FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

State of the Digital Agriculture Sector

Executive Summary

Harnessing the Potential of Digital for Impact Across Agricultural Value Chains in Low- and Middle-Income Countries

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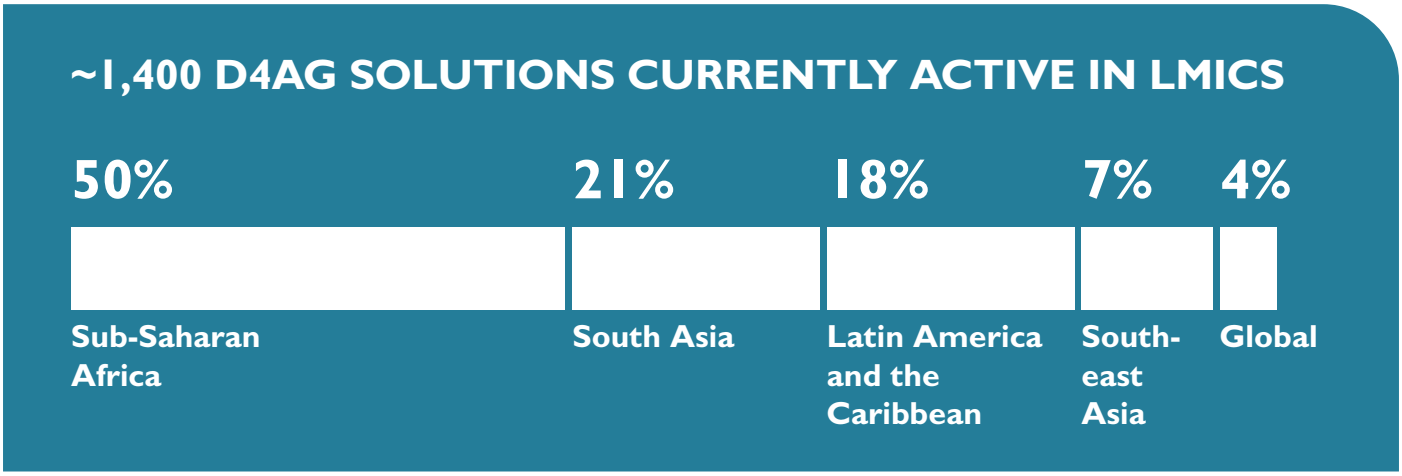
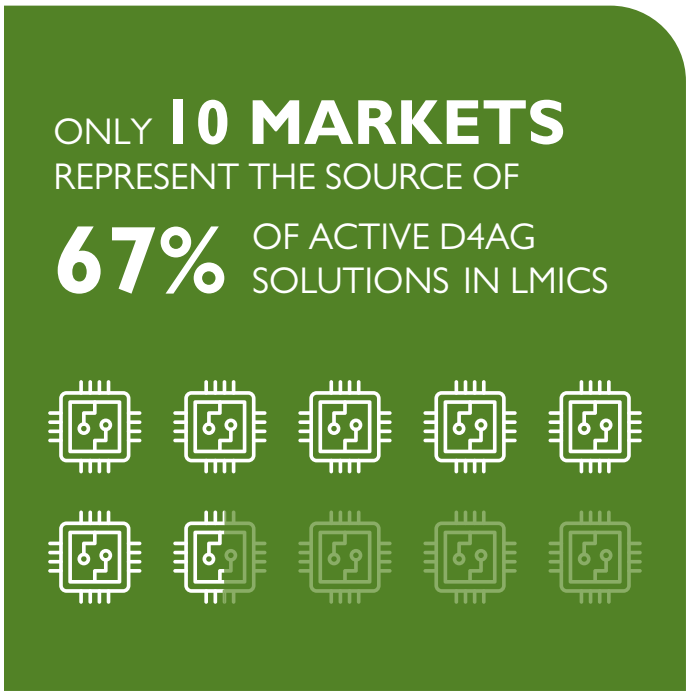
Executive Summary

KEY FINDINGS

The past decade has witnessed an explosion in the global supply of digitalization for agriculture (D4Ag) innovation. Across the regions that comprise the focus of this report—Latin America and the Caribbean (LAC), South Asia (SA), Southeast Asia (SEA), and sub-Saharan Africa (SSA) (hereafter collectively referred to as "LMICs" (low- and middle-income countries))—we identified nearly **1,400 currently active D4Ag solutions**. These solutions represent six different D4Ag use cases: Advisory & Information, Market Linkages & Access, Financial Access, Supply Chain Management, Enterprise Management & Efficiency, and Enterprise R&D. The largest proportion is headquartered in **sub-Saharan Africa (50%)**, though a significant number of D4Ag solutions hail from **South Asia (21%)** and **Latin America and the Caribbean (18%)** regions. Despite showing the largest per-annum growth rate in the number of D4Ag solutions of any region over both the past five and ten years, respectively, **Southeast Asia** still accounts for a relatively small share of the total **(7%)**. The remainder (~4%) are active in but headquartered outside of the LMIC regions of focus (i.e., in North America, Europe, Northeast Asia, or the Middle East). Growth in the number of D4Ag solutions is decelerating. While **nearly half of all D4Ag solutions active in LMICs were started in the past five years**, there is a clear



and consistent slowdown in the annual rate of new D4Ag solutions entering the market. The cumulative annual growth rate (CAGR) of the number of D4Ag solutions from **2012 to 2018 (33% p.a.)** was more than three times larger than that for the next four years, from **2018 to 2022 (9% p.a.)**. The trend of deceleration is common to every region, including relative upstart Southeast Asia. The deceleration certainly reflects a blend of increasing market maturity, consolidation, rationalization, and even COVID-19 impact—especially as sub-scale innovators start to close their doors and some venture-invested companies have shown themselves to be at the end of their ropes.



GEOGRAPHIC DISTRIBUTION OF D4AG SOLUTIONS

61%
in **Latin America & the Caribbean** are headquartered in **Brazil**

86%
in **South Asia** are headquartered in **India**.

