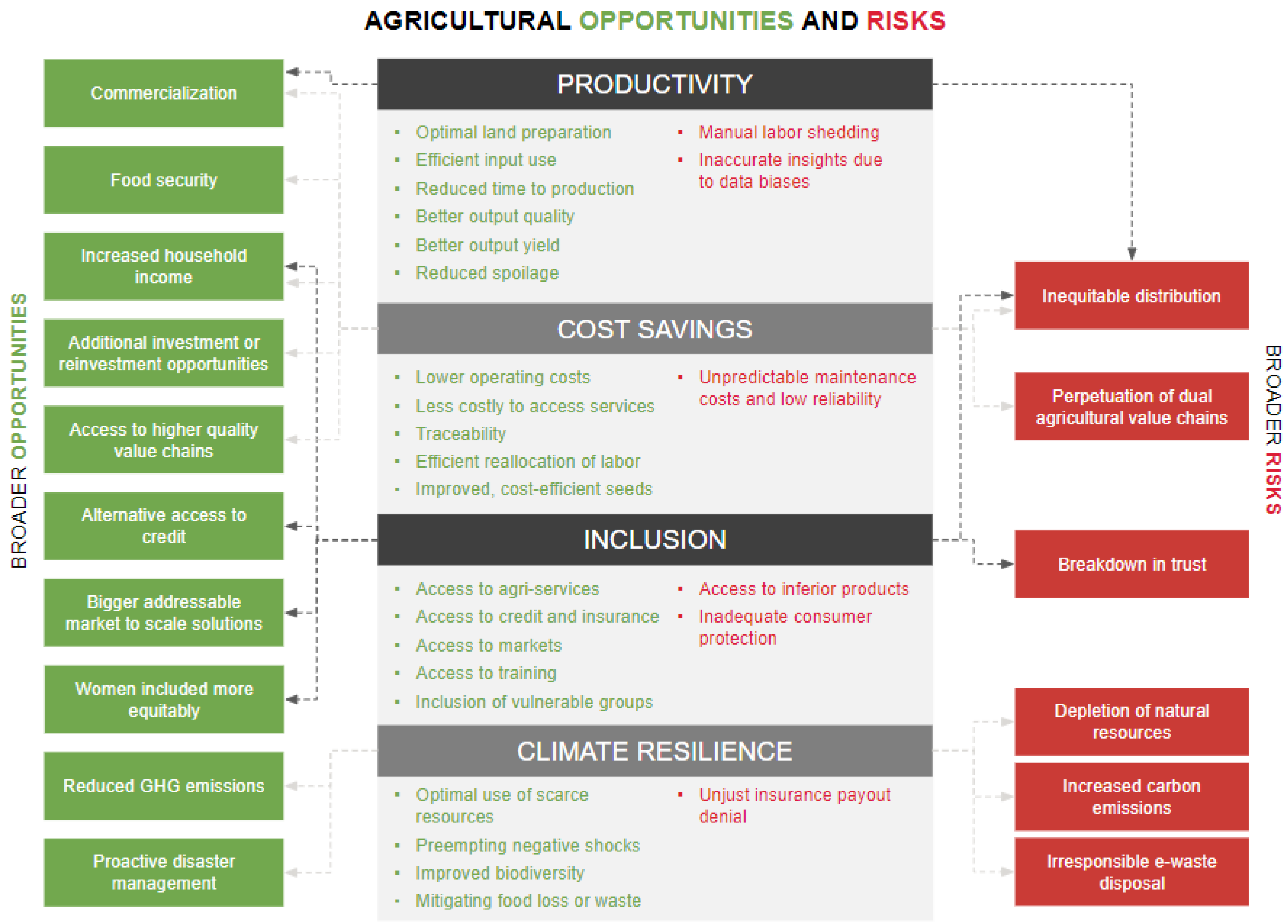
IMPACTS OF AI AND AUTOMATION SOLUTIONS

Determining the impact of AI and automation technologies on agricultural value chains is complex and contested. There are several factors that prevent a clear understanding of the direct and indirect impacts of AI and automation solutions on the agricultural sector. These include:

- ***A lack of empirical data:*** The introduction of AI and automation solutions in agriculture is a relatively new concept, often deployed in emerging countries and particularly in rural areas, where there is a shortage of systematic data collection. Impact data is often only available in isolated cases and is provided by the companies implementing the solutions.
- ***Bundling of solutions:*** AgTech solutions are often bundled together with other products and services, such as inputs, and delivered through a channel offering multiple services, such as an agent network. For example, a digital climate advisory service may also offer SSPs access to microcredit, insurance and rental equipment in addition to advice on climate smart agricultural practices. This makes it difficult to isolate and determine the net impact of any one of these technology solutions or the impact of the technology from the impact of the non-tech products it is bundled with.
- ***Independent implementation of solutions:*** There is a tendency for AgTech solutions to be implemented in silos and without an understanding of the long-term ramifications for SSPs. Poor design can jeopardize adoption rates and the sustainability of these solutions, and can lead to negative outcomes that could have been avoided had they been implemented with a more holistic approach.

To address this complexity, this study identifies the general impact pathways of AgTech solutions. There are four critical pathways through which AI and automation will have the biggest impact: i) improved productivity, ii) cost efficiencies, iii) inclusion and iv) climate resilience. There are two ways that the impact across these pathways can be considered. *Firstly,* impacts can be considered as either opportunities or risks. *Secondly*, these impacts can either be directly attributable to the agricultural value chain as agricultural opportunities and risks or indirectly attributable to broader socioeconomic, environmental or development issues, such as household income, environmental landscape and food security, which may be defined as broader opportunities and risks.

Figure 4: Overview of impact channels and associated agricultural and broader opportunities and risks



Source: Genesis Analytics, 2023

The range of impacts highlights that there may be important impact trade-offs across AgTech solutions. The way that these risks and opportunities emerge varies by channel and is dependent on the context of the AgTech solution and the way in which it was implemented. However, the number of potential opportunities outweighs the number of possible risks. The preceding figure provides an overview of the impact pathways, direct opportunities and broader impacts that are further described below.

