CASA

Commercial Agriculture for Smallholders and Agribusiness

Private finance investment opportunities in climate-smart agriculture technologies

Jonathan Casey, Alexander Bisaro, Alvaro Valverde, Marlon Martinez and Martin Rokitzki

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Commercial Agriculture for Smallholders and Agribusiness

The CASA programme is a flagship programme of the UK Foreign, Commonwealth and Development Office (FCDO) and is intended to increase global investment in agribusinesses which trade with smallholders in equitable commercial relationships, increasing smallholders' incomes and climate resilience.

The programme aims to help agribusinesses to scale up and trade in larger commercial markets. As part of its work CASA generate new evidence and analysis that supports a stronger, fairer and greener agribusiness sector.

Executive summary

This investor-focused study analyses the role of private finance in climate-smart agriculture (CSA) technology innovation and deployment in Africa and Asia. It **focuses in on the perspectives of investors**, identifies technologies and areas that demonstrate commercial viability and investment potential, profiles existing investments in CSA technologies, **explores the motives and incentives that may attract investors to financing CSA technology companies**, and provides a more nuanced understanding of the barriers and bottlenecks that exist for mobilizing greater investment for CSA technology. The findings are based on evidence from 28 interviews with investors and other CSA technology stakeholders, and a review of more than 100 relevant reports and publications.

Most investors tend to approach climate challenges from the perspective of environmental, social, and corporate governance (ESG) screening, looking first at risk, and building from a 'do no harm' perspective, rather than seeking to identify solution-oriented technology investments. Less than 1% of private climate finance is currently directed towards CSA, with enterprises struggling to find appropriately costed investment capital. Increasing private financial flows to emerging and developing economies needs to be supported by **proactively connecting available capital with investable opportunities and encouraging new market structures and business models**.

"Bridging the climate finance gap requires the identification of climate-smart investment opportunities"

Technologies demonstrating commercial investment potential

This report profiles eight technologies identified by interviewees as showing promise for growth, investment viability, and relevance in emerging markets in Africa and Asia for smallholders and agribusinesses.

Solar-powered micro drip irrigation systems, which are able to help farmers in arid and drought-affected areas to sustainably increase yields and crop resilience, with minimal use of scarce water resources and no ongoing energy costs. **Pay-as-you-go models for such systems are flourishing**, helping to overcome the capital expenditure costs for some farmers, with companies such as SunCulture recently securing $11m in (concessional) loans, and Azanga raising $13.5m in Series B equity investments from both private and impact investors.

Biocontrol products and precision applicators enable farmers to minimize the inputs they use for crop protection in their responses to increasing plant health threats driven by climate change. As market and consumer demand for more environmentally friendly food increases, **investors have identified biocontrol products and precision applicators as key technologies in the transition to nature-positive agricultural production**.

Solar-powered cold storage solutions help to prevent food wastage and spoilage, particularly in increasingly humid conditions and extreme temperatures, as well as helping to **ensure that produce can be sold at an optimal time in prime condition, maximizing income for farmers and returns for investors**. Innovative business models in this area are leveraging stored produce as collateral for brokering access to affordable credit for farmers, simultaneously addressing both a key demand-side constraint as well as diversifying revenue streams.

Digital platforms that bundle together climate-smart advisory services with other complementary products and services are **helping to minimize transaction and marketing costs for companies** and providing a more integrated and holistic offering to farmers. Building on existing trusted relationships, successful platform technologies enable farmers to access stress-tolerant inputs and climate information services alongside financial products and services.

Smart irrigation involves the coupling of sensors, control instruments, and irrigation machinery with computer models and meteorological information for real-time farm management. Business models that reduce the investment risks to end-users are **demonstrating commercial viability when targeting horticulture users and innovative payment models, with no upfront costs**.

Biodigesters make use of crop and livestock waste to produce biogas and rich organic inputs for crop farming. Emerging business models involve bundling financial services with product sales. For example, one manufacturer has partnered with a financial technology (fintech) company to enable livestock farmers to purchase equipment on long-term low-cost credit, and is generating additional income from retailing both the biogas and biomass outputs from its product.

Bio-coatings make use of organic inputs for the natural coating of fruits and vegetables, which can lengthen their shelf-life. Bio-coatings can be particularly useful in preserving fresh goods under climate-related stresses, such as increased heat or humidity. **Companies with operations in Africa and Asia have shown interest in working with exporters to use these products in their supply chains.** This reflects the influence of both regulations and changing consumer preferences.

Solar-powered processing equipment enables perishable products to be stored and eaten out of season, reducing pressure on other commodities, and the need to import products, and maximizing the value of the goods by making it possible to sell them when there is a supply shortage. Solar dryers can also achieve this, enabling lower-grade produce that cannot be sold fresh to still have value once processed. **These technologies have relatively short payback timeframes, and are already demonstrating scale and growth in India.**

Key findings

Finance	• There is a real need for more early-stage venture capital and angel investing • Investors need reliable data systems to engage more in nature- and climate-positive business outcomes
Challenges	• A need for growth-stage technical assistance for CSA technology businesses • A lack of affordable finance serving the needs of smallholders and agri-businesses
Business models	• Bundling with complementary products and services while addressing demand-side constraints for farmers is performing particularly well • Pivoting from retailing hardware to service provision in low-income settings

Recommendations

For investors	For enablers	For donors
• Increase early-stage financing • Improve climate risk assessment systems • Seek business models which address the issue of financial access for end-users • Work with enablers to identify investment-ready CSA technologies	• Focus support on growth-stage businesses, not just ideation • Target concessional finance at last-mile distributors • Co-develop clear nature and biodiversity markets and investment guidelines	• Invest in additional research to demonstrate the viability of impact-focused commercial investment models • Raise awareness of innovative CSA technologies • Target demand-side constraints to unlock market potential

How CASA is responding

The Commercial Agriculture for Smallholders and Agribusiness Programme (CASA) is building on work it has done since its inception, in terms of supporting agribusinesses with climate-responsive technical assistance and relevant research for policymakers and investors, CASA has been more intentionally embedding climate change and nature-positive agriculture at the heart of its strategy.

A series of four ‘4x4’ information videos and a number of regional investor forums are planned following COP26, exploring the following: the investment case for climate adaptation in agriculture; commitments to net-zero greenhouse gas (GHG) emissions by 2050; technology-enabled nature-based solutions; and mobilizing private capital towards reaching the $100bn per year climate finance goal.

The research presented here has identified unmet information needs among investors on the range of CSA technologies that exist, viable business models for operating sustainably in low-income contexts, the need for improved guidance on climate risk assessments, and help in verifying nature and climate benefits. CASA's research agenda will address these information gaps, while its technical assistance facility will support agribusinesses to identify and appraise CSA technology options, and the policy research component will explore how to improve the enabling environment for climate-responsive investments in agriculture.

Detailed findings

Investment interest in technologies for avoiding losses and minimizing waste

Technologies for avoiding post-harvest waste and minimizing spoilage targeted at value chain agribusinesses are currently more attractive to investors than production-level technologies targeted at farmers. **Waste reduction technologies enhance market and production efficiencies and maximize profitability**. These CSA technology solutions range from improved logistics management to rapid processing of lower-grade goods, renewable-powered cold storage, and bio-coatings for the preservation of fresh produce.

Awareness of CSA technologies

A number of investors interviewed for this research were only aware of solar-powered irrigation as a CSA technology. Highlighting other innovative types of CSA technologies could open up new investment opportunities in the sector.

Biodiversity and nature-positive investing

Issues of biodiversity, nature, and ecosystem conservation are more central to most impact investors' and development finance institutions' (DFIs') investment portfolios and strategies than those of private equity investors. There are emerging areas of interest in CSA technologies for nature-positive production. Biocontrol products and precision pesticide application technologies in particular were **identified as growth areas by some investors, recognizing the reputational and ecological risks associated with over-use of chemical control products.**

One of the key constraints to greater integration of biodiversity, nature and ecosystem conservation in investment decision-making is the ability to monitor and verify changes that are directly attributable to specific investments and technologies. Investors noted that there were rarely reliable baselines to work from, and that the costs of establishing monitoring, reporting and verification (MRV) systems to understand the positive or negative impacts of technology use or related activities resulting from investments was prohibitive, particularly in already low-margin settings.

Availability of private climate finance for CSA technology

Commercial finance and investment for CSA in Africa and Asia remains very limited, representing just 0.085% of the available debt and equity climate finance available. A significant finance gap exists for scaling companies which have not yet reached a sufficient level of maturity and profitability to attract private equity investment. This creates a major bottleneck in the pipeline of investable opportunities for larger private equity investments **There is a real need for more early-stage venture capital and angel investing** to support innovative CSA technology companies to grow.

An increasing impact focus in commercial finance

The lines between impact investing and commercial investing are increasingly blurred as more capital markets recognize their role in the climate emergency and as regulators drive non-financial reporting. There is a growing trend for private finance investors to move towards an impact focus in their portfolio and investment strategies, while also remaining commercially driven. This has the potential to open up new funding opportunities for some innovative CSA technology providers.

Understanding and responding to climate risk

All types of investors are increasingly incorporating considerations of climate change risk in their investment and lending portfolios, but the degree of integration is very uneven. **There is a business case for CSA technologies which have a clear link back to business resilience and the bottom line**, and that demonstrate the (medium-term) commercial opportunities from enhancing adaptive capacity through innovative technologies.

India is a frontrunner frontier market for CSA technology investment

CSA technologies and companies in India are able to scale faster and with fewer barriers than those in other countries, as the country can be treated as a single market with common regulations, currency, market dynamics and financing. This is aided by very high usage of mobile phones and familiarity with digital services compared to most other markets, which provides a solid platform for digitally driven CSA technology services. India is a market where future transformative technologies could be identified, tried and tested, before transferring to other emerging markets.

Need for growth-stage technical assistance for CSA technology businesses

While there are a multitude of incubators and accelerators available for ideation-stage innovative technology businesses, there are very few which help small enterprises to mature and develop beyond the initial prototype stage. This has left a technical capacity gap to take those enterprises to the next level and become investment-ready.

End-user finance and skills development

Affordable, appropriate, and transparent finance for smallholders and agribusinesses needs to be made available in order to unlock the potential of CSA technologies across Asia and Africa. Affordable finance combined with farmer advisory services presents the greatest potential for maximizing the impact and returns of CSA technologies.