45%
in **Sub-Saharan Africa** come from **Kenya** and **Nigeria**

49%
in **Southeast Asia** are headquartered in **Singapore** and **Indonesia**

D4Ag innovation is (slowly) decentralizing. Only **10 markets represent the source of 67% of active D4Ag solutions in LMICs.** While this is quite high, it is a slight decline from the 70% mark just five years ago, and the 75% mark of 2012. D4Ag solutions active in LMICs hail from an **astounding 81 countries at present,** up from 71 in 2018 and 42 in 2012. While each LMIC region reflects fundamentally different market structures within them, the existence of (typically) one regional D4Ag innovation "hub" is evident: **61%** of D4Ag solutions in Latin America and the Caribbean are headquartered in **Brazil**. **86%** of D4Ag solutions in South Asia are headquartered in **India**. **45%** of D4Ag solutions in sub-Saharan Africa come from **Kenya and Nigeria**—69% from those two plus Ghana, South Africa, and Tanzania. This decentralization, in D4Ag's most populous LMIC startup region, could portend a similar fanning out across other LMIC regions.

Source: Feed the Future Flickr. Photo credit: SM Tamzid Al Fatah

PRINCIPAL GROWTH CHALLENGES FLAGGED BY D4AG INNOVATORS DURING INTERVIEWS

58%
access to funding

38%
difficulties in user adoption

31%
lack of skilled talent

23%
lack of supporting infrastructure

19%
regulatory constraints

REACH & ADOPTION

Reach of D4Ag is continuing to soar, though a lot of headroom remains. Across LMICs, **we estimate that D4Ag solutions have amassed upward of ~50 million active users.** This amounts to about 10% of smallholder farming households in LMICs.[1] **Under the positive scenario, we expect this number to grow to 224 million farmers actively using D4Ag solutions by 2030, reaching a CAGR of 16%.** We need to clarify, however, that for the purposes of this report, when talking about the reach and adoption of D4Ag, we focus on specialized, purpose-built D4Ag solutions, excluding generalized technologies that might be used in agriculture but that are not specifically designed for it (like social media or mobile money platforms, which are sometimes included in other studies). We are also estimating the number of "active users", as opposed to simply the number of registrants, to allow us to consider the impact of these tools on farmers' economic and social lives. Please refer to Chapter 2 for further details.

More than half of current registrations come from South Asia—more specifically, India—where we have observed several D4Ag pioneers balloon to well above 15 million registrants and seen several others grow from scratch to >2.5 million registered users in the past five years. Still, with 160 million smallholder farmers in India, these are still the early days of sector growth.

Growth has been steady, especially at the "top", where the number of **D4Ag solutions with over one million registrants** grew from an estimated 11 to 27 from 2018 to 2022. While the supply of innovation remains somewhat concentrated, users across the continent are getting in on the action. Sub-Saharan African innovators were most "international" (per our count, active in an average of 1.6 countries per solution (mostly within the region), as compared to the next highest (1.3) in Latin America and the Caribbean); and the 10 D4Ag solutions in sub-Saharan Africa with the highest identified numbers of registered users in 2022 represent at least 15 different markets in the region. By number of registered users, Southeast Asia and Latin America and the Caribbean represent a relatively small share. Neither region, for example, could be shown to boast a solution with a registered user base of one million or

1 There are 500 million smallholder farming households in the world. Source: A Year in the Lives of Smallholder Farmers (worldbank.org)

more. In Southeast Asia, this reflects both the combination of relative industry nascency and the diversity and difference of cultural and socioeconomic landscapes across the region. In LAC, though, it is more likely explained by the general difference in solution mix and farmer demographics—a higher share of enterprise management and supply chain management solutions, targeting deployment on large-scale farms and/or through corporate agribusiness clients providing access to large swaths of farms in their supply chains. Among our interviewees (specifically D4Ag startup founders), the key challenge restricting the growth of their solutions was and remains **access to funding (58%)**. A notable **38%** struggle with **difficulties in user adoption**, while **31%** are restricted by **lack of skilled talent** in their regions. Poor supporting **infrastructure** and **regulatory constraints** in LMICs were also commonly referenced as key challenges (by **23%** and **19%** of innovators, respectively).

The extension of D4Ag tools to women, and other potentially disadvantaged sub-populations, remains limited. Recent years have seen substantial investment and knowledge generation with regard to gender & social inclusion in (digital) agriculture, particularly in the design of "inclusive" D4Ag solutions. It is not evident, however, that this is widely practiced in the D4Ag sector. By our estimate, **the average share of users who are female for any given D4Ag solution is 26%**. We are confident that this represents some level of progress in recent years. For sub-Saharan Africa specifically, for example, respondents to a survey of D4Ag innovators that we deployed suggested that ~36% of registered users were female, as compared to 25% reported by "The Digitalisation of African Agriculture Report 2018–2019" authored by CTA and Dalberg Advisors in 2019. But given the centrality of women in agricultural value chains across LMICs, there is certainly a great deal of headroom to be had. There were very few D4Ag solutions identified with an expressed focus on the inclusion of women or other potentially disadvantaged sub-populations. **While more than two-thirds of D4Ag innovators interviewed reported sex disaggregation of registration data, virtually none reported the use of such data for strategic or operational reasons** (e.g., to

ACTIVE USERSHIP OF SPECIALIZED, FOR-PURPOSE D4AG TOOLS

17%	Latin America & the Caribbean
10%	South Asia
6%	Southeast Asia
5%	Sub-Saharan Africa