Necessary preconditions

To realize the positive impact that AI and automation solutions offer to the agricultural sector, several enablers need to be in place. Failure to create an enabling environment for these technologies could result in the identified opportunities not being fully realized, or potential risks not being effectively mitigated. There are several cross-cutting factors that need to be in place, which include:

1. ***Digital inclusion:*** This involves several critical ICT infrastructure requirements that are essential to guaranteeing individuals' participation in digital services. *Firstly,* reliable, fast and ubiquitous **mobile and internet networks** are needed. *Secondly,* many remote AI or automation solutions require smallholder farmers to own a **smartphone device** to manage or engage with the solution. *Thirdly,* access to **electricity** is vital for individuals to access digital solutions. This is a particular concern for individuals located in remote or rural areas, where the majority of smallholder farmers reside, and where expansion of national electricity grids remains a significant challenge. *Fourthly,* capacity building to enhance the **digital and technical literacy** of SSPs (particularly those with limited formal education or older generations). *Fifthly,* the **affordability** of these solutions is critical to inclusion.[7] SSPs with limited financial resources may struggle to leverage solutions if they cannot afford devices or data, are unable to obtain credit or are unable to afford upfront capital investments. *Finally,* there are social and cultural norms that can influence gender

[7] Affordability here also considers whether low-cost domestic assembly of innovative solutions is viable.

dynamics as regards mobile phone ownership within a household. This creates uneven access to AI and automation solutions among men and women.

2. ***Effective public-private collaboration:*** Regulation typically lags behind technological developments which can inhibit the establishment of a secure and trusted environment for digital products and services. Flexible regulatory approaches need to be adopted by governments and policymakers to provide a framework that is fit for purpose in an evolving digital environment. An effective framework provides guidelines for regulating technological developments to ensure effective consumer protection, build trust in digital systems, and prevent data misuse. It does this without stifling innovation. The implementation of effective regulatory frameworks necessitate effective development cooperation amongst public and private stakeholders because, without adequate participation, effective regulation may not have the intended effect of supporting an all-inclusive digital ecosystem.

3. ***Human-centered design:*** A human-centered design approach is critical to the success of AI and automation solutions targeting SSPs. This places the SSP at the heart of the solution development process which ensures that the solution resonates with the SSP's circumstances and is tailored to meet their needs. The approach helps to ensure that appropriate digital channels are used, that relevant services and information are provided, and that the solution is coupled with a sustainable revenue model that supports adoptions by SSPs.

4. ***Holistic and complementary strategies:*** There are many stakeholders developing and offering innovative AgTech solutions. However, these solutions or programmes are often implemented in isolation. This has led to a fragmented market and disjointed progress across countries and markets. Strategies geared toward improving SSP productivity and livelihood requires effective harmonization amongst various stakeholders to be effective.[8] This is separate to the point of stifling competition and innovation, but rather focuses on various policy agendas and programmes being porous and creating an 'open-door' policy amongst program officers and policymakers alike.

[8] The Delivery Models section highlights how inefficient capital may contribute to the fragmentation and congestion of the AgTech solutions market.

IMPACT PATHWAY 1: **PRODUCTIVITY**

Innovations in AI and automation have the potential to advance agricultural productivity and contribute to the maintenance of global food security - an urgent necessity given the predicted rise in global population.[9] Traditional farming methods alone will not be able to support the rising demand for food. However, the introduction of innovative AI and automation methods can help increase food production, allowing for improved efficiency and a better quality of agricultural produce. The priority use cases that are mostly likely to result in positive productivity impacts include farm health monitoring, digital advisory services and automated input provision.

Agricultural Productivity Opportunities

AI and automation solutions can improve SSP knowledge and decision-making across all stages of the agricultural production cycle. This presents several agricultural opportunities for SSPs:

1. ***Optimal preparation:*** Data collected from sensors, satellites, or drones can help SSPs identify optimal areas for new crops and livestock. These data-generated insights can also help SSPs use their arable land more strategically by identifying which crops and livestock are best suited for farming based factors such as soil and grazing quality.

2. ***Efficient input use:*** Automated irrigation systems can ensure that inputs are evenly distributed and efficiently used. AI-enabled weather forecasting helps SSPs plan what type of crop to grow and when seeds should be sown. Automated advisory services in the form of chatbots built into AgTech solutions, and services like ChatGPT could extend knowledge to users who would not have access to it otherwise.

3. ***Reduced time to production:*** Sensor data provides precise readings from soil, water, crops and livestock, which can reduce time to production as inputs can be administered on time and in line with the underlying environmental requirements. Technologies such as drones can identify when certain areas or crops are ready for harvesting while owner-renter platforms, such as TroTro Tractor provide access to mechanization services that can reduce harvesting time, and demand-supply matching platforms can assist SSPs to find appropriate input and output markets.

4. ***Better output quality:*** Precision farming and predictive analytics provide farmers with accurate guidance on irrigation management, crop rotation, timely harvesting and nutrition management for agricultural and/or grazing land. This allows the SSP to cultivate a better quality of produce.

5. ***Better output yield:*** Digital advisory services provide SSPs with real time advice on weather conditions, farming practices, and preferred input suppliers based on the quality of products available. This, combined with predictability in yield forecasting using cropping lifetime, enables SSPs to cultivate better quality output while also using inputs more efficiently. This results in higher yield quantities after harvest periods.

6. ***Reduced spoilage:*** IoT sensors, drones and satellites allow farmers to monitor the incidence of crop diseases and pests on the ground at a micro level as well as from the air at a macro perspective. Aerial or spatial imaging solutions provide farmers with detailed information on current crop health, allowing them to take timely action and mitigating against them losing large amounts of produce as a consequence of pests and bacteria. Radio-frequency identification (RFID) tags or physical bio-sensors also allow SSPs to monitor livestock health. Further, sensor-enabled storage facilities and logistics can help reduce spoilage in the post-harvest and distribution phase of the production cycle.

Broader Productivity Opportunities

Enhancing the productivity of SSPs can also lead to new commercialization opportunities and contribute to local, regional and global food security. Automated on-farm practices, coupled with precision cultivation techniques and digitally accessible advisory services, improves yield quality and results in more output being generated with fewer inputs. This can secure a critical contribution to local, regional and global food security given the expected increase in demand for food and the growing importance of SSPs in meeting this demand. Stronger

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[9] United Nations. 2022. *Global Issues: Population*. Available here.

local production can also improve domestic resilience to global food supply shocks. This surplus yield can further improve SSP commercialization opportunities, generating additional revenue. This, in turn, can generate more income for the household, which can be used to meet other needs. The importance of increases to household income are discussed further under Inclusion.

Agricultural Productivity Risks

Productivity-enhancing applications may have negative impacts on SSP employment, or unintended consequences that weaken SSP productivity. Developing policies and programs that mitigate these two risks will be critical to the wellbeing of SSPs.

1. ***Manual labor shedding:*** automated input provision systems are designed to use water, labor, fertilizer and power requirements efficiently. Consequently, less on-farm labor is required. While labor shedding is a concern, there are several nuances that describe the shifts in labor and the factors that determine how risk-bearing they are. These are discussed in the box below.