"Affordable finance combined with farmer advisory services presents the greatest potential for maximizing the impact and returns of CSA technologies"

If the demand from smallholders for CSA products and services could be stimulated – including through improved access to finance – there would be much less need for supply-side interventions to attract capital flows and financing. One private equity investor noted:

> *"Businesses can grow when farmers can access finance. We are here ready to invest when they do."*

Innovative business models pave the way for scale and profitability

The research identified a number of promising business models that enable some innovative CSA technology enterprises to expand their reach to smallholder farmers while moving towards commercial viability. Businesses which are able to diversify their revenue streams and those that are able to 'bundle' with complementary products and services while addressing the underlying demand-side constraints for farmers – principally access to affordable credit – are performing particularly well. Some companies are pivoting from hardware provision to service provision in low-income settings. Similarly, subscription-based models are being explored through digital advisory services, as well as other production-level services, such as spraying, irrigating and storage.

Table 1: Summary of opportunities, constraints, and knowledge needs identified by interviewees

Opportunities	Constraints	Knowledge needs
Net-zero motivations	Farmers' access to affordable finance	Climate risk assessment and management
Productive uses of renewable energy	Agribusiness and farmer awareness of relevant CSA technologies	Measuring biodiversity- and nature-positive impacts
Nature-based solutions	Managing and understanding risks for farmers	Identifying CSA technologies and investment opportunities
Reducing waste and post-harvest crop loss	Technical capacity of end-users	
Digital platform technologies	Business capacity constraints of agri-SMEs	
	Regulatory risks and (dis)enabling environment	

Recommendations

To increase the scale of private climate finance, a number of actions and changes in practice are recommended for private investors, governments and concessional finance providers, to respond to the challenges and issues identified in the research.

Governments and donors

Demonstrating the viability of impact-focused commercial investment models

Bringing together the expertise of pioneer investors, alongside impact investors and climate experts, could help to share positive examples of how other commercial investment vehicles can pivot towards an impact focus in their portfolios.

Improving climate risk management assessments

Formalized data and benchmarks to help lower the costs of establishing and running impact-focused commercial investment funds, and standardized climate risk reporting protocols, are two ways in which public and private financial institutions alike could work together to improve physical climate risk management systems (Dalberg, 2021a).

National governments could provide more detailed climate risk assessments of agro-ecological zones that are usable by financial institutions. Establishing global guidelines on how to practically consider low-likelihood, high-impact climate-driven shocks would help investors understand how best to identify investment opportunities and areas of potential maladaptive practices.

Raising awareness of CSA technologies

Awareness of the plurality of CSA technologies, and familiarity with their benefits and business models, was generally low among investors. Governments and climate-focused international institutions should work with communities of investors to increase their knowledge and understanding of, and familiarity with, CSA technologies relevant to smallholder contexts, and the ways in which such technologies can also improve supply chain climate resilience for many food trade businesses.

Identifying and measuring nature-positive investment opportunities

Profit-driven investors looking for impact struggle to determine relevant outcomes from CSA technologies. To mobilize investment from the private sector in nature-positive and regenerative agriculture, donors can support activities to educate investors on the value propositions, business resilience and profitability benefits, and commercial opportunities of these investments, and can support the development of accessible, standardized monitoring, reporting and verification (MRV) systems and technologies.

Donors can invest in digital access to support CSA investment

Countries with stronger and more affordable digital connectivity infrastructure are a fertile area for CSA technology innovation and adoption. Leveraging digital technologies is important for increasing market efficiencies, lowering transaction costs and enabling many smart technologies to operate effectively.

DFIs and concessional finance providers

Financing the 'missing middle'

The public good nature of CSA technologies should be recognized. Thus, to reach the $100bn climate finance goal, DFIs and other public finance funders should look to shoulder more risk in investing directly in early-stage CSA technology innovators. Concessionally costed finance is vital for preventing promising innovations falling into the 'valley of death' between incubator investors supporting start-ups and impact financiers seeking established and scaling enterprises. DFIs need to become open to lower ticket sizes, greater risk and more management costs in specialized CSA technology funds if they are to enable promising CSA technology ventures to scale.

Supporting the missing middle

Public, private and philanthropic providers of technical assistance support should shift their focus away from ideation- and initial innovation-stage support to focus instead on enhancing the capacities of CSA technology enterprises to develop into investment-ready operations. This will require longer-term engagements, with technical assistance being deployed alongside capital.

Business model innovation

Focusing on innovative models to enhance access to appropriate consumer credit and information services will likely have a greater effect on private finance investments in CSA technologies than any supply-side intervention. Investors should consider the potential opportunities CSA technology innovators could bring if coupled/bundled with other technologies and services, and the potential opportunities for revenue diversification and pivoting towards alternative service provision models in different contexts. Further research into successful examples of CSA technology business models as they emerge will play an important role in demonstrating such value propositions.

Risk aversion in regard to new technologies and practices is an issue that is common to farmers across the world, not just those in emerging markets. CSA technology providers need to build business models around trusted relationships and transparent trade-off considerations with farmers. This means looking to integrate CSA technologies into – or in partnership with – enterprises that already have established relationships with farmers, such as off-takers.

Support through concessional finance, subsidies and grants, as well as advisory support, is likely to be required across the board to speed up the adoption of these CSA technologies, and to accelerate their development into investment-ready ventures.

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Acronyms

AfDB	African Development Bank
AGRA	Alliance for a Green Revolution in Agriculture
B2B	Business to business
CASA	Commercial Agriculture for Smallholders and Agribusiness Programme
CBI	Climate Bonds Initiative
CSA	Climate-smart agriculture
DFI	Development finance institutions
ESG	Environmental, social and corporate governance
FAO	United Nations Food and Agriculture Organization
GCA	Global Commission on Adaptation
GHG	Greenhouse gas
IPM	Integrated pest management
MRV	Monitoring, verification and reporting
SCF	Standing Committee on Finance (UNFCCC)
TEC	Technology Executive Committee (UNFCCC)
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WRG	Water Resources Group

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Images courtesy of Pixabay.

1. Introduction

The UK Foreign, Commonwealth and Development Office's (FCDO's) CASA[1] programme works to increase economic opportunities for smallholders in Africa and South Asia to step up and trade in growing commercial markets. The programme aims to increase investment in agribusinesses which source from, and supply to, smallholder farmers, and generates new evidence and research that amplifies the case for doing business with smallholders and agricultural SMEs.

Climate change represents a serious threat to the world's 475 million smallholder farms and to the ability to feed the world's growing population (Acumen, 2021). Climate-driven natural hazards, such as droughts, floods, pests, invasive plants and diseases, are increasingly impacting yields and damaging the natural resource base upon which farmers' livelihoods depend, while threatening the return and impact capacity of agricultural investments (IPCC, 2021). Apart from being extremely vulnerable to climate change, agriculture is one of the largest contributors to global GHG emissions, accounting for around a quarter of all emissions annually (IPCC, 2019).

To meet the challenges of decarbonizing the sector, enabling it to adapt to climate change, and to function in a nature-positive way, technology innovations are playing a critical and potentially catalytic role in the transition to low-carbon, resilient and environmentally sound farming systems. All of these issues combined might be seen as off-putting for conservative investors, but they also present **an opportunity to achieve climate targets while offering emergent investment opportunities for both impact- and return-focused investors in primary and secondary agriculture.**[2]

1.1. Aims of the study

As part of CASA's research and evidence component, FCDO has commissioned this study to **analyse the role of private climate finance in CSA technology innovation and deployment in Africa and Asia**. The study explores existing and emerging agricultural innovations to address climate adaptation and mitigation needs across agricultural value chains, how private climate financing is being used, and the main challenges to bringing CSA technology innovations to market and scale.

While much research has been undertaken in this area, the focus of most previous research has been on the use of public funds for CSA technology investment and innovation, and the use of public and philanthropic funds to attract private investment – often not informed by investor perspectives.

This report focuses on the perspectives of investors. It identifies technologies and business models they see as demonstrating commercial viability and investment potential, profiles the existing investments in CSA technologies, explores the motives and incentives that may attract them to financing CSA technology companies, and provides a nuanced understanding of the barriers and bottlenecks that exist in regard to mobilizing greater investment. More information on the context of this research is detailed in Annex 2.

[1] For more information, see www.casaprogramme.com

[2] Primary agriculture refers to raw agricultural products produced by farmers. Secondary agriculture refers to treated or processed goods with some level of value addition.

1.2. Research questions

This study aims to analyse the role of private climate finance in CSA technology innovation and deployment in Africa and Asia, from the perspective of investors and lenders, and to identify the innovative CSA technologies and business models gaining traction. To that end, this report explores the following five primary research questions:

- What CSA technologies are attracting interest from investors?
- What is the profile of current investments in CSA technologies?
- What are the barriers and bottlenecks constraining investment in CSA technologies?
- What are the business models being pioneered to overcome growth challenges?
- What are the incentives, instruments and motivations for increasing investment in CSA technologies?

2. Methodology

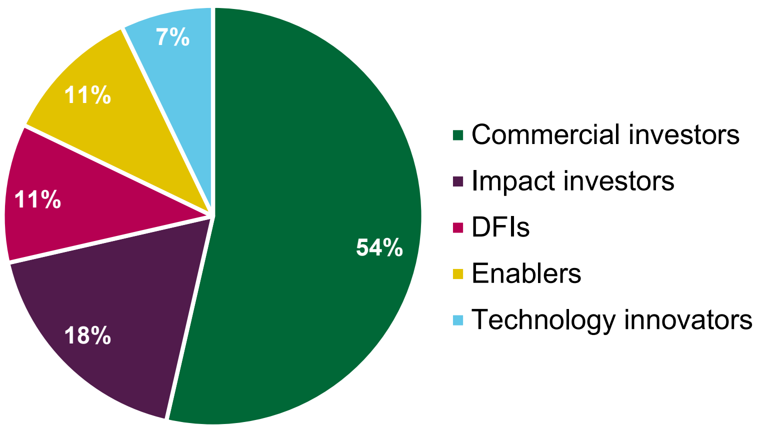
2.1. Literature review

More than 100 relevant publications were identified through a semi-systematic approach, using keyword searches of publication databases, academic journal portals, and internet search engines. The vast majority of sources that were identified are 'grey' literature (i.e. not published in academic journals). The information in the literature was used to shape the initial plans and focus for the research during the scoping stage (see the separate scoping stage report). Information and data from the literature has also been used to complement, validate or challenge findings from the interviews that were undertaken, and to provide insights to develop recommendations based on good practice examples of mobilizing private climate finance.