Estimated percentage of farm enterprises

THE AVERAGE SHARE OF USERS WHO ARE FEMALE FOR ANY GIVEN D4AG SOLUTION IS

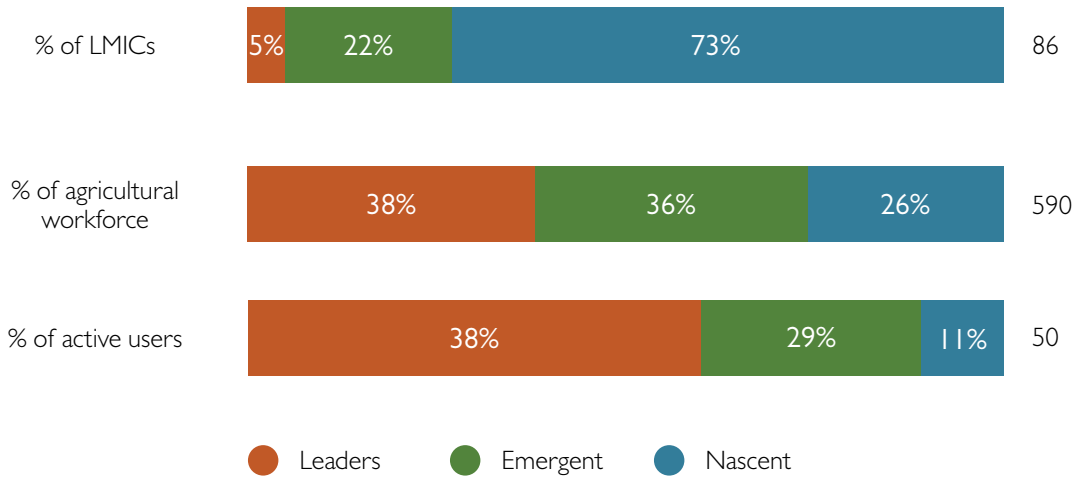
~40%

of D4Ag solutions are tackling at least two D4Ag use cases

tap into a commercial opportunity of uniquely underserved users). **Zero innovators whom we engaged or surveyed reported collecting registration data disaggregated across other (than sex and age) sociodemographic factors**. As such, the extension of D4Ag tools to other sub-populations (i.e., ability, indigeneity, sexual orientation, and minority status) remains unknown. What is known is that there are just about no commercial D4Ag solution providers (and certainly none at scale) that have centered social inclusion (beyond gender) within their organizational and business strategy.

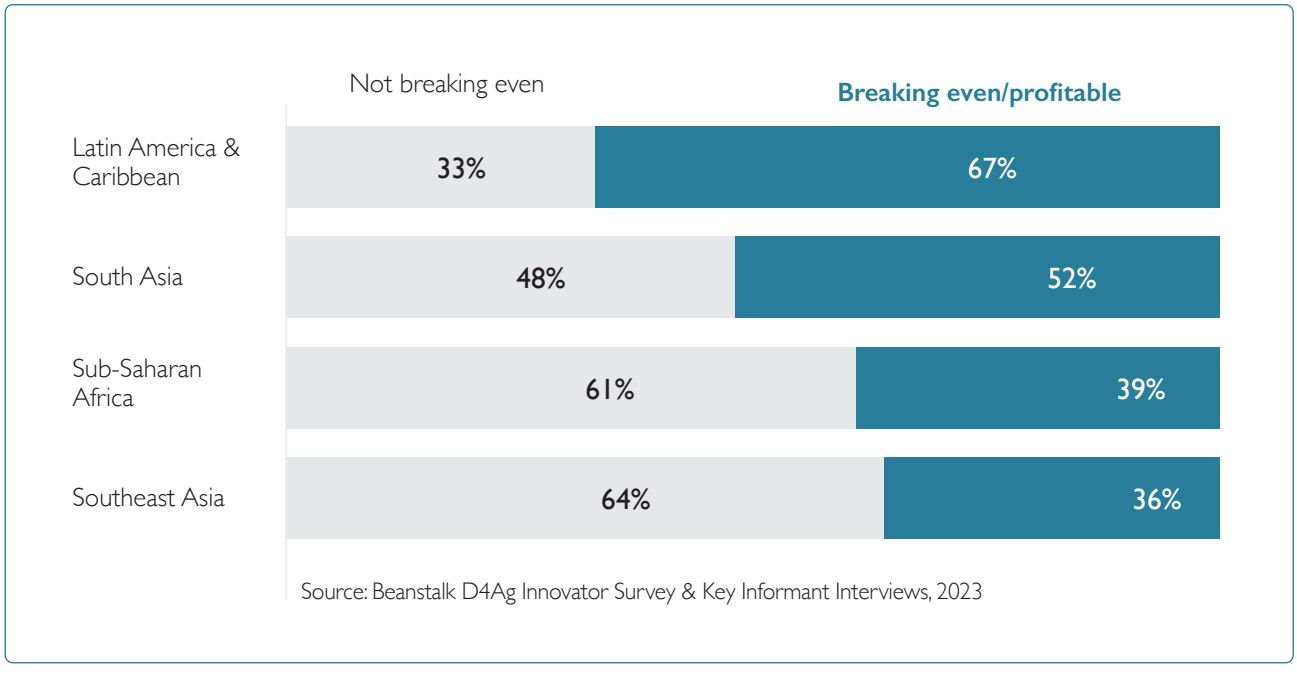
While the mix of use cases offered by solutions is relatively stable, both "divergence" and "convergence" are at play. As compared to 2018, the relative share of D4Ag solutions offering each of the six identified D4Ag use cases is relatively unchanged. The most notable shift is a decrease in D4Ag focused on **"Advisory & Information" (26% in 2018 to 22% in 2022)**, set against an almost equal increase in D4Ag focused on "Market Linkages & Access" (26% in 2018 to 30% in 2022). We believe this is meaningful and driven by factors including easier monetization, the post-COVID sustained demand and comfort with e-commerce and digital marketplace solutions, as well as a general challenge for D4Ag innovators to open new line items of cost (i.e., for standalone advisory services) apart from existing transactions. While the often-forecasted rise of "super platforms' has not yet been realized at scale in LMICs, there is a clear trend toward bundling, with **nearly 40% of D4Ag solutions tackling at least two D4Ag use cases**. New business models and revenue pathways (i.e., novel financial services and carbon marketplace solutions) are driving greater diversification of the offerings within respective use cases—we bucketed into more than 20 different use case sub-categories (see Glossary).

ESTIMATED SHARE OF AGRICULTURAL WORKFORCE AND ACTIVE D4AG USERS IN MARKETS OF NASCENT, EMERGING, AND LEADING D4AG ECOSYSTEMS (2023)



COMMERCIAL STABILITY

Commercial viability is improving, but quite unevenly. Our findings suggest that as much as **half of established** (excluding "pre-commercial") **D4Ag innovators** across LMICs **are operating at or above breakeven**. Clustering is quite regional: innovators in sub-Saharan Africa and Southeast Asia are—according to our survey—much more commonly unprofitable. Less than **40% of commercial innovators report operating at or above breakeven in those regions. The same numbers for South Asia and LAC are 52% and 67%**, respectively. There is a lack of baseline data to compare with on a global scale, but—both on the whole, and within regions—we are confident that this is a significant lift upward from recent years. A survey deployed for the development of CTA's 2019 report, for example, found that only 26% of their respondents were operating at or above breakeven—a jump to 39% in five years is significant. We were surprised, however, to find that the relationship between profitability and scale (of user base) was not significant. The proportion of profitable enterprises with 1,000 to 50,000 registered users (64%), for example, was far above the same proportion of enterprises with 50,001 to 500,000 and those with 500,001 to 1,000,000 registered users (35% and 50%, respectively). This indicates that unit economics is not just a function of scale: as these solutions expand from one geography to another, one crop to the next one, profitability often gets adversely impacted. At the same time, it is quite clear that different use cases have shown a more straightforward path to revenue generation and profitability than others.