BOX 8: CONSIDERING THE LABOR EFFECTS OF AI AND AUTOMATION

On-farm laborers often perform menial tasks, with employment being influenced by seasonal fluctuations. Additional ad hoc labor is required during particular periods such as planting or harvesting. However, automated on-farm processes minimize the demand for this ad hoc labor. As such, these individuals will have fewer seasonal employment opportunities in a sector that is typically a significant and reliable employer of low-skilled labor.

The overall labor shedding impact attributable to the introduction of AI and automation is dependent on underlying country and local circumstances. In South East Asian countries, where population rates are decreasing, the introduction of a blended workforce, combining digital solutions with traditional farmers and tools, is proving to be effective as there are fewer people entering the farming profession due to the physicality required by the profession, which is becoming unmanageable for aging populations. This, coupled with high job rate turnover and seasonal externalities, which makes small-scale producers dependent on highly mobile migrant labor, makes the profession unattractive or unsustainable. AI addresses these labor challenges by augmenting or removing certain on-farm jobs and reducing the need for unreliable, ad hoc labor. However, in African countries, where the majority of populations are youthful and population growth rates are increasing, on-farm automation likely presents a greater risk to overall unemployment rates.

Although labor shedding in agriculture will occur in some instances, like most disruptions, the introduction of automation technology will lead to new sources of employment. Research on the impact of automotive technologies such as robotics, and AI on job security can portray misleading insights if the methodologies used do not factor in important dynamics.[10] The adoption of new automation technologies in the agricultural sector can bring additional commercial viability as it will require additional investment, infrastructure development and service provision, all of which will require new skills and jobs. Further, previous predictions of the impact of technology on agricultural employment failed to take into consideration that as economies evolve; jobs that become redundant are replaced by new jobs that are created as a result of progress. Finally, when analyzing whether automation negates job creation, it is important to consider whether automation technologies can realistically be fully automated or whether they require other manual inputs overseen by humans.

Many of the new jobs being created in the deployment of AgTech solutions are relatively low-skilled jobs with minor barriers to entry. For example, the need to deliver AgTech solutions through in-person intermediaries is creating demand for booking, sales and engagement agents in rural areas. At least 35% of AGRA's village-based advisors (VBAs), described in more detail in the Delivery Model section, have commercialized their roles by becoming agents for agri-input dealers. Booking agents on platforms like HelloTractor can access financing options to purchase their own tractors and become tractor owners themselves once they have enough tractor services booked. An in-depth study conducted by the Bureau of Labor Statistics

[10] Economists Carl Benedikt Frey and Michael Osborein published a 2013 working paper on impact of automation technologies on existing jobs. The methodology used to estimate this impact has since been proven inaccurate and over inflated the predicted impact.

(BLS) found that, despite farmworkers and agricultural equipment operators being high-risk occupations that are subject to redundancies as a consequence of automation, between the period of 2019 and 2029 job opportunities will grow by 1.0% and provide 9,100 new jobs.[11] Actual figures are likely to be even greater given that, between the period 2008 and 2018, employment in this sector was projected to decline by 2.4% but actually grew by 9%.[12]

2. ***Inaccurate insight due to data biases:*** AI-enabled solutions that produce biased or inaccurate insights could result in SSPs making incorrect on-farm, harvest and post harvest decisions. Inaccurate data inputs used in these solutions, poor localization of these solutions, and inadequate quality assurance for these solutions may result in AI hallucinations, where solutions incorrectly address SSP challenges and impede productivity by producing nonsensical outputs. Further, the need for contextually relevant datasets hinders progress in building AI applications that are scalable and robust for populations across the globe. SSPs that suffer from actioning poor insights may not have trust in and choose not to use AgTech solutions again.

Broader Productivity Risks

Differences in SSP adoption rates of AgTech solutions may result in a widening productivity divide between groups of SSPs. If innovative technologies are not adopted evenly amongst SSPs, there is a risk of an inequitable distribution of benefits. This may occur if SSPs that are more commercialized, or have higher incomes, are able to take advantage of AgTech solutions to improve their productivity, competitiveness and earning potential. This would widen the productivity divide between these SSPs and the remote or lower-income SSPs that may not have access to these solutions or be able to afford them. A perpetuating cycle may continue to increase the divide between SSPs who can access these solutions and the SSPs that are the most vulnerable and require the most support. While this dynamic will be true for farmers within a particular country, it can also be true when considering inequitable distribution between countries. The phenomenon of AgTech hubs in certain LMICs, such as India, Kenya and Nigeria, has the potential to significantly improve the productivity and competitiveness of agricultural exports from these markets relative to the LMICs in which SSPs have not adopted these solutions.

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[11] United States Bureau of Labor Statistics. 2022. *Monthly Labour Review: Growth trends for selected occupations considered at risk from automation.* Available here.

[12] Ibid.

IMPACT PATHWAY 2: **COST EFFICIENCIES**

Cost efficiencies are one of the foremost opportunities presented by AgTech solutions. Spending on AI technologies and solutions within the agriculture sector is estimated to reach USD 4 billion by 2026 - a compound annual growth rate of 25.5% between 2020 and 2026.[13] This significant investment in AI and automation technologies present ample opportunities for smallholder farmers to harness opportunities for cost efficiencies. Digital advisory services allow SSPs to use inputs more efficiently. Smart tractors, agribots and robotics present a viable solution for agricultural operations that struggle to find sufficient labor. Smart farming practices also allow SSPs to reduce waste by applying the appropriate mix and amount of pesticides to affected areas only, or through precise irrigation and fertigation with targeted crop protection application. All of these solutions lower operating costs incurred by small scale producers.

Agricultural cost saving opportunities

1. ***Lower operating costs:*** There are several ways that SSP operating costs can be lowered by AgTech solutions. Digitized booking platforms and online equipment rent models result in reduced land preparation costs being incurred by small-scale farmers as they no longer need to own expensive machinery or incur the costs involved in trying to source this equipment. Precision farming methods also allow farmers to use inputs more efficiently, which reduces how often they have to be replenished. Precise soil readings translate into more targeted applications of fertilizers; automated on-farm processes such as irrigation reduce the amount of laborers required; and, solar-powered solutions like water pumps can help smallholders save energy costs

2. ***Less costly access to services:*** The digitization of essential agricultural services such as community advisory, tractor renting and the purchasing of inputs incurs fewer costs for SSPs as they no longer have to travel to the nearest village or city to access these services.