2.2. Semi-structured interviews

Interviews were held with 28 organizations during August and September 2021. Of the 28 interviews conducted, 15 were with commercial finance providers, five were with impact investors, three were with DFIs, three were with 'enablers'[3], and two were with technology innovators. These interviews followed a semi-structured line of questioning aligned to the primary research questions.

Figure 1: Interviewees



The interviewees were contacted based on their existing investment portfolio demonstrating some level of engagement in CSA technologies, or showing an interest in engaging in the sector, such as information from their strategies or investments in other agri-tech companies or technology platforms. A list of interviewees is provided in Annex 1.

2.3. Limitations

The primary objective was to get an investor perspective on CSA technology investment opportunities – an often-overlooked area despite the repeated assertion that private finance will be vital to addressing the adaptation and mitigation aims of the Paris Agreement, and crucial to mobilizing the finance required to meet the $100bn per year climate finance goal. With a limited sample size, the findings should be seen as indicative, rather than representative, of the investor community.

[3] Enablers refers to organizations and individuals that play a supporting and enabling role in scaling CSA technology enterprises, creating links between innovators and investors, and providing knowledge products.

Investors do not always have full knowledge of the specific business models and details of technologies for all investments across their portfolio, particularly where agriculture is a small component of their investment and lending portfolio. As such, obtaining detailed information about specific technologies and means of enhancing user uptake among smallholder farmers and agribusinesses was often challenging. To complete the technology profiles and the analysis of the interviews, information was also drawn from secondary literature

The technology profiles do not represent an endorsement of their climate impacts by the authors. While the interviews and literature support the identification of potential CSA and biodiversity impacts of these technologies, the actual impact these technologies have *in situ* and in agricultural value chains at scale will depend on a range of contextual factors. Impacts are context-dependent, and benefits and trade-offs vary from location to location.

3. Technology profiles

This section provides an overview of eight CSA technologies that were identified as being of particular interest to investors during the research interviews, either as existing investments in their portfolios or in relation to investment candidate companies. Additional information on the technologies was identified through the literature review. The eight profiles aim to summarize key areas of information about each technology, including the related business models and the potential climate-related issues they seek to address.

3.1. Technology assessment matrix

The technologies were assessed against a matrix of key criteria, listed below. The aim of this process was to pinpoint the technologies that have a strong combination of both commercial investment potential in the near term, as well as direct climate impacts for smallholders and agribusinesses in emerging markets. The criteria were as follows:

- existing investment by interviewee organizations
- identified investment by third parties (through database and literature review)
- operating in smallholder/low-income contexts
- demonstrable CSA impact (adaptation/mitigation/productivity)
- builds adaptive capacity and/or value chain resilience
- an investable technology product or service (i.e. not a practice or supporting service)
- emerging business models demonstrating an ability to reach scale
- positive impacts on nature and biodiversity
- addresses current and future smallholder farming/agribusiness needs

3.1.1. Technology analysis

The research team came together to consider the technologies identified by the interviewees against these criteria. Each technology was scrutinized and, where possible, information and evidence from the literature was used to corroborate or challenge the findings from the interviews. The team had planned to score and rank each of the technologies. However, it became apparent that this would not be possible as the relative score against each criterion is highly dependent on the context of its use. For example, a solar irrigation system may be extremely effective in one location but could exacerbate existing water scarcity issues in another, and the efficacy of a digital advisory service depends on the quality and relevance of the information it provides and the digital infrastructure in a given locality.

Hence, it was decided that the criteria would instead be used to determine the technologies deemed most relevant to investors and as having the greatest CSA benefits. Following this process, a number of technologies were excluded from further analysis and profiling. These technologies, briefly summarized in Annex 2, either had a low relevance to smallholder agriculture contexts and/or more limited relevance to commercial investors.

Of the eight CSA technologies covered in the profiles, each demonstrates some promise for wide-scale adoption, CSA impacts and investment viability in Africa and Asia. These technologies cover both on-farm and off-farm opportunities, adaptation and mitigation impacts, and a range of technology types, from digital services to hardware products.

3.2. Introduction to technology profiles

- Solar-powered drip irrigation
- Smart irrigation systems
- Solar dryers and processors
- Food preservation bio-coatings
- Biocontrol products
- Biodigesters
- Digital CSA advisory platforms
- Solar-powered cold-chain storage

The technologies covered in the profiles cover both hardware and software technologies, and both on-farm products and post-harvest services. **These technologies were selected for profiling as they had been identified by investors as being of particular interest, as well as demonstrating significant CSA impact benefits in terms of adaptation, mitigation, biodiversity benefits and/or improved productivity.**

They each include examples of innovative business models which are demonstrating ways in which investments in these technologies can be viable, if creative approaches to overcoming key barriers and constraints are taken. These include examples of diversified revenue streams to enhance financial viability, bundling of CSA technologies with other complementary products and services, and subscription models to ensure consistent revenue.

The technologies were all identified as being of relevance to smallholder farming and agri-SMEs, although not all of them are currently being utilized by these user groups in Africa and Asia. For example, bio-coatings are predominantly used in retail markets in high-income countries, but investors noted the downward shift of these technologies along the value and supply chains, towards the farm gate, particularly in export-oriented markets.

While challenges remain in regard to enabling these CSA technologies to be transformative in supporting CSA production at scale across the two continents, these profiles highlight the value they can offer to farmers, SMEs and investors alike, and highlight beacons of innovative practice and business models that can attract greater private finance.

Support from governments, international climate change institutions and technology intermediaries could help to catalyse further technology and business model innovations for these prioritized CSA technologies, and could create a pipeline of investment-ready enterprises that, together, could be part of a food systems transformation towards low-carbon, climate-resilient smallholder agriculture.

3.3. Technology profiles

3.3.1. Drip irrigation

Snapshot

Solar-powered micro drip irrigation systems help farmers in arid and drought-affected areas to sustainably increase yields and crop resilience, with minimal use of scarce water resources and no ongoing energy costs. Pay-as-you-go models are helping to overcome the capital expenditure costs for some smallholder farmers

Table 2: Drip irrigation snapshot

Key benefits	• Reduces water use • Lower running costs • Avoids use of diesel
Challenges	• High upfront costs for farmers • Systems can clog up and break • May exacerbate water insecurity in highly depleted regions
Impact areas	• Adaptation • Mitigation • Productivity
Business models	• Pay-as-you-go finance model • Retailing to cooperatives, and collective purchasing

Technical description

Drip irrigation is a type of micro-irrigation system that has the potential to save water and nutrients by allowing water to drip slowly to the roots of plants, either from above the soil surface or buried below the surface. It involves dripping water onto the soil at very low rates (two to 20 litres per hour) from a system of pipes, often with the addition of soluble fertilizer.

The systems place water directly into the root zone and minimize evaporation. Depending on how well designed, installed, maintained and operated it is, a drip irrigation system can be more efficient than conventional irrigation systems, such as surface or sprinkler irrigation. Drip system technology is adaptable to terrains where other systems cannot work well due to climatic or soil conditions, and areas where there are restrictions on water use.

CSA issue areas

- Crop resilience to stresses
- Water use efficiency

CSA impacts

Adaptation

Drip irrigation technology can support farmers to adapt to climate impacts by improving the efficiency of water use and providing water to crops in hot, dry conditions. In seasonal droughts, drip irrigation reduces demand for water and reduces water evaporation losses by providing the necessary water resources direct to the plant. A well-designed drip irrigation system reduces water run-off through deep percolation. The system significantly reduces the water required for irrigation, and uses considerably less power to operate than conventional irrigation systems. This makes drip irrigation particularly useful for areas of water scarcity and with limited energy services.

Mitigation

Drip irrigation systems operated by solar power or zero-electricity systems can avoid the GHG emissions produced from conventional diesel-generated irrigation systems.

Productivity

Drip irrigation increases productivity in areas with permanent or seasonal water scarcity. Although the exact numbers vary according to location, climate and crop type, drip irrigation can increase a crop's yield compared to traditional methods, offering **double – or in some cases even up to triple – the crop output compared to unirrigated rainfed land** (WRG, 2016). The delivery of added nutrients to crops through soluble chemical fertilizers (fertigation) can further increase yields in a cost-effective manner.

Nature and biodiversity impacts

Drip irrigation lowers the quantity of run-off of agricultural contaminants, such as fertilizers, from fields to rivers and lakes, addressing the leading source of water pollution. Even with the use of non-organic fertilizers through the irrigation system, the direct application allows rapid uptake by the crop, thus largely precluding run-off.

Challenges to scale and adoption

The cost of investing in drip irrigation technologies remains the main barrier to adoption by large numbers of smallholders. Many business models are dependent on subsidies to reach even the more affluent smallholder farmers. In India, for example, where the average system costs over $3,000, 60% subsidy and 35% concessional finance terms were required to enable smallholders to invest in solar-powered drip irrigation systems in one area (TERRI, 2019). In areas where conventional irrigation systems cost a fraction of the price of these CSA technologies, and where water resources are being rapidly depleted, it is vital that such subsidies are deployed carefully to allow a more rapid transition to CSA production.

Business models

Drip irrigation is a relatively low-risk technology for smallholders if they are able to access finance, and providing a micro-finance solution is therefore likely to drive up sales. Pay-as-you-go models are helping to overcome the capital expenditure costs for some farmers, with companies such as SunCulture recently securing $11m in loans, albeit from concessional finance providers (Jackson, 2021), and Azanga raising $13.5m in Series B equity investments from both private and impact investors (Angaza, 2020).

3.3.2. Smart irrigation

Snapshot

Smart irrigation systems use a range of on-farm instruments and remote sensors to optimize water use and enable farmers to adapt to unpredictable weather patterns. They are often used in conjunction with solar-powered drip irrigation technologies. Business models that reduce the investment risks and upfront costs of smart irrigation systems to end-users are being explored at greatest scale in Asia

Table 3: Smart irrigation snapshot

Key benefits	• Reduces water use • Highly adaptable to environmental changes
Challenges	• High upfront costs for farmers • Requires good connectivity • Cost efficiency best on larger plots
Impact areas	• Adaptation • Productivity
Business models	• ‘As a service’ rental model • Retailing to cash crop producers

Description

Smart irrigation involves the coupling of sensors, control instruments and irrigation machinery with computer models and meteorological information for real-time control of soil moisture and nutrients, to ensure crops are irrigated (and fertilized) in the most optimal way. Smart irrigation technologies involve a wide range of rather high-tech equipment and products, as well as digital information services, Internet of Things networks and remote sensors.