Profitability of Surveyed D4Ag Innovators, Per Region
(% of innovators surveyed (n=75))

FUNDING & INVESTMENT

Funding and investment for D4Ag, while not systematically tracked, have clearly seen a massive upswing in recent years. Cumulatively through 2021, **LMIC regions had seen the deployment of ~US$13.2 billion in funding and investment for AgTech** more broadly (approximately one-third of the global total). About **US$5.8 billion (44%) of this total has come from (sub-)commercial investors**, including venture capital and private equity. Lesser shares have come from other categories of funding, including private foundations, development finance institutions (DFIs), and multi/bilateral investment vehicles. Africa's (sub-)commercial investment market, which has supplied merely 12% of the region's US$5.4 billion AgTech investment to date, is uniquely shallow across LMIC regions (LAC was the next lowest, at 47% of regional investment from (sub-)commercial investment). The vast majority (by number of investments) remains in pre-seed to Series A investments, with India as a standout for the prevalence of later-stage investments in mature D4Ag startups. What is clear is that the bulk of funding and investment for D4Ag has continued to be directed toward specific innovators rather than cross-sector investments (i.e., in data and digital infrastructure (apart from mobile and internet connectivity)). More specifically, the lion's share of investment has been directed toward "Market Linkages" and "Financial Access" solutions (>US$1 billion in 2021), where there are clear models for monetization, familiar pathways to scale, and an understanding and acceptance of large capital requirements to "win." With everything above accounted for, bootstrapping is still the most common funding pathway for D4Ag innovators: the **vast majority (77%) of active D4Ag innovators in LMICs have not raised external funds**.

LMIC REGIONS HAVE SEEN THE DEPLOYMENT OF

~$13.2 BILLION
IN FUNDING & INVESTMENT
FOR AGTECH

About **$5.8 BILLION (44%)** of this total has come from
(SUB-)COMMERCIAL INVESTORS

Source: Feed the Future Flickr. Photo credit: Imran Abdullahi

IMPACT

We are getting a clearer picture of the impact of D4Ag, but there is still more "noise" than "signal." Theoretical impact pathways point to the potentially transformative role of D4Ag in economic, environmental, and social outcomes for farmers and stakeholders across agricultural value chains. To date, the "evidence" remains mostly anecdotal and housed in innovators' marketing collateral. Professional and academic impact studies have generally been limited to "economic" aspects of impact and have been centered on validating positive rather than potential negative impacts from D4Ag deployment. Still, we are gaining a better understanding over time as to how, and under what conditions, different D4Ag solutions are generating positive impact.

Productivity (strong evidence): While the magnitude is difficult to pin down (independent studies have shown a range of **0–170% yield improvement**, with little clustering in between), the contribution of D4Ag to improved productivity—through, for example, improved weather forecasting, fertilizer application recommendations, or simply making possible the purchase of enhanced inputs—has been corroborated across LMICs in various geographical and value chain contexts. What is also clear is that access to information, whether prices or new production practices, is typically insufficient to enable practice change. The greatest returns have been observed in the deployment of combined "Advisory & Information" services with "Market Linkages" or "Financial Access"—which unlock liquidity and means of practice change for producers—and are cognizant of the "physical" realities of producers' locales (i.e., known availability of recommended inputs). Much less explored is the impact of D4Ag on the productivity of agribusinesses across the supply chain (i.e., cost savings from improved demand forecasting).

Income (strong evidence): Income effects of D4Ag have been observed with regularity over the past decade (typically from **2% to 20%, but with some positive outliers citing up to 60% income improvement on- and off-farm**). Beyond the economic impact of productivity, there are several other pathways through which D4Ag has shown promise in advancement of net income within and across the agricultural supply chain. Most tangibly and commonly, this effect has been on cost savings—i.e., procuring quality inputs at cheaper prices; or applying labor, chemicals, fuel, and fertilizer more efficiently. Additionally, dating back to the first deployments of "Market Linkages" solutions and mobile phones more broadly, farmers continue to demonstrate clear benefits from improved price realization—leveraging digital tools to better time marketing, and investing in highest-return marketing partnerships. A new class of emerging D4Ag solutions are enabling an additional income effect through new revenue streams, as exemplified through digital measurement, reporting, and verification (d-MRV) tools unlocking access to carbon markets, and entrepreneurial opportunities afforded through equipment-leasing tools. While most nascent among income improvement pathways for D4Ag, these solutions present potentially the most transformational economic impact pathway dependent specifically on the advent of digital tools, opening new pathways for even smallholder farmers to generate return on assets apart from commodity production. It is important to recognize, however, that "physical" assets—infrastructure, quality inputs, trusted expertise, marketing and logistics partners, fit-for-purpose equipment and machinery, etc.—are crucial ingredients to unlock the value of digital in each of these income improvement pathways, and often represent the "weak link"

IMPACT OF D4AG OBSERVED TO DATE

Productivity
independent studies have shown **0-170% yield improvement**

Income
typically from 2-20%, but with some positive outliers citing up to 60% income improvement on- and off-farm

Gender Equity
Growing body of evidence supporting claims of positive impact on women from D4Ag

Social Inclusion
Public and development agency research at the intersection of digital agriculture and broader social inclusion seems relatively nascent.

Environmental Sustainability
D4Ag will unlock further opportunities for climate change adaptation and resilience.

in the chain. As with productivity, less explored and validated to date have been the impacts of D4Ag on costs and returns for agribusinesses, agriculture adjacent businesses (i.e., financial services providers and mobile network operators), and governments. For example, digital tools' impact on the cost efficiency of customer acquisition and support activities, rural loan book value and (non-)performance, and government benefits provisioning—all of which indirectly benefit smallholder farmers—has not generally been in the spotlight.