3. ***Traceability:*** SSPs and the value-chain stakeholders they work with sometimes have to prove they are compliant with specific input quality and ethical pay standards before being able to access certain markets. This has traditionally incurred costly certification processes. The introduction of blockchain technology and other automated tracking technologies, such as QR codes, enables more cost-effective traceability of information across the food supply chain, reducing the cost and effort of certification for SSPs.

4. ***Efficient reallocation of labor:*** Automated on-farm practices and access to additional equipment via digital platforms allow for the more physically demanding farm practices to be augmented. This allows farm workers who previously would have endured these activities to direct their efforts elsewhere, potentially allowing for lower turnover rates and reduced injury rates which farm owners could be held liable for.

5. ***Improved, cost-efficient seeds:*** Genomic technology can accelerate the rate of genetic improvement for seeds, which typically takes between 10-15 years using traditional plant breeding methods.[14] Specifically, sequencing of plant genes allows for the identification of genetic lines with “deleterious mutations” in the genomes that can subsequently be deleted.[15] Essentially, this method of identification allows for the detection of seeds that have genetic alterations that increase their susceptibility to diseases. The elimination of these seed types provides SSPs with more climate-resilient seeds, minimizing the costs of crop loss.

Broader cost saving opportunities

Impact pathways through which cost saving impacts can be realized can provide SSPs with three additional areas of opportunity. Reduced operating costs bolsters household income for SSPs. This income can then be redirected to other services that enhance livelihoods such as education, healthcare and housing maintenance or repairs, or even to savings, which increase financial resilience. Increased household income presents opportunities for SSPs to reinvest this income in order to make their farms more robust and, subsequently, even more profitable.

[13] Forbes. 2021. *10 Ways AI has the Potential to Improve Agriculture in 2021*. Available here.
[14] Bohra, Abhishek et al. 2020. *Genomic interventions for sustainable agriculture*. Plant biotechnology journal vol. 18,12 (2020): 2388-2405. Available here.
[15] Varshney, Rajeev K et al. 2018. *Can genomics deliver climate-change ready crops?* Current opinion in plant biology vol. 45,Pt B (2018): 205-211. Available here.

Finally, cost saving technologies can allow farmers to access higher quality value chains as higher household income allows for improved access to finance, payment solutions and the social capital required to organize producers and communities across a value chain. Traceability solutions can also allow SSPs to participate in higher-value, export-oriented value chains.

Agricultural cost saving risks

Costs associated with the implementation of AgTech solutions may create risks for technical providers and SSPs. This is detailed below:

1. ***Unpredictable maintenance costs and low reliability:*** The equipment required to implement IoT sensor networks or automated systems often entails high upfront costs. This can crowd out lower-income rural farmers, especially women and young people, who do not have sufficient income or who typically struggle to access credit from accessing these technologies. Farmers who are able to purchase these technologies may also incur significant and unpredictable maintenance costs if they inherit the responsibility for maintaining a device once it has been paid for or funding has reached its tenure. This subsequently places the long-term viability of the AgTech solution in jeopardy, as the farmer may not be able to afford the upkeep of the technology. AgTech providers that offer shared services using drones must also carry these high upfront costs and are at risk of not recovering them if there is insufficient uptake of these services.

2. ***Losses owing to genomic seed variation:*** Governments that fully subsidize the introduction of a certain genomic seed variety for farmers with bundled yield-based and weather-based index insurance are vulnerable to financial losses if these crops are attacked by pests that result in complete crop failure. Despite the farmers being insured against unforeseeable weather and yield events, the government will make a complete financial loss. An unintended consequence of this extent would be significant for LMICs, in which agriculture is a significant contributor to GDP[16], and could create ripple effects in which the adoption of such new and improved seed varieties are curtailed.

Broader cost saving risks

AgTech solutions can run the risk of perpetuating the 'dual agricultural value chain' characterization of LMICs that is created by differences in affordability between groups of SSPs. The agricultural sectors of developing countries are often characterized by dual value chains operating in parallel for the same product: one informal or traditional and the other formal or modern. Many AgTech solutions aim to help SSPs save costs and improve their productivity, enabling them to access more formalized or commercial markets. However, these digital solutions are often offered to SSPs as a 'smart farming-as-a-service' model, which has an automated service disruption function if the farmer fails to pay their monthly subscription fee. This poses a challenge for lower-income SSPs, who do not have consistent and reliable monthly incomes, which is not uncommon given the cyclical nature of the sector. This may compound the challenge of adoption disparities amongst SSPs where inequitable distribution of AI and automation solutions only allow some SSPs access to modern value chains, as discussed above. Alternatively, there is a risk that, in an adequately regulated digital ecosystem, AgTech solution providers will be guided to adopt a 'leave no one behind' approach and create incentive pricing methods tailored to the demands of SSPs. Business model solutions such as pay-as-you-go (PAYG) are an example of such approaches. However, such solutions present a greater risk with cost savings on the technical provider side.

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[16] Typically, agricultural production contributes between 18% and 40% of GDP in LMICs.

IMPACT PATHWAY 3: **INCLUSION**

Advances in AgTech solutions are critical for broadening access to opportunities and promoting inclusion in the agricultural sector. The combination of technology and traditional farming methods has the potential to drastically improve inclusion by providing more equitable access to agricultural opportunities for all genders, abilities and ages. More than 500 million households depend on smallholder farming for their livelihoods, despite the fact that they have access to only 25% of arable land globally.[17] The majority of these SSPs, who produce more than a third of the world's food, experience financial or market exclusion, leaving them susceptible to diminished incomes and lower productivity. Alternative credit scoring and buyer-seller matching via digital platforms present opportunities for SSPs to be more included in formal services that enable the agricultural sector. This can allow for alternative income streams for SSPs by establishing incentives on premiums earned due to responsible, sustainable farming.

Agricultural inclusion opportunities

A deliberate effort to design AI and automation agricultural solutions to enhance inclusion has the potential to open up several access points. These include:

1. ***Access to agri-services:*** AgTech solutions can provide rural and remote SSPs with access to fundamental agricultural services digitally. For example automated digital climate advisory services provide SSPs with access to precise, timely information triggered to adapt to real-time weather events, preferred inputs and farming techniques via feature phone channels like USSD or SMS, regardless of their location.

2. ***Access to credit and insurance:*** AgTech solutions create new sources of data to understand and model SSP behavior. This includes data on digital payments, WhatsApp community forum engagement and more. These alternative data points can be used to develop creditworthiness models that support the extension of credit to excluded SSPs. The estimated annual demand for credit from SSPs in LMICs is USD 160 billion but just over a third of this demand is being met (USD 54 billion).[18] [19] In addition, AgTech solutions are making the provision of agricultural insurance products more widely available through bundling. Covering more SSPs with insurance is critical to protecting livelihoods when SSPs face devastating shocks to their livelihoods caused by weather or pest events.