CSA issue areas

- Crop resilience to water stresses
- Water use efficiency

CSA impacts

Adaptation

Smart irrigation systems lead to a highly efficient use of water. In areas that face increased water scarcity due to climate change, these technologies can ensure crop cultivation optimizes the available water resources as efficiently as possible. Smart irrigation is promoted as a solution to the salinization of irrigated soils by offering the ability to accurately determine the flushing of salts through the soil profile, depending on the soil type and salinity measurements.

Mitigation

Smart irrigation systems have no direct GHG emissions mitigation impacts, but by optimizing the irrigation process they can minimize power usage, including from solar-powered pumps and sensors.

Productivity

Productivity gains materialize through cost savings due to minimized water and nutrient waste as well as increases in labour productivity. Irrigation technologies can dramatically increase crop yields, particularly in arid and semi-arid contexts.

Nature and biodiversity impacts

Efficient irrigation generally lowers nutrient run-off and hence can lead to reduced water pollution of nearby water bodies.

Challenges to scale and adoption

Generally, the costs of smart irrigation information services for consumers are still relatively high, given the capital costs of investing in the necessary equipment. Larger areas of land than those typically farmed by smallholders are required to maximize the potential of the technology and to achieve sufficient returns on investment. Most smallholder plots are too small for satellite earth observation services to provide detailed, accurate advice. The technology also requires farmers who are conversant with and confident in the use of digital technologies and infrastructure.

In addition, smart irrigation solutions are reliant on internet connectivity. In sub-Saharan Africa, internet connectivity remains comparatively expensive, with 1GB of data costing almost 7% of monthly income, compared to just 1.2% in South Asia (GSMA, 2019). This represents a key barrier to scaling up smart irrigation in Africa.

Business models

A commercial lender highlighted that in South Africa, business models involving drip irrigation combined with smart digital monitoring also appear to be generating interest, particularly where water availability, costs and regulatory restrictions make conventional irrigation prohibitive.

While the investment in smart irrigation technology is capital-intensive a shift towards business models that reduce the investment risks to end-users can be seen. An impact investor highlighted a company that offers a package encompassing the entire system – design, hardware, installation, servicing, etc – with no upfront cost to the farmer. The system is installed at the impact investor's expense; in return, the investor is paid based on the revenues from increases in crop yields. Referring to a company in India, they highlighted:

> *"A subscription-based approach for smart water [irrigation] optimization has already saved billions of litres of water. We typically target horticulture farmers and those growing high-value crops and crops that are very water-sensitive."*

3.3.3. Biodigesters

Snapshot

Biodigesters convert plant and animal waste into both biogas for energy and biomass for soil enrichment. This is a growing area of business and is increasingly being adopted by smallholder farmers, especially those with mixed livestock and crop holdings. Biodigesters are generally not a stand-alone product but are rather integrated into broader shifts in farm production strategies.

Table 4: Biodigester snapshot

Key benefits	• Reduces farm waste • Provides energy and farm inputs • Avoids harm to environment
Challenges	• High upfront costs for farmers • Training needs for system operation and use of by-products • Requires supporting technologies e.g. those than can use biogas fuels
Impact areas	• Mitigation • Productivity
Business models	• Part of a wider package of equipment and support • Retailing biogas and biomass • Carbon credit schemes

Description

While biodigesters have been around for many years and use widely understood technologies, more efficient and affordable products have recently been developed. In addition, the general growth in livestock farming in Africa and Asia has meant greater market size for biodigesters, which make use of livestock waste as a primary input.

Biodigesters at the household level provide clean energy, with virtually no transport costs, and reduce the drudgery of fuelwood collection. They can be linked to clean cookstoves for efficient food production, with much lower indoor air pollution compared to other typical fuel sources and with lanterns for high-quality illumination.

CSA issue areas

- Livestock GHG mitigation
- Crop GHG mitigation and carbon sequestration
- Crop resilience to stresses and shocks

CSA impacts

Adaptation

Biodigesters do not directly produce adaptation benefits; however, if farmers utilize the biomass slurry remaining after the digestion process has been completed, it can improve soil health and moisture retention, and lower the need for synthetic nutrient inputs.

Mitigation

Biodigesters may provide GHG mitigation benefits by:

- producing biogas which can enable the substitution of more polluting GHG-emitting fuels (coal, oil, firewood, charcoal) in production processes
- producing biomass that can substitute for inorganic fertilizers, thus reducing embedded emissions in the chemical input production processes, and emissions from chemical fertilizer use

Productivity

Biodigesters are a key enabler of a transition towards low-carbon growth and production, while the use of the expended biomass can also increase crop yields.

Nature and biodiversity impacts

The use of biogas as a substitute for fuelwood can help to avoid tree cover loss and maintain important natural habitats. Biodigesters can reduce the likelihood of animal waste leaching into nearby waterbodies, causing contamination. The use of biodigester slurry can also reduce the use of inorganic fertilizers (with associated run-off and soil health risks) and improve soil quality.

Challenges for scale and adoption

Farmer finance is a major challenge for biodigester adoption as upfront capital costs are beyond the financial capacity of many smallholders. Most existing examples of biodigester adoption by smallholders are dependent on donor or blended finance providing subsidies to facilitate uptake. However, there are some emergent models, such as Sistema-bio, which has been well developed in Latin America and is now moving to Africa, which uses both pre-financing and community-led models to overcome capital challenges.

Furthermore, biodigesters form an important element in integrated farming systems, where nutrients from multiple crop waste streams are recycled. In some regions, this may require changes in production systems and the education of farmers before uptake of the technology can be expected to occur. Examples of biodigester projects from Indonesia, India and Vietnam illustrate that biodigesters are integrated into broader changes in farming strategies that include cropping changes, changes in farm inputs, and marketing activities. Building smallholder skills and capacities in each of these areas is thus necessary to achieve adoption at scale.

Business models

Biodigesters can be seen as a stand-alone hardware product; however, in practice, they are generally embedded in larger shifts in farm production practices, and thus are brought to market in bundled product/services that include technical assistance.

As biodigesters tend to be a cottage industry operated by small-scale local manufacturers, they can be difficult to invest in. Instead, investment targets can be producer organizations or large companies sourcing from farmers who use these technologies. One investor based in East Africa noted their growing interest in biodigesters, given broader shifts in livestock farming practices:

> *"We see great opportunities for waste-to-energy technologies. We are investing in companies and cooperatives using these technologies, and the uptake is growing as more [smallholder] farmers keep pigs and cattle."*

In Indonesia, a start-up aims to link sustainable coffee production and biogas through biodigesters producing biogas from coffee processing waste as an input into the coffee roasting process undertaken on small-scale coffee plantations. The business model is based on creating a market for green products and involving several local farming communities which can directly benefit from the creation of green job opportunities. Given its early stage, the business model is currently supported by development finance and the Indonesian government.

Another emerging business model involves bundling financial services with product sales in order to address affordability issues for smallholder farmers: for example, a biodigester manufacturer partnering with a fintech company have together created a financial payment model that allows smallholder livestock farmers to purchase equipment on long-term, low-cost credit. The model includes farmers selling the biogas generated to local enterprises and using the leftover biomass for crop cultivation, in order to both generate revenues for the farmer and reduce their agricultural production costs.

At a larger scale, in South Africa some larger export-oriented agribusinesses have received cap-ex loans from a commercial bank and invested in biodigesters for fruit waste. The driver of this investment is the high cost and poor quality of energy supply in the country, which makes alternative energy provision more attractive and necessary.

3.3.4. Biocontrol products

Snapshot

These technologies enable farmers to minimize the inputs they use for crop protection in their responses to increasing plant health threats driven by climate change. As market and consumer demand for more environmentally friendly food increases, investors have identified biocontrol products and precision applicators as key technologies in the transition to nature-positive agricultural production.

Table 5: Biocontrol snapshot

Key benefits	• Reduces chemical pesticide use • Enhances biodiversity
Challenges	• Limited localized production and logistical challenges of distribution • Negative farmer perceptions • Skills and information required for effective application
Impact areas	• Adaptation • Biodiversity • Productivity
Business models	• Franchising production units • Bundling with other services

Description

Biocontrol technologies make use of biological derivatives, such as fungi, oils and pheromones, to enhance crop resilience to pest and disease attacks, which are forecast to become increasingly prevalent under future climate change scenarios (FAO/IPPC, 2021). Biocontrol products are usually used in combination with integrated pest management (IPM) farm management techniques to maximize their effectiveness as **a nature-based solution to both climate and environmental risks**. Biocontrol products can be used to replace some or all of the use of chemical control products, such as pesticides.

CSA issue area

- Crop resilience to stresses
- Crop resilience to shocks
- Biodiversity and ecosystem services
- Sustainable and safe inputs

CSA impacts

Adaptation

Biocontrol technologies can improve resilience to increased incidence of pest and disease shocks under future climate scenarios. By improving plant health, crops can be more resilient to climate-driven shocks, such as floods, drought and extreme temperatures.

Mitigation

Biocontrol technologies provide GHG mitigation benefits by substituting for chemical pesticides in agriculture production, resulting in total farm GHG emissions reductions of 1–16%, depending on the particular farming system and crops cultivated (CropLife, 2012; Audsley, Stacey, Parsons, & Williams, 2009; Lal, 2004).

Productivity

Biocontrol technologies affect productivity through increased resilience to shocks and stresses; they can also increase yields by minimizing losses due to biotic shocks and stresses.

Biodiversity and nature impacts

Biocontrol technologies have positive biodiversity impacts compared to conventional alternatives – in particular, by decreasing chemical inputs in agriculture production that have a negative impact on biodiversity, such as broad-based insecticides. Combining biocontrol products with IPM approaches further enhances biodiversity, as habitats for beneficial flora and fauna are developed and protected (CABI, 1994).

Challenges for scale and adoption

Biocontrol technologies are attracting growing interest among investors. However, there are several challenges in scaling up investment and adoption by smallholder farmers in Asia and Africa. For example, logistical difficulties are posed by the need to distribute live cultures, with the need for careful storage, transport and handling, sometimes involving cold storage.