Gender Equity (some evidence): In general, it is clear that the sector is not collecting enough information on gender-specific and gender-disaggregated usage and outcomes from D4Ag to make systematic claims on the impact of D4Ag on gender equity in LMICs. There is, however, a growing body of evidence supporting claims of positive impact on women from D4Ag, particularly with respect to women's economic empowerment. Digital tools have shown the capacity to support women to improve productivity and income through improved access to knowledge, resources, and financing, as well as develop wage-enhancing professional qualifications. The boundaries and limitations of D4Ag's positive impact on gender equity, as well as potential negative impacts of D4Ag on gender equity, have been anecdotally and quite commonly reported, but less observed. This is likely due to both sensitivity and the challenging nature of this kind of targeted research—for example, due to the purported "invisibility" many women users of D4Ag—as well as a general lack of looking for the "negatives" of D4Ag by self-interested

parties. We know that social norms, resource inequities, and intrahousehold responsibilities can limit or outright counter positive impacts from D4Ag. While there are anecdotal stories of such being circumvented, this comes with social consequences and risks, which should be acknowledged and considered for locale- and cultural-specific contexts. Much less explored have been the implications of the D4Ag ecosystem's development on gender equity across agricultural value chains, and vice versa (i.e., how D4Ag sector growth is contributing to education and employment for women and girls in STEM, or alternately how increasing gender equity in LMIC investment ecosystems influences funding for innovators tackling GESI-specific challenges).

Social Inclusion (low-to-no evidence): As touched on previously, there is very little disaggregation of data on registration—let alone usage and outcomes—for sociodemographic segments outside of "gender" (and to some extent, "age"). This includes people living with disabilities, indigenous peoples, ethnic minorities, culturally and linguistically diverse populations, individuals of various sexual orientations, and various further globally and locally relevant social strata. Public and development agency research and programming at the intersection of digital agriculture and broader social inclusion for these sub-populations seem relatively nascent. Thus—beyond sparse evidence of individuals' broadening their professional networks through D4Ag—what we have learned about the potential for D4Ag to support broader social inclusion is largely theoretical and anecdotal. Theories and anecdotes do, though, hold promise—whether in the case of digitizing otherwise inexpressible land titles (see **Papyrus** in Haiti), providing tools for intermediaries to better support people living with disabilities to advance agricultural enterprise (see **RehApp**), or extending digital advice and information through interactive voice response (IVR) and video rather than text for those with low literacy and/or language skills. A closer review of experiences and outcomes for specific sub-populations will help to clarify the real potential of D4Ag to improve broader social inclusion.

Photo credit: M-Shamba

Environmental Sustainability (low-to-no evidence): As discussed previously, agriculture and climate change are fatefully intertwined. Agriculture, in virtually all countries and production systems, is one of the world's top two to three greenhouse gas (GHG) emitting industries. At the same time, (smallholder) farmers are uniquely vulnerable to the effects of climate change. For many, AgTech (of which D4Ag is a subset) has become synonymous—or at least, a subdivision of—ClimateTech. The deployment of technology solutions and broader practice change have long been identified as critical to the fight against climate

change, and to adaptation through it. First, this comes through the potential for climate change mitigation—i.e., d-MRV's enablement of carbon offset projects in LMICs, variable rate fertilizer prescriptions reducing nitrous oxide emissions through degasification of overapplied nitrogen fertilizer, or feed optimization tools improving the methane intensity of bovine meat production. Physical inputs—such as biological replacements to synthetic fertilizers, methanogenesis-limiting feed additives for ruminants, and labor-saving technologies for alternate wetting and drying of rice paddies—could have equal or more significant effects and will likely be critical complements to digital innovation. D4Ag will also unlock further opportunities for climate change adaptation and resilience—i.e., AgFinTech tools enhancing access to credit for water-harvesting infrastructure on-farm, digital microbial libraries and discovery platforms supporting the development of drought-resistant crop varieties, or weather forecast apps advising farmers to take rapid action to prepare fields ahead of extreme weather events. However, the impact of D4Ag on climate change mitigation, adaptation, and resilience in practice has yet to be systematically assessed. In fact, there is good reason to believe that in many cases the opposite could be true (i.e., more nitrous oxide emissions due to increased access to and use of synthetic fertilizers).

ECOSYSTEM FOUNDATIONS

Across LMIC regions, "Foundations" of the D4Ag ecosystem have undergone substantial transformation in the past five years, though there is room yet to grow.

Policy and Regulation: Policy maturity related to D4Ag varies across LMICs, and a consistent trend reveals a fragmentation and oversight of the sector in overall digital transformation policies. We identified only **23 LMICs with policies specific to digital agriculture, 10 of which are in sub-Saharan Africa**. This has often resulted in D4Ag falling between the cracks or being micromanaged by multiple entities without clear prioritization.

The direct involvement of governments in D4Ag has produced mixed results, sometimes fostering the development of productive and

Source: Feed the Future Flickr. Photo credit: Guilherme Castro, Cromai

Policy and Regulation:

23 LMICs

with policies specific to digital agriculture, 10 of which are in sub-Saharan Africa

People and Skills:

31% of innovators

we surveyed called this out as a principal concern

inclusive innovation ecosystems, and at other times directly competing with and crowding out private innovators. For example, government-sponsored platforms often offer similar services at a subsidized cost or for free, making it difficult for private enterprises to compete. Furthermore, when/if these government-led initiatives fail, they tend to undermine trust in similar private-sector services. Further, policy misalignment across levels of governance is quite common across LMICs, often leading to diluted strategies and constrained support for D4Ag ecosystems.

People and Skills: Despite the obvious potential, D4Ag ecosystems globally are **struggling to attract and retain skilled staff. As much as 31% of innovators we surveyed called this out as a principal concern** (up to 44% in sub-Saharan Africa), particularly with respect to software development, data science, and business development. The movement of talent from rural to urban areas and/or to international tech hubs—the "double brain drain"—further exacerbates this issue. However, countries are implementing creative strategies to counter the talent drain, such as locally targeted tech hubs, incentives for returning professionals, and leveraging the diaspora strategically for expertise and capital.