3. ***Access to markets:*** Digital platforms and the rise of e-commerce present more efficient mechanisms of matching buyers and sellers, especially when underlying infrastructure, such as roads and network coverage, already exists. This creates opportunities for more SSPs to sell produce to more formal or modern markets at a fair price. Appropriate consumer protection and fair market competition regulation will become increasingly important as more and more SSPs engage with e-commerce platforms. This is to ensure that the slashing of prices to beat competition, or alternatively, price gouging does not occur for SSPs and consumers respectively.

4. ***Access to training:*** Online training content and customized training services can provide SSPs with the opportunity to improve their practices. Agent networks and intermediaries that leverage AgTech solutions can also serve as digital ambassadors and help less digitally savvy farmers upskill themselves.

5. ***Inclusion of vulnerable groups:*** The rise of AgTech solutions presents an opportunity for marginalized groups, such as women, young people and disabled people, to be included. For example, automated on-farm processes make farming practices less physically demanding, a critical requirement for inclusion of disabled people. In addition, many AgTech solutions, such as Sooretul or CreditAccess Grameen, are specifically geared towards the needs of rurally based women. Additionally, the rise in female entrepreneurs focusing on the development of AgTech products and services provides young women in rural communities using these solutions with influential role models and leaders.

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17 GSMA. 2021. *Emerging business models to support the financial inclusion of smallholder farmers.* Available here.
18 GSMA. 2021. *Emerging business models to support the financial inclusion of smallholder farmers.* Available here.
19 ISF Advisors. 2022. *State of the Sector: Agri-SME Finance.* Available here.

Broader inclusion opportunities

Inclusive digital agriculture empowers vulnerable groups and breaks down barriers to entry. This can result in several follow-on benefits. Firstly, if more households are able to participate in the agricultural sector as a result of digital technologies, there will be an overall improvement in household income levels in rural areas. Secondly, by leveraging alternative data for credit scoring purposes, SSPs will have additional options for accessing the capital or debt financing required for purposes other than farming such as tertiary education or the purchasing of a home or vehicle, which means they would no longer have to self-fund or rely on predatory lenders. Thirdly, greater participation in the agricultural sector creates a bigger addressable market, which can help AgTech solutions scale on the back of greater demand for these solutions. Finally, women can be included more equitably in the agricultural sector as a result of access to digital financial services, online training, online advisory services and improved market opportunities. Women are the backbone of the agricultural sector and play critical roles across many parts of agricultural and off-farm value chains. However, in many LMICs, their contributions are either underestimated or limited by prevailing societal norms or gender-specific barriers. By facilitating greater access for women, there is also the opportunity to narrow the gender wage gap as automated on-farm technologies mitigate against women being excluded from on-farm labor as jobs that require extreme physicality can now be automated.

Agricultural inclusion risks

Several risks directly related to the agricultural value chain can arise if adequate due diligence practices or human-centered design (HCD) approaches for AgTech solutions are not adopted. These include:

1. ***Inferior products:*** Digital platforms that provide SSPs with easier access to inputs from a variety of suppliers may expose them to an increased risk of purchasing inferior or counterfeit products. Poor platform security, policies and protocols may result in weak oversight and inadequate verification of sellers and their products. This is likely to be an effect of inadequate funding or investments in the agriculture sector,[20] coupled with the significant upfront investment required to develop e-commerce platforms within the limitations of tight margins, which can compound the issue of counterfeiting, adulteration and substandard product development. This could result in dire consequences for an SSP. For example, if a farmer is sold diluted fertilizer, this could result in an accelerated rate of crop deterioration. Further, out-of-date or old pesticides can become too dangerous to use. However, if there is poor product oversight, these products can still be made available to SSPs in LMICs where e-commerce controls are more nascent.

2. ***Inadequate consumer protection:*** Effective regulation is critical to ensuring the responsible development of digital solutions, particularly those that relate to digital finance. Out-of-date policies and regulations that do not cater for the dynamics of new technologies may not protect consumers from new risks. For example, if data protection policies are inadequate or consent is not obtained by smallholder farmers, data monetization business models can result in the third parties accessing farmer information through AgTech service providers. The ethical paradigms of implementing AI and automation technologies across the agricultural value chain Is discussed further in the below information box.

BOX 9: AI ETHICS AND DATA GOVERNANCE

The implementation of AI and other innovative solutions across the agricultural value chain can lead to several key ethical considerations that have the potential to strip farmers of their autonomy and lead to breakdowns in trust. In addition to the data accuracy issues discussed above, these include.[21]

1. ***Data ownership:*** There are concerns regarding the collection and dissemination of farmer data to third parties. This raises the contentious issue of whether farmers should relinquish control of farm data to

[20] Currently the annual shortfall in agri-financing is estimated to be USD 160 billion.
ISF Advisors. 2022. *State of the Sector: Agri-SME Finance.* Available here.

[21] Ryan, M. 2019. *Ethics of Using AI and Big Data in Agriculture: The Case of a Large Agriculture Multinational.* ORBIT Journal, 2(2). Available here.

BOX 9: AI ETHICS AND DATA GOVERNANCE

these parties, who could subsequently use it to influence other farmers. Further, data retrieved from farms is often inaccessible to farmers themselves. This causes tension between the agribusinesses' intellectual property rights and the protection of the farmer's data ownership.

2. ***Economic issues:*** The use of smart information systems is relatively expensive, which may create a digital divide across slightly more commercialized farms that are focused on monoculture compared to more varied, subsistence farms.

3. ***Privacy and security:*** Agricultural Big Data is susceptible to privacy and security risks because it could be used nefariously by corrupt governments, competitors, or market traders. This is particularly the case in LMICs, where there is less data protection regulation. Alternatively, Big Data can be used in legitimate ways that still ultimately disadvantage SSPs. For example, accurate soil productivity maps that are accessible by more commercial, financially secure farmers can be used for legal targeting and acquisition of land by these larger corporations or governments at an undervalued price owing to information asymmetries.

4. ***Accuracy and Accessibility of Outputs:*** Automated advisory services are prominent in agri-food systems and in bundled AgTech solutions. The impact of automated advisory services by SSPs is influenced by the accuracy of the services and their availability in languages the SSPs can understand. SSPs who receive inaccurate and incoherent outputs from AI enabled AgTech services may experience adverse consequences. This may be due to AgTech solution developers leveraging models that are trained using insufficient data, leveraging inappropriate models, or inadequately evaluating the accuracy of model outputs. Automated advisory may be exclusionary for SSPs in LMICs that speak under-resourced languages as there is insufficient data to effectively train models to operate in these languages..