There are also challenges related to farmers' perceptions of the efficacy of non-chemical treatments, and their knowledge of biocontrol products and appropriate application methods and timings. While the availability of products in rural areas is a critical barrier, there also needs to be training and sensitization of farmers to biocontrol products and practices, in order to develop a sustainable market demand for the products (Kansiime, Mugambi, Migiro, Otieno, & Ochieng, 2020) (Zhang, Day, & Sivapragasam, 2021).

Farmer adoption remains a major bottleneck and poses a risk to enterprise growth, mostly due to costs but also due to trust, as new technologies need to be marketed and promoted through trusted agents who can also provide training.

Business models

Emerging business models that could potentially bring biocontrol technologies to smallholder farmers involve companies that bundle products/services under a single offering. For example, one investor described a bundling of products/services by two of its portfolio companies. This involved bundling biocontrol technologies with biological nitrogen-fixing additives and microbial protein products to replace typical animal feeds, leading to mitigation benefits at multiple points along the value chain.

Franchising the production of biocontrol products is also being explored by some biocontrol companies, enabling more localized production of cultures, which would help to overcome the distribution and storage issues of more centralized production systems (IITA, 2015; Singh, 2014).

Biological control at the commercial agriculture level is being driven by consumers in key markets. For example, the Kenyan flower sector has moved extensively to biological control following mandates from UK supermarkets to reduce the use of pesticides in greenhouses. A model using out-growers to supply these markets (such as in the case of avocados) has the potential to stimulate the expansion of the use of biocontrol products to smallholder farmers.

3.3.5. CSA digital advisory services

Snapshot

The bundling together of climate-smart advisory services with other complementary products and services is helping to minimize transaction and marketing costs for companies and is providing a more integrated and holistic offering to farmers. Building on existing trusted relationships, successful platform technologies are helping farmers to access stress-tolerant inputs and climate-smart knowledge services, alongside access to financial products and services.

Table 6: Digital advisory services snapshot

Key benefits	• Enhances farm management skills • Provides a platform for bundling with other services • Scalable and adaptable to different user needs and contexts
Challenges	• Low willingness to pay for services • Poor connectivity and high data costs • Systems regularly struggle to scale
Impact areas	• Adaptation • Mitigation • Biodiversity • Productivity
Business models	• Subscription models • Fees and commission on third-party services and products • Potential value in (anonymous) data

Description

Digital climate-smart advisory services for farmers provide specific information on agricultural practices, meteorological forecasts or market information, delivered through mobile phone applications and online portals (CTA, 2019).

Digital information services are often bundled together with multiple other services to improve access to farmers who would otherwise be unwilling to pay for them directly. For example, an off-taker could provide access to the services for free to the farmer in the expectation that the advice will lead to increased production of better-quality products.

These services are dependent on both hardware infrastructure – such as, for example, remote surveillance systems – as well as software infrastructure. Data inputs include a wide range of earth observation and remote sensing data, farm-level data and market data.

CSA issues areas

- Information and advice for CSA farm management
- Water use efficiency
- Sustainable and safe inputs

CSA impacts

Adaptation

Digital climate-smart advisory services offer opportunities for smallholders and agribusinesses to adapt to climate change through the dissemination of skills and techniques and support services for climate-smart practices (GCA, 2021), including:

- improved soil health through advice on climate-smart soil management
- efficient water use
- optimal crop diversification
- optimal crop planting, treatment and harvesting times

This is particularly appropriate as seasonal weather expectations change (in both duration and intensity) from the norm: such services allow farmers to act based on actual or data-driven predicted events, rather than through acquired knowledge and tradition. Through the bundling of services, more specific benefits can be determined that can support the overall resilience of smallholder farmers, such as, for example, access to financial and insurance services (SwissRe, 2020).

Mitigation

The dissemination of skills and techniques for climate-smart practices can contribute to the reduction of GHG emissions through improved land-use practices.

Productivity

Digital advisory services can contribute to the sustainable increasing of agricultural productivity and incomes. A recent study reports a substantial average increase in income (30%) and productivity (23%) for smallholder farmers in sub-Saharan Africa due to the use of digital advisory services (CTA, 2019). This increase is even higher when including all digital services that can be offered as a bundle. Specifically, for advisory services, CSA practices that increase productivity include:

- optimal or improved and sustainable yields from improved inputs, including timely agronomic advice tailored to specific crops and regions
- providing up-to-date information on weather, allowing farmers to anticipate and act on damaging weather events
- access to markets, which enables farmers to produce for market demand and reduces post-harvest losses
- pricing information, which enables farmers to extract greater value
- access to inputs and reduced costs

Challenges for scale and adoption

Even as connectivity improves and cell phone usage expands, the main challenge to adoption is ensuring high levels of engagement among farmers and increasing their willingness to pay for services through increased value propositions for users (GSMA, 2020; CTA, 2019).

Evidence from the WISER project suggests that multi-year public investment is needed to achieve sustainable capacity development for climate information services, even in countries with already well-established meteorological capacity. Supplemental donor funding may be needed for considerably longer periods in low-income countries with very limited human resource capacity and physical infrastructure (Dupar, Weingärtner, & Opitz-Stapleton, 2021).

Further issues for scale are the lack of interoperability between systems and data formats. There are also potential risks for smallholders when technology is owned solely by a private sector entity, which can lead to vendor lock-in, which contributes to wariness among some smallholder famers in regard to trusting such systems (Birner, Daum, & Pray, 2021).

Business models

Business models for digital advisory services can be categorized into the following categories:

- focused or single services delivering only advisory services directly to farmers or aggregators, such as farmer groups
- bundled services that deliver integrated and/or grouped services for a range of clients – including, for example, for access to finance, insurance, or markets
- specialized intermediary services

Provision of digital services is a rapidly expanding market, particularly in Africa. By 2019, there were already more than 200 digital advisory services operating with the business model of bundled service provision, with around a quarter of services generating sufficient revenues to break even.

There is an estimated addressable market of $2.3bn in annual revenues from bundled digital advisory services in Africa alone, of which just 6% is currently being realized through existing services (CTA, 2019). This demonstrates the untapped market opportunity in this area. Figure 2 demonstrates the variety of business models emerging in digital climate advisory services, and their varying levels of maturity.

While agricultural digital advisory services are often the digital continuation of traditional extension services, a more innovative model has emerged that consists of bundling different services in a user-friendly service. This can strengthen the value proposition for its users and help achieve scale towards commercial viability while reducing infrastructure and marketing costs (Birner, Daum, & Pray, 2021). This was echoed by an investor who mentioned that:

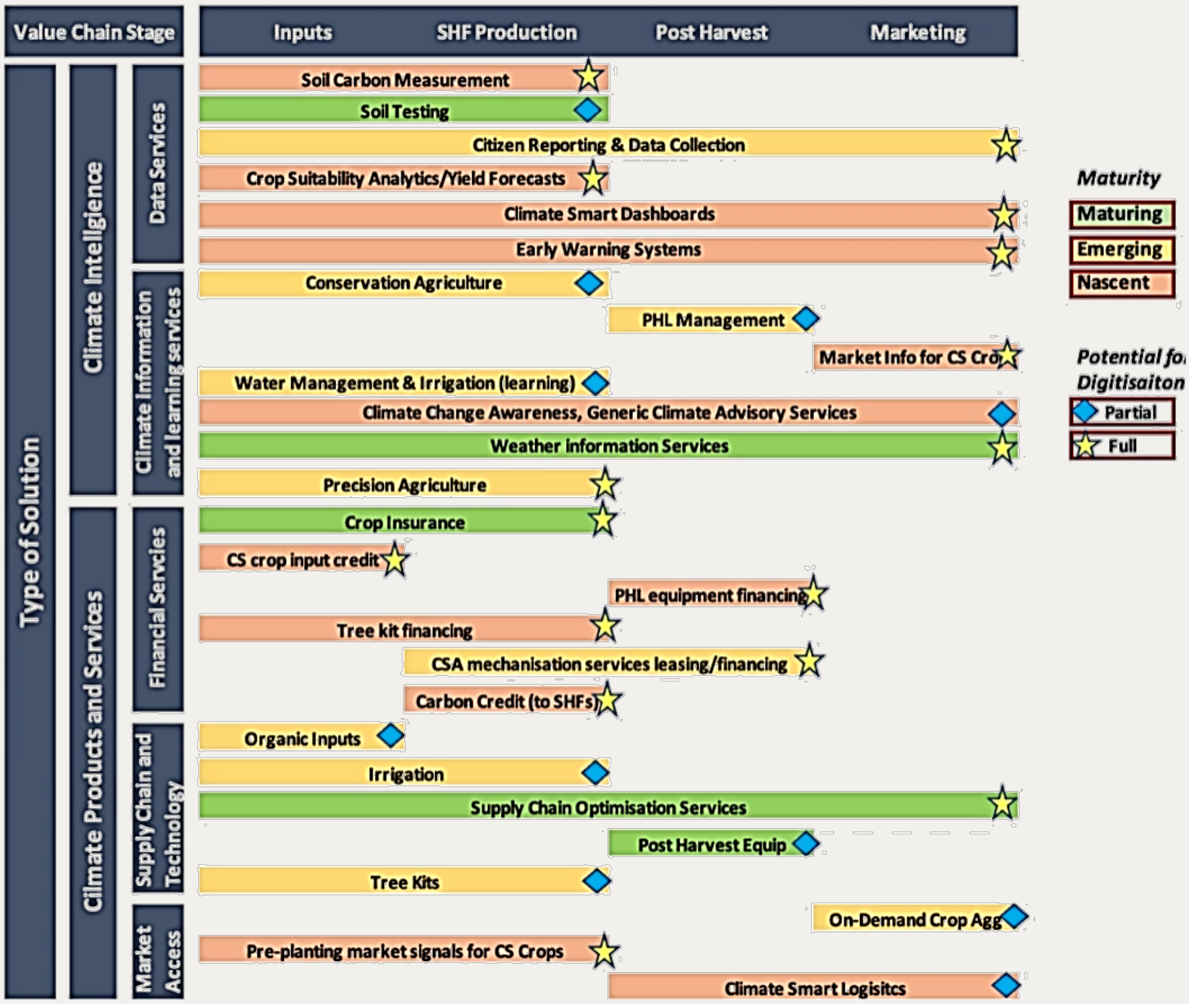
> *"Data-driven companies show real growth potential. The potential is in the use cases of the data. We're investing in companies making use of satellite data, incorporating it into advisory services for farmers."*

The efficient integration of different data systems could lead to lower costs for farmers to collect and aggregate information (Devare, 2020) (GCA, 2021). This was also echoed during an interview with an impact investor who stated that

> *"Integrating different data systems effectively and having lower costs for farmers to collect and aggregate information is very promising as a business model."*

Some services are offered for free to users, with revenue generated by commission, business to business (B2B) fees or grant finance. Others charge a small subscription fee per user, although typically this revenue stream alone is insufficient to cover operating costs. Models which integrate financial services as part of the offering are able to increase end-users' willingness to pay, and to reach commercial viability (Valverde, 2020) (CTA, 2019).