Universities, when empowered, can become transformative forces in D4Ag ecosystems, as seen in India. Educational institutions also play a significant role in promoting gender & social inclusion within the D4Ag sphere by creating opportunities for underrepresented groups, contributing to ecosystem dynamism and inclusivity. However, many face challenges due to a fragmented inclusion of digital skills in agricultural curricula and a lack of collaboration between universities.

D4Ag innovators often compete with sectors perceived as more attractive (e.g., FinTech, HealthTech, EdTech) for specific skills, compounded by the perception of agriculture as "slow" and backward-looking. Regionally, this situation varies, with examples like Latin America, where recruitment of agricultural talents is challenging due to competition from established agribusiness corporations.

Knowledge and Capabilities: The level of digital literacy varies widely across LMICs and often acts as a significant barrier to the effective adoption of D4Ag tools. The challenge is not just about understanding the basics of the internet and devices use, but also about grasping the diverse requirements that different D4Ag solutions might demand. For instance, some tools might function optimally on specific mobile data networks or require regular updates and synchronization. A lack of familiarity or comfort with these requirements can hinder

users from maximizing the benefits of these tools, or even from using them at all.
In response to literacy challenges, innovators are exploring methods to make D4Ag tools more accessible and enjoyable, such as the "gamification" of tools. Simultaneously, hybrid models combining physical and digital delivery channels are emerging as a solution to enable participation in digital systems without requiring extensive individual digital literacy.

Contrasting experiences in places like India, where digital literacy among target users is often underestimated, indicate the necessity for a more nuanced understanding of digital literacy levels across different contexts. It underlines the need to tailor D4Ag solutions to the abilities and expectations of target users.

In markets and regions where basic literacy still poses a significant barrier to digital adoption, alternative delivery channels such as video delivery or IVR have been used extensively. Far from 'silver bullet' solutions, though, these come with their own limitations.

Networks and Social Capital: Social media and messaging platforms like WhatsApp, Facebook, and YouTube have become essential for networking, market intelligence, and knowledge sharing within the D4Ag communities across LMICs. They serve as platforms where farmers share experiences, ask questions, and receive advice, enhancing agricultural productivity. We have identified, for example, four different YouTube channels dedicated to agricultural knowledge dissemination in India alone with more than one million subscribers, and 10 similarly focused LMIC-based Facebook groups with more than 100,000 members.

On the other hand, the means of network-building and knowledge dissemination continue to multiply. Newsletters, podcasts, blogs, and similar content delivery platforms have fostered new virtual spaces for knowledge sharing, enhancing industry understanding, and exposing users to innovative practices in D4Ag. Non-textual platforms like TikTok have also shown effectiveness in engaging audiences and disseminating information.

Source: Feed the Future Flickr. Photo credit: Maria Luisa Ramirez Cruz

Research and Development (R&D) Funding for Sustainable Agriculture

US$10.5 billion
annual funding gap

Access to Credit for Farmers

~1.4 billion adults
still unbanked as of 2021, globally

Funding and Investment: Funding remains critical for the growth and sustainability of D4Ag ecosystems. This includes funding not only for individual innovators, but also for the advancement of a nurturing, robust D4Ag ecosystem.

Funding for Individual Innovators: Innovators developing D4Ag solutions often face resource constraints. Adequate capital is required to support research, development, product market readiness, scaling operations, enhancing innovation, capacity building, and risk mitigation. From our interviews and research, we were consistently pointed to common and persistent gaps in commercial investment landscapes crucial for LMIC-based innovators (i.e., in sub-Saharan Africa, the "missing middle" between small-scale grants below US$50,000 and typical threshold ticket size for venture capitalists (VCs) at US$750,000) and working capital (i.e., overdraft facilities and short-term debt). Overall, access to funding was the most referenced barrier faced by D4Ag innovators in LMICs, with almost 60% of solution providers admitting to facing such difficulties. There is also a clear lack of visibility on early-stage D4Ag startups, specifically grant-funded and unfunded solutions, in LMICs. This can largely be attributed to the fact that many existing databases often fail to capture data on early-stage solutions in these markets: For example, three leading investment databases (Pitchbook, Tracxn, and Crunchbase) each contained only 30%–40% of the >1,300 solutions that sit in our database. This lack of visibility in the market constrains investors' pipeline building, due diligence process, and ability to identify co-investors, ultimately lengthening transaction timelines or dissuading investors from entering new markets, thereby contributing to persistent funding gaps.

Infrastructure Funding: D4Ag relies heavily on technology-driven infrastructure, such as physical and digital networks, data centers, and hardware. Investment in infrastructure is vital for successful deployment and scalability of digital agricultural tools and platforms. However, infrastructure often receives disproportionately low attention from the public sector.

Research and Development (R&D) Funding: R&D funding fuels scientific and technological advancements for agricultural innovations. Despite the growth in agricultural public sector support, it often fails to meet its aims of improving food security, livelihoods, and environmental sustainability. **An investment gap exists in R&D for sustainable agriculture intensification in LMICs, currently standing at US$10.5 billion annually.**

Source: Feed the Future Flickr. Photo credit: Rakotonantoandro Lalaina

Access to Credit for Farmers: Financial access is crucial in the D4Ag funding ecosystem. Farmers often rely on credit to acquire necessary agricultural inputs, but may resort to borrowing from informal sources with high interest rates and unfavorable terms. Despite an increase in credit to agriculture, its growth has been slower than in other sectors. Furthermore, significant gaps in financial inclusion remain, with **around 1.4 billion adults still unbanked as of 2021, globally.**

Data and Infrastructure: The role of data and infrastructure in D4Ag has grown significantly, with substantial investments leading to noticeable improvements in the availability of public sources of weather, soil, productivity, and market information. The effectiveness of D4Ag solutions is highly dependent on the quality, accessibility, reliability, sustainability, and relevance of these infrastructures. A strong D4Ag infrastructure in LMICs should be robust, able to withstand various challenges and handle large data volumes from multiple sources. It should be accessible to all stakeholders and reliable in providing accurate and timely information. The infrastructure should also be sustainable, both environmentally and economically, and remain relevant by delivering data and insights that directly support the needs of its users.