5. ***Environmental protection:*** IoT sensors, robots and devices may cause harm, distress, and damage to animal welfare and the environment if they are not disposed of responsibly. This aspect is discussed in more detail under Climate Resilience.

It is of paramount importance that SSPs understand the value of the data they are providing or generating before engaging with AgTech solutions. As such, it is important that efforts are made to build SSP knowledge of the value of and rights to their data so that SSPs understand how their data will be used by AgTech solution providers before consenting to its use.

Broader inclusion risks

Improper use of data and failure to engage with the most vulnerable of SSPs can negate the positive opportunities for inclusion in the agricultural sector. The potential risk of disintermediating digital platforms providing SSPs with inferior products or the incorrect advice can lead to a breakdown of trust in digital products and services generally and the long-term participation of SSPs in the digital economy could be jeopardized. Similarly, there could be ongoing exclusion barriers amongst those SSPs that are the most vulnerable and thus the hardest to include due to affordability barriers. A further consequence could be an ever greater income divide between individuals who are able to afford these enabling factors and those who cannot such as aging farmers, farmers with less digital or technical literacy or female farmers who cannot access credit.

IMPACT PATHWAY 4: **CLIMATE RESILIENCE**

Agricultural value chains and agri-food systems have an important relationship with climate, and can be both affected by and a contributor to climate change. The implications of climate change are already affecting food security through rising temperatures, unpredictable changes in precipitation patterns and higher frequency of extreme weather events such as droughts or flash flooding. On the other hand, over 29% of total greenhouse gas (GHG) emissions are attributable to the food system.[22] Technological innovation can play an important role in safeguarding agri-food systems against adverse climate changes, whilst also making agricultural practices less demanding on the environment. Of the priority use cases analyzed, genomic innovation and alternative insurance access present the most significant opportunities for enhancing SSP resilience to climate change.

Agricultural climate resilience opportunities

AI and automation technologies have the potential to enhance SSP resilience to climate change and natural disasters by opening up access to assets and mechanization, improving decision-making, and extending access to insurance. These technologies could allow for several agricultural opportunities to be realized. These include:

1. ***Optimal use of scarce resources:*** Automated irrigation systems and fertilizer administration allow for more uniform and precise administration of inputs. This can lead to more sustainable land management as the use of natural resources, including water and soil, can be optimized. For example, less water would be wasted, allowing for sustainable water systems and better nutritional content in the soil, improving the longevity of cropland and the quality of harvests. Smart farming techniques have demonstrated a positive impact on feed conversion ratios (FCRs) for aquaculture farming practices, which results in improved water quality for the surrounding area by reducing instances of overfeeding.[23] Overfeeding can lead to water contamination, pollution and fish mortality.

2. ***Preempting negative shocks:*** Together with on-the-ground data, satellite information can make SSPs more proactive to climate events and enable them to pre-plan responses rather than reacting to these events after the fact. Satellites provide an immediate first impression of weather events without requiring lengthy assessment first. This allows for environmental data to be distilled into actionable information; reaching SSPs via automated messaging platforms. In addition, automatic dispatch of emergency services can be linked to certain 'tipping points' that can be identified by satellites using machine learning. This can make SSPs more resilient to climate events such as droughts, pests or diseases. Further, these innovations assist SSPs in adapting to longer-term stresses such as erratic weather patterns or the shortening of certain seasons.

3. ***Improved biodiversity:*** Biodiversity helps to sustain vital ecosystem structures and processes, such as soil protection and health, water cycle and quality, and air quality. It also provides the genetic resources for the breeding of new, locally adapted crop varieties. Biodiversity is therefore essential for agricultural production and food security. AI and automation technologies can improve invasive mechanical agitation of soil during the land preparation phase and allow for more environmentally sustainable preparation of arable land. This, coupled with integrated crop and weed management, will ensure that agricultural land is better conserved. In addition, innovations such as microscopic radio transmitters and radar-reflecting tags can be used to track invasive insects to their nests and destroy their colonies.[24]

4. ***Mitigating food loss or waste:*** More than a third of global food production is lost or wasted.[25] This results in unnecessary GHG emissions, the wastage of natural resources and unnecessary soil erosion. Precision agriculture mechanisms and automated fertilizer systems can help reduce harvest loss to pests and diseases. Automated, energy-efficient cold storage and blast cooling technology can also be used to help maintain post-harvest quality and reduce spoilage, while buyer-seller matching is critical to preventing unnecessary food loss and waste.

[22] The Intergovernmental Panel on Climate Change. 2022. *Food Security: Special Report on Climate Change and Land.* Available here.
[23] GSMA. 2022. *Assessment of smart farming solutions for smallholders in low and middle-income countries.* Available here.
[24] For more information on these technologies, see *Wildlife Conservation Society,* available here; or *Challenges and Prospects in the Telemetry of Insects*, available here.
[25] The World Bank. 2022. *Climate-smart Agriculture.* Available here.

5. ***Climate resilience and alternative income:*** The concept of a carbon sink resulting from the sequestration of carbon in the soil or from averted emissions will have a net positive influence on GHG emissions and/or CO2 levels. This is relevant to SSPs in their efforts to generate alternative revenue by using carbon sequestration data as business intelligence to monetize with purchasers, which would bring in premiums, or with carbon traders/off-setters, which would bring in cash as an alternative source of income.

Broader climate resilience opportunities

Climate smart agriculture leveraging AI and automation technologies can improve agricultural management and reduce the negative aftermaths following climatic shocks. According to the Intergovernmental Panel on Climate Change, it is critical to augment supply-side agricultural practices to address future GHG emission concerns. Climate smart agricultural practices such as increased soil organic matter and erosion control, improved cropland, livestock, grazing land management, genetic seed improvements for tolerance to heat and drought, and diversification of biomes can all result in **lower greenhouse gas emissions**. Less biodiversity loss and weather prediction models present an opportunity for *ex ante*, **proactive disaster management measures** to be taken; minimizing the devastation of climatic events. For example, climate smart agricultural technology prevents nutrient-rich topsoil from being washed away. Healthy topsoil with high organic content and vegetation can effectively regulate against sand or dust storms, acting as a windbreak. Further, soils and their associated ecosystems can counteract the devastating impacts of flooding by reducing or delaying runoff, thereby lowering flood volumes and reducing damage.