Figure 2: Digital climate advisory services business model maturity levels



Source: GCA, 2021

3.3.6. Bio-coatings

Snapshot

The use of natural bio-coatings offers the potential to reduce post-harvest losses from handling, senescence and fungal and pathogenic contamination. This technology is likely to be brought to Africa and Asia by companies with fresh fruit and vegetable value chains for the more developed regulatory environments of the Global North.

Table 7: Bio-coatings snapshot

Key benefits	• Reduces post-harvest waste • Maximizes crop value • Reduces chemical use
Challenges	• Mostly applied downstream, so limited direct impact for farmers and agri-SMEs • Difficult to implement in mixed-crop systems as each crop requires a specific bio-coating
Impact areas	• Mitigation • Productivity
Business models	• Engagement with global supply chains and retailers • Potential for franchising production

Description

Bio-coatings make use of organic inputs for the natural coating of fruits and vegetables, which can lengthen shelf life and can be used as an alternative to chemical treatments, such as fungicides. They can be particularly useful in preserving fresh goods under climate-related stresses, such as increased heat or humidity, and are produced primarily from organic plant waste (e.g. shells, stems or pips), according to regional availability.

CSA issue areas

- Crop resilience to stresses
- Avoiding waste

CSA impacts

Adaptation

Bio-coating can increase the resilience to climate stresses – and thus reduce post-harvest losses – of fruits and vegetables, particularly during periods of increased temperatures and humidity.

Mitigation

Bio-coating may provide GHG mitigation benefits by reducing overall food waste and thus reducing food production needs and the related food sector GHG emissions. However, such benefits accrue at the food system level and are thus difficult to attribute to a particular CSA technology.

Productivity

Bio-coating technologies directly affect productivity by reducing food loss from the decay of fruit and vegetables during storage, transport and handling, increasing their shelf life. Bio-coatings thus also increase the financial viability of fruit and vegetables production in settings that are exposed to heat and humidity stress.

Biodiversity and nature impacts

Bio-coatings have no direct impacts on biodiversity and nature, although they can reduce the use of chemicals products and fungicides.

Challenges for scale and adoption

Key constraints on the adoption of bio-coating CSA technologies in Asia and Africa remain the issues of cost and distribution, with investments primarily focused on markets in the Global North. However, as international companies seek to improve productivity and value retention in their global supply chains in response (in part) to climate change hazards, it is possible that such technologies will become increasingly prevalent in Africa and Asia.

A further challenge in African and Asian contexts is the need for long-term, patient finance, as research and development for bio-coating products can typically take seven to 10 years.

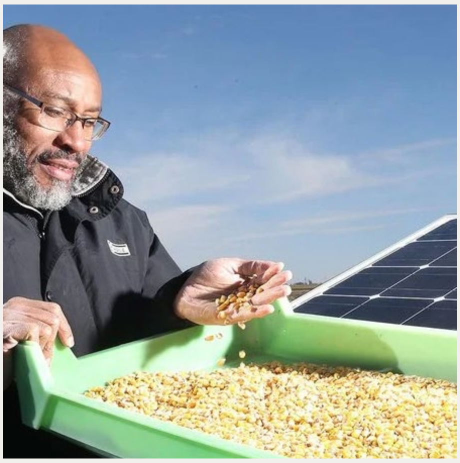
Business models

Post-harvest fruit and vegetable protection is currently attracting significant investment, particularly for high-value and rapidly perishable crops. While bio-coating is growing in Europe and North America, there is not yet large-scale expansion into Africa and Asia. Companies from these regions with supply chains in Africa and in Asia are most likely to be interested in introducing these products into local production and processing.

Recent developments that have attracted significant venture capital investment appear to be more effective than traditional products, due to organic additives, and can be engineered to the specific fruit or vegetable in question. One commercial investor explained that;

> *"Food waste is a massive issue, it holds back the sector from being more profitable. And consumers are sick of chemicals, and are more aware of what they're buying. We see so much potential in bio-coatings. We've made investments ourselves, but there have been some big raises by others in the US recently. It's going to be big business. We expect to see our companies working outside the USA, tackling these issues at source with farmers. We're not there yet, but we see the trajectory."*

3.3.7. Solar-powered processing and dehydration



Snapshot

Solar-powered drying and processing enables crops to be processed to market standards for moisture content, improving prices for farmers as well as ensuring long preservation times for products consumed at home. Technologies are available for a range of production scales, with innovative pre-financing becoming available for both individuals and communities.

Table 8: Solar-powered processing snapshot

Key benefits	• Reduces post-harvest losses • Maximizes crop value • Avoids use of diesel
Challenges	• High upfront costs • Not required year-round
Impact areas	• Adaptation • Mitigation • Productivity
Business models	• Integrated market approach • Retailing to cooperatives, and collective purchasing

Description

Solar-powered processing and dehydration technologies include products at different scales, from small-scale solar-powered conduction dryers to large-scale coffee mills. Solar dryers avoid spoilage and wastage of fresh produce, while also being accessible for smallholders. They enable perishable products to be stored and eaten out of season, reducing pressure on other commodities or the need to import/transport similar products from other climatic regions. They also maximize the value of the goods by allowing farmers to preserve crops and sell them when prices are high.

CSA issue areas

- Resilience to stresses
- Improved productivity and incomes

CSA impacts

Adaptation

Solar-powered processing and dehydration technologies can reduce post-harvest losses due to extreme temperatures, high humidity, sudden rains etc (Tomar, Tiwari, & Norton, 2017). They can also provide more rapid restarting of activity following a climatic shock compared to grid-based technologies, and can help ensure that a supply of stored, processed goods is available to consume during lean months or during periods of climate-induced stresses or shocks. For example, in Thailand up to 90% of banana crops can be lost post-harvest due to extreme weather, with solar dryers able to reduce losses to less than 10% (Janjai, 2012).

Open-air drying of goods is common across much of Africa and Asia, particularly for grains and coffee. However, shifts in seasonal rain patterns and changes in humidity driven by climate change are making open-air drying increasingly difficult. Solar dryers provide a means of drying crops even under changeable climatic conditions (Udomkun, et al., 2020).

Mitigation

Solar-powered processing and dehydration technologies can produce mitigation benefits by:

- using renewable energy or solar radiation, which reduces GHG emissions compared to conventional generator-powered alternatives in areas with a poor electricity supply
- reducing overall food waste and thus reducing food production needs and the related food sector GHG emissions. (However, such benefits accrue at the food system level and are thus difficult to attribute to a particular CSA technology).

Productivity

Solar-powered processing and dehydration technologies directly affect productivity by reducing post-harvest losses, particularly under conditions of extreme temperatures or humidity, enabling the use and sale of lower-grade produce and maximizing income-generation opportunities.

Challenges for scale and adoption

The upfront cost of solar-powered process technology is a key challenge to achieving adoption and scale with smallholder farmers. Single-unit solar conduction dryers currently cost roughly $1,200. While this would be prohibitively expensive for direct sale to most smallholder farmers, financing arrangements are also being included in emerging business models through the use of microcredit schemes and concessional and grant finance for cooperatives and farmer collectives, with several successful examples across sub-Saharan Africa and East Asia (Udomkun, et al., 2020; Holt, 2016).

Business models

One example of an emerging business model involves a developer of solar-powered food processing and dehydration technology who has established a financing model that provides guarantees to a network of micro-finance lenders who provide low-cost three- to five-year loans to farmers. The company also acts as a market broker with off-takers, secondary processors and large corporations, making the transaction more attractive to risk-averse smallholder farmers. The model has been successful, with 12,000 farmers currently using the equipment and this number doubling annually. The company raised $2.5m from a number of investors, including impact investors, in a seed funding round in 2019, and is now looking towards Series A financing.

For larger equipment (e.g. solar-powered coffee processing equipment), aggregator businesses or cooperatives provide a route to collective purchasing and access to the equipment for aggregated processing.

3.3.8. Renewable energy-powered cold storage solutions

Snapshot

Renewable-powered cold storage systems help to prevent food wastage and spoilage, particularly in increasingly humid conditions and extreme temperatures, as well as helping to ensure that produce can be sold at an optimal time in prime condition, maximizing income for farmers.

Innovative business models in this area are leveraging stored produce as collateral for brokering access to affordable credit for farmers, simultaneously addressing both a key demand-side constraint as well as diversifying revenue streams.

Table 9: Cold storage snapshot

Key benefits	• Minimizes post-harvest losses • Avoids the use of diesel or other fossil fuel power generation • Maximizes value of crops
Challenges	• High upfront costs for agribusinesses • Maintaining near capacity usage throughout the year • Dependent on good market links and distribution networks
Impact areas	• Adaptation • Mitigation • Waste minimization
Business models	• Franchising models • Diversified income streams from financial service brokering

Description

Solar-powered cold chain storage can reduce food waste, making more agricultural products available for smallholders, both for subsistence and sale, while maintaining and maximizing the value of the goods. Conventional cold rooms often run on diesel motors at relatively high cost and with high GHG emissions. Solar-powered cold chain storage is particularly attractive in rural areas, where unstable or unavailable electricity supply presents a challenge for conventional cooling technologies.

CSA issue areas

- Crop resilience to stresses
- Crop GHG mitigation and carbon sequestration

CSA impacts

Adaptation

Solar-powered cold chain storage technology can increase farmers' resilience to climate stresses by reducing post-harvest losses of high-value items of fruit and vegetables, particularly during periods with increased temperatures and humidity. Research suggests that the use of solar-powered cold storage could reduce post-harvest losses by as much as 80% (Affogon, Mutungi, Sanginga, & Borgmeister, 2015).

Mitigation

Solar-powered cold chain storage technologies can produce mitigation benefits by:

- using renewable energy, which reduces GHG emissions compared to conventional cooling technology alternatives
- reducing overall food waste, and thus reducing food production needs and the related food sector GHG emissions. (However, such benefits accrue at the food system level and are thus difficult to attribute to a particular CSA technology).