Despite increased data availability, factors like accessibility, comprehensibility, granularity, and data integrity limit the contribution to the D4Ag ecosystem: **23% of surveyed innovators said that a lack of supporting infrastructure prevents them from scaling their solutions.** A few countries, like India, have made notable efforts to invest in more sophisticated agricultural data warehousing and analytics infrastructure. In the spotlight—for challenges, opportunities, and complexity at present—are "data sharing" and "data governance."

Sophisticated software capabilities are becoming more accessible in D4Ag, with machine learning (ML), blockchain, artificial intelligence (AI), systems integration, and customer relationship management (CRM) leading the way. However, these technologies also present issues related to cost, complexity, rural connectivity, digital literacy, and data privacy and security. For example, transparency and interpretability of AI-driven decision-making have raised ethical questions. Hardware requirements and associated costs are key considerations, often impacting uptake and business models in D4Ag. Some promising models, like hardware as a service (HaaS), have emerged, offering skills-building and entrepreneurship opportunities.

Internet connectivity, data affordability, and device ownership remain significant barriers to D4Ag adoption among smallholder farmers in LMICs. Despite some improvements, internet and mobile penetration, as well as data rates, continue to be challenges, particularly for those with low or unstable income. **While the smartphone adoption rate in emerging markets has grown to ~40%,[2] only about one-third of farms less than 1 hectare in size are served by 3G or 4G services.**

Data and Infrastructure

23% of innovators
said that a lack of supporting infrastructure prevents them from scaling their solution

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2 Accelerating Affordable Smartphone Ownership in Emerging Markets, GSMA, 2017
Mehrabi, Z.; McDowell, M.J.; Ricciardi, V.; Levers, C.; Martinez, J.D.; Mehrabi, N.; Wittman, H.; Ramankutty, N.; Jarvis, A. (2020) The global divide in data-driven farming. Nature Sustainability, Online first paper (02 November 2020) ISSN: 2398-9629

CHALLENGES, CONSOLIDATED

Consolidated from and reflecting on the assessment of LMIC-based D4Ag ecosystems across the globe, seven core challenges stood out as most constraining the emergence and sustainability of an inclusive, climate-smart, and commercially viable D4Ag sector:

Disconnected knowledge sharing and collaboration networks:

Traditional agricultural insights are often overlooked, causing disconnects and missed opportunities in D4Ag initiatives. Duplication in donors' D4Ag programs leads to inefficiencies and reduced potential for learning. Siloed government operations obstruct the sharing of best practices across regions, further hindering progress.

Uncertainty of financial viability:

Concentration of funding neglects certain sectors, and a lack of successful exits diminishes growth prospects. Underserved financing areas hinder small-scale innovators, while donor-driven market distortions risk long-term sustainability. A lack of visibility and data on early-stage D4Ag solutions in LMICs contributes to persistent funding gaps.

Poor accessibility and quality of physical and digital infrastructure:

Public data issues, duplication, and lack of sharing incentives can lead to misinformed decisions. A disproportionate focus on crops over livestock and aquaculture misses potential opportunities. Infrastructure challenges, including gaps in middleware and hardware constraints, limit D4Ag's reach and efficacy.

Shortcomings in user engagement and market penetration:

Digital fatigue and a lack of physical support diminish user engagement. Misunderstandings of target markets due to lack of diverse input lead to solutions misaligned with users' true needs. Moreover, a common feeling of distrust towards top-down developed technologies among farmers and reservations about sharing personal and farm data further hamper the adoption.

Constraints on climate-smart D4Ag deployment and credibility:

Limited localized climate data constrains effective adaptation and mitigation strategies. The neglect of public data assets and absence of government frameworks impede aligned climate-focused efforts. The risk of "greenwashing" threatens market integrity and trust in sustainable initiatives.

Persistence of gender inequality and social exclusion:

Barriers like access and cultural norms limit penetration among marginalized groups. The absence of strong incentives and skewed representation results in biased or misaligned solutions. A lack of standardized gender & social inclusion indicators complicates measuring and promoting inclusivity.

Lack of quality impact measurement:

Unattended adverse impacts risk causing unintended harm. An existing evidence gap combined with challenges in quality measurement and lack of data transparency at a market-level obstructs a clear understanding of D4Ag's true impact.

FUTURE OUTLOOKS

A few forward-looking trends—some bolder than others—stand out in particular as highly likely to bear fruit given historical trends, expert perspectives, committed investments and policies, and market cyclicality.

Ecosystem Foundation Development: From an infrastructural perspective—drawing on current trends and planned investment—we are expecting significant growth in smartphone and 3G+ connectivity in the coming decade, enabling much broader access to D4Ag among remote and diverse farming segments. For example, it is expected that by 2030, mobile internet penetration will reach 64% globally (up from today's 55%). Device ownership gaps are expected to narrow, with smartphone adoption in regions like sub-Saharan Africa reaching 87%. From the regulatory perspective, we expect a new wave of regulations and policies drawing and building on pioneering governments in respective regions. These regulations are likely to not only provide greater clarity, confidence, and room to operate for D4Ag innovators and ecosystem partners, but also serve as foundational elements for the mainstreaming of GESI principles and climate change management strategies. We also expect broader "integration" of D4Ag with ClimateTech / climate change management—both in perception and in practice, signifying the strategic alignment of agricultural innovation with broader global agendas, particularly ensuring that development is inclusive and responsive to the planet's changing climate.

Macro Market Dynamics: Despite the aforementioned deceleration in D4Ag solution growth in recent years, we are expecting a "re-acceleration" in the number of D4Ag startups driven primarily through geographic diversification—"emerging" D4Ag ecosystems earlier in the D4Ag innovation S-curve. We expect that re-acceleration and expansion to newly maturing D4Ag markets will facilitate additional "boom" and "bust" cycles—more meteoric rises and falls that will reverberate through the sector. Hopefully, these will be moderated with success stories and learnings from the past decade so that shaken confidence can be avoided. Moreover, we anticipate a further "split" and divergence in trajectories, and perhaps ecosystems, between enterprise- and farmer-facing D4Ag—reflected in different

FORWARD-LOOKING TRENDS FOR WHICH WE HOLD A HIGH DEGREE OF CONFIDENCE

- Smartphone Accessibility
- Regulatory Evolution
- Climate Change Integration
- Divergent Trajectories
- Volatile Market Dynamics
- Expansion in Emerging Markets
- Continued Relevance of 'Point Solutions'
- Business Model Innovation
- 'Digitally Native' Agribusinesses

investor bases, growth cycles, and commercial viability. As use cases, business models, and ecosystems diversify, it will be increasingly important that D4Ag strategies and perspectives avoid being overly monolithic.