Agricultural climate resilience risks

Although innovations in climate-risk insurance that leverages digital technologies provide meaningful examples of positive impact for some, there are many remaining obstacles that prevent insurance coverage from becoming the default situation in LMICs. Comprehensive risk management is essential to better protect SSPs in developing countries, who will be more adversely impacted by climate change than SSPs in developed countries. However, access to insurance across LMICs remains unequal and fragmented. Further, insurance offerings often lack access to rich, localized datasets, which assist in creating tailored products to address the risks faced by SSPs. It is estimated that weather-related disasters have claimed the lives of over 1 million individuals and amounted to over USD 4.21 trillion in financial damages over the past 20 years.[26] This is anticipated to worsen in years to come as climate events become more frequent and devastating, which is of greatest concern for low-income households who do not have sufficient financial means to cope with climate shocks.

1. ***Unjust denial of insurance payouts:*** Satellite data presents a new opportunity for developing bespoke alternative insurance models for the climate risks endured by SSPs. However, if these insurance models do not factor in geographic and climatic nuances, there is a risk that SSPs will be unfairly denied their policy payouts. These nuances are discussed in further detail in the information box below.

BOX 10: WEATHER-BASED INSURANCE

Satellite data and remote sensing technology can significantly improve the financial resilience of SSPs by providing proactive early-response measures. However, there are certain factors that distort the concept of 'blanket' climate-based risk insurance for SSPs. Satellite data allows for the remote monitoring of indices such as soil moisture content, precipitation, vegetation health and others. It can also be used to forecast extreme weather events such as storms. Collected over a long enough time period, this data allows for forecasting on crop yields and underlying environment conditions.

Building disaster resilience in LMICs is essential to minimize the volatility in crop yield and income that SSPs will face when confronting worsening weather patterns. This requires that several obstacles be overcome in order to establish sustainable demand for and trust in climate-based insurance policies by SSPs. These include:

[26] Development and Cooperation. 2022. *Managing climate risk with private insurance*. Available here.

1. ***Investment and infrastructure challenges:*** Growth in private-sector-led investment in climate-based risk insurance programs is hindered by substantial initial investment costs and continued high operating costs owing to infrastructure issues. Considerable market research is required to understand the financial needs of SSPs ahead of product development, which requires substantial upfront investment. Further, the underlying circumstances of SSPs require insurance companies to offer climate-based insurance policies to them at very low premiums. Distribution and climate-account management are also difficult due to power supply and internet access barriers in rural and remote areas. Not only do these factors adversely impact on the long-term sustainability of these product offerings, they also deter many private insurance companies from entering this space, resulting in a limited choice and low reliability of climate-based insurance options for SSPs.

2. ***Nascent product knowledge:*** SSPs typically have limited knowledge of how insurance products work, a factor that could be taken for granted when they sign insurance contracts. Further, governments' understanding of effective insurance cover can be outdated or limited as it relates to a particular sector such as climate risk in agriculture. Consequently, misalignment about the level of investment required to create effective insurance products can occur in government and the private sector.

3. ***Crop variation discrepancies:*** AI solutions that implement field boundaries and crop-type identification for insurance purposes are highly effective in monoculture environments but, in instances of intercropping, they are not as effective. Consequently, geospatial services that are used for advisory and insurance have the tendency to be optimized for monoculture farming, which is often not the case for subsistence or small-scale farming, where intercropping is necessary. Further, a movement toward monoculture practices in itself has environmental implications. For example, it is more difficult for several species of bees to pollinate in areas that lack crop variation.

4. ***Data discrepancies do not account for micro-climates:*** Insurance companies require reliable statistics regarding both weather conditions and the damage incurred by weather-related events, and data collection is a bigger challenge in rural and remote areas. This, coupled with the influence of microclimates, negatively impacts the accuracy of the statistics used to inform insurance policy payouts. For example, inaccuracies in critical threshold readings that determine whether or not a policy is paid out may emerge due to:

   a. Challenges in measuring rain distribution such as rapid rainfall over a short period compared to more evenly distributed rain over a longer period.
   b. Rainfall on windward and leeward sides of hills, mountains or ridges as some of these areas receive more rain than others.
   c. Follow-on events subsequent to certain weather patterns. For example, rainfall after a significant drought period can lead to the hatching of locust eggs and result in significant and immediate crop depletion.

It is critical that innovations in climate-based insurance take into consideration these challenges to ensure SSPs are sufficiently protected against risks associated with climate change and extreme weather conditions.

Broader climate resilience risks

The positive gains made in the resilience of SSPs to climate change due to AgTech solutions could be jeopardized by adverse knock-on effects. More than 3.5 billion people and 70% of crop production are vulnerable to climate change.[27] [28] If AI and automation technologies are not appropriately monitored and regulated, there is a risk that these figures will become even more significant. Smart farming technologies are intended to make agricultural processes more efficient and, by doing that, to increase the productivity of SSPs. However, there is a risk that the productivity of intensive farming practices in, for example, aquaculture and the production of soybeans, meat and dairy, is improved to such an extent that the associated depletion of natural resources becomes

27 Development and Cooperation. 2022. *Managing climate risk with private insurance.* Available here.
28 Bill & Melinda Gates Foundation. 2021. *Smallholder farming is a proven path out of poverty, but climate change is changing the rules.* Available here.

irreversible. For example, agrochemical fertilizers and pesticides can accelerate soil degradation and erosion as they sidestep the process whereby nutrients are naturally returned to the topsoil layer of croplands from the biodegradation of leftover vegetation from the previous season's harvest. This critical microbial process ensures that nutrients are able to be transferred from the soil to the plant subsequent to the land preparation phase of farming. Further, intensive fish farming can result in eutrophication, where the waste produced from farming practices distributes excess nutrients into neighboring water supplies, disrupting the balance of water ecosystems.

Although climate-smart agriculture has the potential to lower GHG emissions due to agriculture, there is a risk that the increased usage of data-transmitting devices will create new dependencies on data centers, which contribute to emissions. Data centers currently account for over 2% of all global carbon emissions, which is equivalent to the total contribution of the airline industry.[29] The increased computing power required to run smart tech applications in the cloud will result in more data centers being required and in usage of these centers increasing, which has the potential to exacerbate the carbon emissions they produce.