Productivity

Solar-powered cold chain storage directly improves productivity by reducing food loss from the decay of fruit and vegetables during storage and handling, and in particular under conditions of extreme temperatures or humidity.

Challenges for scale and adoption

While developed countries have roughly 200m^3 of refrigerated storage capacity per 1,000 people, the average in low-income countries is 19m^3, and in Kenya and Nigeria it is less than 3m^3 (Salin, 2018).

Solar cold room storage is expensive: a recent study of technology options in Nigeria finds that capital costs are typically in excess of $20,000–$30,000, and ongoing annual maintenance and running costs are $2,300–$5,000, with interest rates on loans for the full or partial cost of around 23%. Only when usage is extremely high, and the value of the produce also relatively high, does the system become economically viable (Obanubi, et al., 2021).

At a value chain level, the economic benefits of cold chains largely depend on the ability to achieve price premiums from agricultural products. However, realizing these price premiums depends very much on not only the ability of buyers and consumers to assess product quality, but also their willingness to pay premiums for such products. This means that export-oriented companies may be more viable in the near term.

Lack of financing inhibits the ability of smallholders to invest in or pay for the use of cold storage technologies. Affordable financing for capital costs remains a major hurdle for adoption at this level.

The seasonal variation in production volumes for crops (as well as changes in ambient temperatures throughout the year) may mean that cooling infrastructure is only used during peak (and/or hot) seasons, which reduces the cost efficiency of large-scale cold chain storage solutions. This can in turn lead to reduced returns on investment and longer payback periods – firms in Nigeria have struggled to maintain threshold space utilization rates to make cold room storage technologies viable investments (Obanubi, et al., 2021).

Business models

While this is a nascent area of technology, the growth potential is large in both Africa and Asia. One innovator highlighted that

> *"[Solar] cold storage is very nascent here [in India], but it is very exciting, there is a lot of potential. People use supermarkets more often and goods need to get to retail without being spoiled by the sun and rain."*

Innovative business models in this area are leveraging stored produce as collateral for brokering access to affordable credit for farmers through a warehouse receipt finance model. This simultaneously addresses a key demand-side constraint as well as diversifying revenue streams. This has led one company in India to enable farmers to access over $150m in finance from banks. More recently, the company has become a direct lender themselves in areas where bank finance remained limited, providing over $30m worth of low-cost micro loans to farmers using their services. This pioneer firm in India has raised over $40m in private equity investments in recent months, having demonstrated its commercial viability and diversified revenue streams through farmer financing.

The cost of use per unit/user for solar-powered cold chain storage technology depends on the business models of the companies providing these units or infrastructure. For instance, business models that provide a service (i.e. space in a cold storage unit) can provide cold storage at a much lower cost to the user than the infrastructure itself. Innovative business models, such as subscription-based access to cooling services, or product/service bundles that include farmer financing, are helping to overcome some of the challenges to adoption and use.

4. Innovative business models

To address and overcome the barriers and bottlenecks in regard to mobilizing greater investment for CSA technology, the interviewees highlighted a range of innovative business models now being deployed by some of their CSA technology investees, or potential investees they have initiated engagement with. These are described in the sections below.

4.1. Tech-enabled platforms and bundling of services

One increasingly popular approach to minimizing transaction and marketing costs – among other benefits – is ‘platform’ companies. These are not CSA technologies *per se*, but rather they bring under a common portal or marketplace a range of agricultural goods and services that can each play an important role in supporting farmers and agribusinesses to transition to more climate-smart methods and enhance their adaptive capacities. One investor noted that bundling financing with new technologies is essential as

> *“Single service provision is unsustainable and ineffective. We need bundled CSA technology [platform] services, including finance for farmers.”*

These platforms typically rely on digital and mobile-based services, and present users with a range of services and products. These often include providers of stress-tolerant seeds and crop varieties, weather information services, and basic advisory services (GSMA, 2021). But, crucially, business models that also partner with small-scale finance providers are able to offer lower-cost credit and insurance products to farmers and small agribusinesses through their platforms, and to increase end-users’ willingness to pay for services (CTA, 2019) (Valverde, 2020).

Access to these financial services not only stimulates the market for other products and services on offer (which the user can then purchase with credit), but it also offers diversified revenue streams for the platforms. They are often able to receive a commission for new customers and transactions mediated by the platform.

Moreover, value is now being identified in the data generated by the platforms, with the expectation that customer data could be monetized by selling it to financial service providers, particularly in contexts where they are often unable to build strong credit rating systems for previously unbanked customers.

4.2. Subscription models

Investors see great promise in subscription-driven business models, such as subscriptions for ploughing and spraying services, or for the use of digital climate information tools. The promise of continuous revenue streams is particularly appealing to investors. Such models also build customer loyalty and trust over time, and provide a platform for ‘up-selling’ additional value-added services. Building greater data profiles of customers is also possible over the longer-term engagement that is made possible through subscription models.

The relevance of subscription models to CSA is being explored in relation to digital advisory services, as well as other production-level services, such as spraying, irrigating and storage. This gives low-income farmers the opportunity to utilize modern technologies and farm more efficiently and sustainably by only paying for services as they need them, rather than needing to invest in technologies themselves. Interviewees noted that these models need to be adaptive to the needs and income patterns of smallholders too.

4.3. 'As a service' models

Some companies are pivoting from hardware provision to service provision in low-income settings. One investor highlighted that a precision agriculture equipment manufacturer they invest in is pivoting towards a 'spraying as a service' model as they look to expand in Ethiopia. By partnering with local service providers and biocontrol product distributors, they are now able to offer precision spraying services to smallholder farmers on an as-needed basis. This dramatically expands the market for the use of the equipment and offers more regular revenue streams. For smallholders, it also means they only paid for what is needed, although service costs on very small plots may still be prohibitive, given the fixed costs involved in the service provision.

Such services are already helping to expand access to crop protection products in some markets, and reducing waste from inefficient spraying for other farmers. If expanded to other technologies with greater climate impact, these 'as a service' business models may be effective in expanding access to CSA technologies, and in generating sufficient revenue and market growth to attract private capital investment.

A range of new 'last-mile distribution' enterprises are helping to scale access to climate-smart technologies. These companies excel in expanding the market reach of products and services, through deep knowledge, trusted relationships and ongoing support (Global Distributors Collective, 2019). Concessional finance provision for these enterprises could help unlock market growth for CSA technologies, creating a greater investment case.

4.4. Collective purchasing

Although not a business model that is being driven by technology companies themselves, interviewees noted that they are increasingly seeing examples of farmers collectively investing in CSA technologies, particularly through cooperatives. This includes collective investment in hardware technologies, such as micro-irrigation, and post-harvest equipment, such as low-power dehydration units to avoid spoilage in increasingly humid conditions. For irrigation services in particular scale is important as the 'break even' point for investing in such technologies often requires use across several hectares of land, something which may only be possible for smallholders when investing alongside their neighbours and peers.

The aggregation of purchasing power among groups of low-income farmers is vital for enabling access to more costly hardware CSA technologies, such as through farmer cooperatives or village enterprise groups. One interviewee highlighted a trend of similar models for collective investment in climate and weather information services, particularly in areas where farmers in cooperatives grow the same crops in similar localities. While this is beneficial for the farmers, it may also limit the growth potential of companies providing such services, or may necessitate changes to their business models to account for multiple users of a single service, to generate increased revenues.

There are now breakthrough fintech services which are enabling simplified group purchase and lending products for smallholder farmers, for service technologies such as cold storage facilities. They have developed a mobile app to simultaneously digitize group sale and lending. The app's algorithm calculates the credit worthiness of group members and automatically manages payments among the group. This is helping to catalyse last-mile technology distribution in Kenya (iBAN, 2021).

4.5. Leasing and pay-as-you-go finance

For smallholder farmers and agribusinesses with larger incomes, such as horticulture farmers and those specializing in high-value crops, leasing and pay-as-you-go finance models can be attractive. Building on the successes of solar home system companies like M-KOPA and BBOXX (Moore, 2019), hardware CSA technology companies are now also experimenting with such models, particularly in solar-powered irrigation, with technology now available to remotely deactivate the systems should a customer fall behind on payments.

Last-mile technology distributors are increasingly able to reduce the transaction costs for retailing climate-smart technologies by leveraging digital sales management platforms and other digital business services (Jansen, Kanda, & Baranda, 2021).

4.6. Alternative revenue generation

Some innovative businesses are looking beyond traditional means of diversifying their revenue streams and pivoting their business models to expand beyond technology provision. A strong example is the use of warehouse receipt financing by a solar-powered cold storage technology company. This company is using verified produce stored in their containers as collateral, to broker access to credit for the farmers storing their fresh produce, enabling them to invest in quality inputs and improved farm management practices, while avoiding wastage and allowing goods to be sold later for higher prices.

The company is able to take a commission from the brokering, expanding their revenue streams beyond storage fees. They have already brokered more than $150m of microcredit for smallholders in this way. More recently, they have diverged further into direct lending themselves with repeat customers, and have already built up a direct loan portfolio of over $30m. This diversification from technology service provision to financial intermediary has helped this company to attract more than $40m in private finance in recent months, as investors see the growth of revenues alongside resilience impacts and customer retention.

5. Interview findings

These findings represent the things that investors are thinking about – reputational risks, changing consumer demand, new market opportunities, and physical climate risks. This is motivating them to think about how they need to move towards low-carbon and climate-resilient approaches in their investment portfolios. Table 10 summarizes the key benefits of investing in CSA technologies, as reported by the interviewees.

Table 10: CSA technology benefits

Opportunity	Benefits for investors
Reduce GHG emissions	• Achieve net-zero investment portfolio • Minimize any future carbon accounting costs • Identify opportunities for carbon credit payments
Reduce food waste	• Increase profitability of investees • Create new revenue streams • Maximize market potential
Supply chain resilience	• Minimize supply chain disruption from climate shocks and stresses • Maximize profitability of value chains • Ensure business continuity
Climate risk adaptation	• Reduce risk sensitivity • Enable investees to pivot to new opportunities
Expand portfolio footprint	• CSA technology investments are a means of engaging in emerging markets • Build new networks and identify further investees
Enhanced brand reputation	• Respond to consumer and shareholder sustainability demands • Be seen as a leader among peers

The key areas of interest, the main constraints to mobilizing more investment capital, and the main areas of knowledge needs, as revealed by the interviews, are set out in Figure 3, showing the number of times each topic was mentioned by the interviewees.