Business Model Evolution: While technological innovation is certain to remain both unflinching and important, business model innovation is likely to be more critical to the next wave of opportunity for D4Ag—unlocking new revenue streams, financial products, and intermediary models for the sector. With greater technological precision and business model diversification, we envision that—despite a general trend toward D4Ag platforms and bundles—there remains plenty of opportunity for "point solutions" targeting previously unaddressed challenges (especially deployed in conjunction with "physical" tools). Lastly, we anticipate the emergence of "digitally native" corporate agribusinesses. Much attention has been paid to prospects for and market developments indicating agribusiness majors (i.e., Bayer, Corteva, Syngenta, Yara, UPL, etc.) going "digital," but much less on D4Ag pioneers going "physical." We predict that we will start to see at-scale challengers to traditional agribusiness majors from D4Ag innovators who may more deftly leverage a "phygital" approach and lean less on (while competing with) legacy agri-product sales (i.e., leaning instead on bio-based alternatives, higher-margin services, etc.).

In addition to these "likely" predictions, we have framed a pair of "alternative futures," which we believe represent and model the lower and upper bounds for the growth, reach, and impact of D4Ag across LMICs in the next decade—what we call "derailing" and "thriving" scenarios. The aim is not precision, but a reflection of the magnitude of difference in getting the future "right" versus "wrong" for D4Ag sector development. The two scenarios reflect potential D4Ag-influenced futures drawn out across lines of smallholder livelihoods ("down and out" or "up and in"), innovation ("stifled" or "distributed"), environment ("degradation" or "regeneration"), culture ("erasure" or "enrichment"), inclusion ("systematic barriers" or "equitable access and benefit"), and digital foundations ("exploitation" or "shared stake and benefit")—as well as what such divergent outcomes could suggest for individual stakeholders.

In 10 years' time, we estimate that under the achievement of the "thriving" scenario, ~US$500 billion of value enabled by D4Ag is added to the agriculture industry every year across LMICs, representing an increase of 28% in value of total agricultural output across focus regions. In the "derailing" scenario, the majority (90%) of potential value, equivalent to US$450 billion, is eroded away by low uptake, low supply, and efficacy of solutions. Successful adoption of D4Ag solutions is the critical success factor—we see farmers accelerating adoption four times faster when the ecosystem is "thriving" versus "derailing," **reaching an average adoption rate of 38% across the LMICs by 2033, encompassing a vast population of 224 million users** who will have integrated D4Ag tools into their daily agricultural practices. From a gender inclusion perspective, **we estimate the gender gap to close by more than half, bringing 64 million more females into the D4Ag user ecosystem.** Lastly, there is huge potential for D4Ag to reduce farm-gate GHG emissions by 9% (-360 MMT CO2eq). D4Ag can create greater efficiencies, thereby enabling a lower climate footprint; however, farmers may also then choose to invest more into resources such as fertilizer inputs and fuel-based farm machinery, causing a worsening effect on GHG emissions (+140 MMT CO2eq per annum).

TWO SCENARIOS PAINT THE RANGE OF ALTERNATIVE FUTURES WE BELIEVE ARE POSSIBLE FOR D4AG IN LMICS - A $450B+ P.A. QUESTION

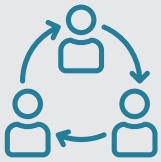
Under the 'thriving' scenario, ~US$500 billion of value enabled by D4Ag is added to the agriculture industry annually across LMICs, an increase of 28% in value of agricultural output across focus regions.

Innovation is **distributed**

D4Ag will reach an average **adoption rate of 38%** across LMICs, covering **224 million users**

Environmental **regeneration**

Farm-gate **GHG emissions** will fall by **9%**



Equitable access and benefit for all

The gender gap will close by more than half, bringing **64 million more females** into the D4Ag user ecosystem

Shared stakes and mutual benefit

Under the 'derailing' scenario, 90% of this potential value – US$450 billion – will be eroded by low uptake, low supply, and efficacy of solutions.

Innovation is **stifled**

D4Ag will reach an **adoption rate of ~10%** across LMICs

Environmental **degradation**

Systematic barriers to gender & social inclusion

Expectation of **exploitation**

RECOMMENDATIONS

With a focus on orienting the LMIC D4Ag ecosystems toward the "thriving" scenario, we have formulated a series of strategic recommendations (accompanied by illustrative and referenceable actions) for stakeholders across the D4Ag ecosystem:

1

Support the formulation and implementation of inclusive, climate-smart policies for D4Ag

Focus on creating robust policy frameworks that promote climate-smart digital agriculture, taking into account industry standards, regional alignment, and infrastructure development.

2

Invest in capacity building & knowledge sharing across the D4Ag ecosystem

Emphasize training for a digitally native agricultural workforce, close knowledge gaps on D4Ag's impact across diverse sectors, and promote digital literacy and empowerment especially among marginalized groups.

3

Sustain, boost, and diversify funding and investment for D4Ag

Drive more adaptive and outcome-oriented funding structures, identify and address principal funding gaps, and ensure investors incorporate impact into core investment processes and structures.

4

Accelerate the development of infrastructure to support D4Ag

Expand funding pathways for essential infrastructure, whether physical (i.e., rural telecommunication, warehousing, cold storage, and environmental monitoring technologies) or digital (i.e., data warehousing, farmer/land registries, environmental and demographic data layers, etc.).

5

Foster collaboration and data & resource sharing across the D4Ag ecosystem

Encourage multi-stakeholder engagements, comprehensive and accessible data on D4Ag innovations in LMICs data-sharing platforms, and strategic partnerships—both within and across the regions—to collectively address common challenges and visions for D4Ag and boost funding to the sector.

6

Hone in on D4Ag end-user needs through focused and inclusive engagement

Support and encourage innovators to differentiate with clear value propositions, embed inclusivity, and prioritize deep user engagement. Support and encourage primary producers to experiment, feedback, and advocate for capacity building.