In addition, if the use of smart farming technologies such as IoT sensors becomes more widespread in the future, this can result in irresponsible e-waste disposal, which has irreparable consequences for the environment. For example, informal disposal of electronic equipment through shredding or melting material releases dust particles and toxins into the air, aggravating air pollution and damaging respiratory health of nearby communities. While the negative effects on air from informal e-waste recycling are most dangerous for those who handle this waste, issues with pollution can be widespread geographically. The burning of e-waste releases fine particles into the air, which can travel thousands of miles, creating numerous health risks including chronic respiratory diseases and cancer. Improper disposal of e-waste in regular landfills or in illegal dumpsites releases heavy metals and flame retardants into the soil, causing contamination of the underlying groundwater, which can adversely impact croplands and biodiversity in the area. The introduction of heavy metals such as mercury, lithium, lead and barium causes chemical reactions including acidification and toxification, which is unsafe for animals, plants and people and which ultimately depletes the availability of clean drinking water. Finally, there are adverse environmental costs associated with rare earth mining as rare earth minerals are a critical input in the manufacturing of many smart farming technologies and devices. Mining practices can create pollutive consequences and irreversible environmental land damage.

[29] NowVertical. 2022. *The Impact of Data Centers on Global Carbon Emissions & How Removing ROT Data Can Help Reduce It.* Available here.

IMPACT TRADE OFFS

The impact assessment has identified how disruption from tech innovation will inevitably create both winners and losers. Overall, the identified impact pathways are largely positive in significantly increasing the capabilities of the SSPs who can access these solutions, with some significant risks across the value chain. This section concludes with eight trade-offs for consideration.

1. ***In the quest to grow income-generating work opportunities in agriculture, it is important to consider which groups are likely to be the winners and the losers.*** The millions of SSPs that rely on farming activities to earn an income or support their families are the greatest potential stakeholders, where they are able to leverage AgTech solutions to secure more sustainable livelihoods. Many additional jobs will be created through the provision of AgTech solutions, including for the lead farmers and agents that can earn an income from distributing AgTech solutions, and the agri-preneurs who can become tractor owners, input dealers or data collectors. The likely losers in this case are low-skilled laborers providing seasonal and manual labor on farms and in the processing parts of the value chain. The key to managing this trade-off is to determine how best to support those pushed out of work opportunities by transitioning them into new opportunities, especially given that a farm laborer will not automatically be able to take up new opportunities in the AgTech value chain.

2. ***Leveraging technology to include underserved groups has massive potential, but comes with its own set of risks to manage*.** Significantly improving access to agronomic advice and the financial services required to implement modern farming practices will help to 'level the playing field' among SSPs given the current gaps in agricultural advisory, credit and insurance. However, this will necessarily involve exposing SSPs to digitally delivered services they are not familiar with, creating new consumer protection, ethics and environmental risks. LMIC regulators will have to consider approaches that balance the need for innovation with protecting vulnerable consumers, including the requirement that AgTech providers build the understanding and capacity of their new customers and extended producer requirement responsibilities for environmental protection.

3. ***Supporting SSPs to commercialize and 'upgrade' production for higher value, export-oriented value chains can pose a threat to local food security.*** AgTech solutions will support SSPs to achieve the quality, volume and certifications required to commercialize and access export value chains with better market prices. This shift in production choices may lead to reductions in the supply of food and in the nutritional diversity of food in local communities if SSPs move away from producing local staple food items that have lower market prices. This trade-off is not necessarily created by AI and automation. Debates about commercialization and its impact on the social structure of rural societies are not new but will be intensified by the potential these technologies have to support rapid commercialization.

4. ***The high-touch intermediated delivery models required to include SSPs in AgTech solutions also restrict the scalability benefits of automation.*** Delivering AgTech solutions to SSPs through trusted intermediary networks is critical for inclusion and uptake. However, this approach has inherent scale limitations due to the cost of building intermediary networks and the current limitations on delivering truly personalized automated services. Managing this trade-off may require developing commercially-viable intermediary networks, such as shared agent networks that can be used by multiple providers, and investing in AI technologies that can safely and effectively emulate the experience of engaging with a trusted human intermediary. Natural-language-processing AI applications will be particularly impactful here.

5. ***Commercial incentives among AgTech providers do not always align with public good outcomes.*** Private AgTech providers guided by commercial objectives are better suited to delivering sustainable impact using efficient business models and pursuing revenue sources that offer pathways to scalability. These interests are sometimes misaligned with the broader need to create replicable and inclusive solutions, create competition amongst AgTech providers, and protect SSPs from exploitation. Philanthropic and donor funding targeted at AgTech providers with less commercial models that are, however, willing to share IP or data, may nevertheless be an inefficient allocation of capital if there is not a sustainable business case. Determining conditions for donor or public sector funding that maintains the virtues of commercial incentives but also contributes to public good objectives will be key.

6. ***A vibrant market of many AgTech providers can stimulate innovation and competition, but often leads to fragmentation and barriers to sustainability.*** A market with numerous AgTech providers offering similar solutions that require and compete for large sources of demand may be inefficient and unsustainable. However, the competition that this creates can stimulate innovation. This consideration is relevant in local and international contexts - scaled AgTech solutions from markets such as India, Kenya and Nigeria might be easier to replicate in smaller, foreign markets at the expense of locally developed solutions. The trade-off between market innovation and sustainability could be navigated by understanding the benefits and risks of ‘picking winners’, avoiding negatively influencing competitive forces and facilitating partnerships between stakeholders such as AgTech companies and research institutions, AgTech providers and distribution platforms and start-ups and commercial investors. It could also include developing market infrastructure that removes the distribution and customer management layer of providing services.

7. ***‘Narrow’ datasets enable the development of specific solutions and intelligence whereas ‘broad’ datasets may facilitate the development of widely relevant solutions and intelligence.*** Narrow datasets can, for example, refer to data collected on a specific farmer, community or value chain. This might include IoT devices for a farm or drone footage of a specific crop type in a specific area. ‘Broad’ data is more reusable. This might include the collection of machine-readable text for languages, satellite data with ground truth, or sparse networks of IoT devices across a region collecting rainfall data. Investment in data collection technologies and the development of open datasets is costly and need to be prioritized. This will require identifying the areas of data collection that offer the highest returns.

8. ***Openly-accessible digital infrastructure will reduce barriers to innovation, but may not offer the same quality and functionality as privately managed alternatives.*** Data and technology infrastructure, such as country AGRIS for country data or FarmStack by Digital Green for infrastructure, can be made openly accessible. Solutions such as these provide wider access to the inputs needed for research and innovation, and reduce the costs innovators must carry to test and then develop new solutions. Infrastructure can also be provided by private players such as CropIn, which may offer pay-per-use access to dependable infrastructure or access to datasets that the company has invested in gathering and cleaning. Figuring out which elements of various AgTech solutions are valuable and sustainable to provide on an open-source or white-label basis will be critical in supporting the development of an optimal mix of open and private infrastructure.

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