Figure 3: Key themes from interviewees

5.1. Investment priorities and profiles

5.1.1. Growth of impact focus in private finance

There is a growing trend of private finance investors moving towards impact-focused portfolios and investment strategies, yet remaining commercially driven. As one private equity investor claimed:

> "Climate change is a tailwind for disruptive innovation in agriculture."

The lines between impact investing and commercial investing are increasingly blurred. Commercially driven investors interviewed for the research included those focused on climate adaptation and resilience, food security, sustainable development, and innovative agriculture. This is opening up new funding opportunities for some innovative CSA technology providers. In addition to those interviewed for this research, there are other emerging examples of private equity funds targeting climate-smart technologies for social impact on a purely profit-motivated basis, such as the TPG RISE Climate Fund, which recently raised $5.4bn for its inaugural fund (TPG RISE, 2021).

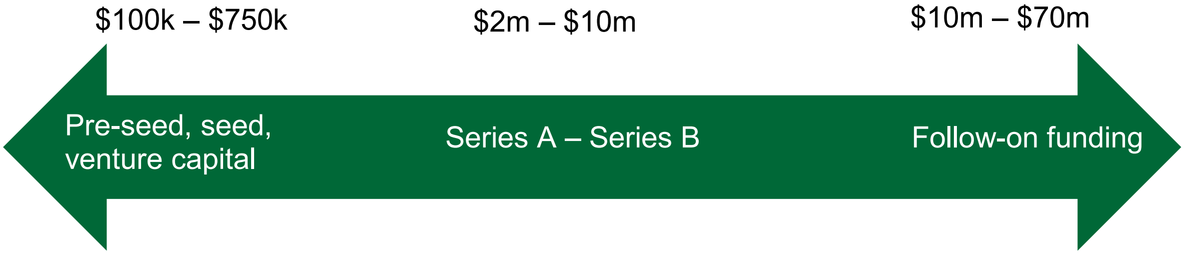
Profit-driven investors looking for impact struggle to determine relevant outcomes from CSA technologies. Areas like renewable energy are more mature markets, with clear impacts on carbon reduction, social benefits, and long-term enabling policy environments. Demand-side issues are less of a challenge in this area, although constraints remain in regard to full commercial viability for supplying very low-income customers for home generation. The pull of renewable energy and sustainable forestry investments means there is little space for CSA technologies to compete in terms of either financial gain or impact.

5.1.2. Investment profiles

The profile of investments across private investors, impact investors and DFIs is primarily in growth equity, financing maturing companies with sustained growth and profitability patterns. Typically, these investments start at $2m or higher for minority stakes in the companies, at the Series A stage. Later-stage investors typically look for investments in excess of $10m, and often look for a controlling stake in a company. Among our interviewees, most growth-stage investors provide follow-on investments for increased stakes as companies mature and demonstrate growth potential, with a total exposure of up to $70m per company. Figure 4 shows the range and stage of investments made by the interviewees' companies.

There were two impact investors focused on earlier-stage funding, providing finance of $100,000 to $750,000 in seed and pre-seed ventures, alongside business incubation and technical assistance. These work on investment theses, aiming to identify gaps in the market where new, innovative businesses could thrive and meet demand. Neither focus on nature and biodiversity impacts, although they do not rule out such investments.

Figure 4: Typical ticket size of investments



There are some evergreen investors, but most investors look at holding terms of around seven years, ranging from four to 12 years across interviewees. Growth-stage private equity investors are typically looking for double-digit growth of 20–30% year on year, which is a significant hurdle for many nascent CSA technology companies operating in emerging markets, with small margins and constraints on demand-side market activation. As one investor put it: *"They need to be tall enough to ride the rollercoaster"*.

"Investors are looking for 20–30% growth per year, a big hurdle for many CSA technology companies operating in emerging markets."

Most growth-stage private equity investors and impact investors alike look to co-invest with a partner investor. This is also seen as a means of mobilizing more capital and spreading risk, primarily it is about the skills and opportunities those co-investors could bring, to help take companies to the next level – by opening up connections to new markets, for example. But this is seen as more challenging for CSA technologies, where there are far fewer investors experienced in this area and willing to take the risk on 'unproven' businesses.

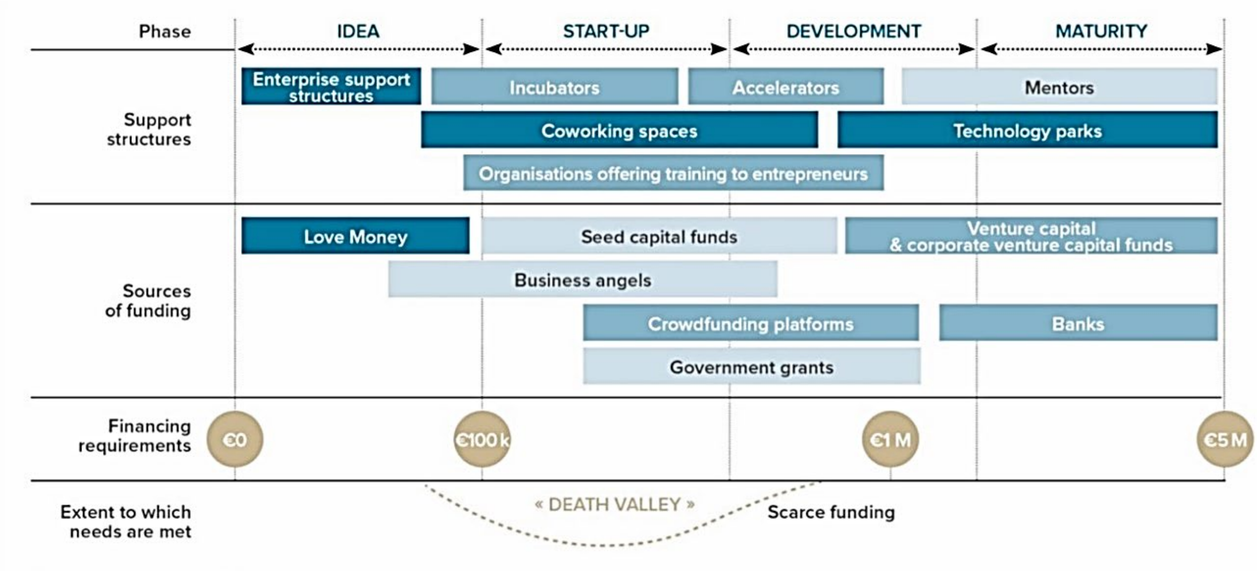
5.1.3. Early-stage investments

There is very little angel investing and venture capital investing taking place in CSA technologies relevant to small-scale agriculture in Africa and Asia. The two commercial investors interviewed as part of this study that do finance seed and pre-seed ventures focused those aspects of their portfolio downstream towards retail, logistics, and delivery services, rather than technologies for upstream primary and secondary agriculture.

The agriculture sector in both Africa and Asia is seen to be too risky for early-stage financing by private finance providers. Even for digitally-enabled platform technologies, the costs associated with distribution, marketing and operating across multiple countries is considered to be prohibitively costly for most angel and venture capital investors.

Debt finance is focused only on more established businesses, with reliable revenue streams and securable collateral. The high failure rate of agri-tech start-ups makes commercial lending to such businesses too risky for banks to consider. Micro-finance is therefore the only viable option for such companies, but the scale of this is far too small to have any catalytic potential for growing and developing CSA technology SMEs.

Figure 5: Stages of technology funding



Source: Village Capital, 2020

5.1.4. CSA technology investment is very nascent

Investments in CSA technologies remain a small proportion of most investment portfolios. CSA technology is not identified as an asset class, and if it was, it would be a small sub-category of an already small sectoral portfolio in most cases. This poses challenges for quantifying the levels of investment in these technologies, and for further research into possible incentives for mobilizing greater investment. Investments are usually categorized by investors more broadly as agri-tech, renewable energy, or environmental services.

Even for finance providers that more readily invest in agri-tech solutions, these tend to be in supply chain logistics, market linking, and waste minimization, rather than in technologies which address the underlying climate vulnerabilities of producers and upstream value chain actors. One investor noted that this is typically because the further downstream the investment, the greater the size of the customers being served, typically through B2B digital services enhancing efficiencies, rather than business-to-customer (B2C) – in this case farmers – business models.

The interviews identified a number of smaller direct investments in companies sourcing from smallholders that promote CSA practices, and investments in medium-sized farms and cooperatives utilizing some CSA technologies. These are generally not scalable opportunities, but they indicate a gradual shift towards more climate-conscious investing.

5.1.5. India is a frontrunner frontier market for CSA technology investment

An important finding is that CSA technologies and companies in India are able to scale much faster and with fewer barriers than other countries. Investors believe that this is due to the size of the national market, as the country can largely be treated as a single market, with common regulations, currency, and market dynamics.

CSA technology adoption in India is aided by very high usage of mobile phones and familiarity with digital services compared to most other markets, providing a solid platform for digitally-driven CSA technology services. India can therefore be seen as a frontrunner in CSA technology innovation and investment, where future transformative technologies may be identified as having growth potential before transferring to other markets.

> “CSA technologies and businesses can scale faster and with fewer barriers than in other countries

5.1.6. Enabling policy environments shape healthy markets

Enabling policy environments are seen to be important in shaping the long-term investment pipeline, with businesses reacting to policy incentives to address market gaps, financial incentives and new opportunities. Kenya was given by interviewees as a good example, where policies promoting CSA, agricultural value chain strengthening, and digital financial solutions over a number of years has led to a stronger pipeline of innovative agri-tech companies, which over time has evolved with more novel business models and first-to-market service-level technology innovations.

5.2. Opportunities, constraints, and knowledge gaps

The issues identified by the interviewees as being key considerations in their investment decision-making are summarized in Table 12 below. They are detailed further in the following sub-sections in this section.

Table 11: Summary of opportunities, constraints, and knowledge needs identified by interviewees

Opportunities	Constraints	Knowledge needs
Net-zero motivations	Farmers' access to affordable finance	Climate risk assessment and management
Productive uses of renewable energy	Agribusiness and farmer awareness of relevant CSA technologies	Measuring biodiversity- and nature-positive impacts
Nature-based solutions	Managing and understanding risks for farmers	Identifying CSA technologies and investment opportunities
Reducing waste and post-harvest crop loss	Technical capacity of end-users	
Digital platform technologies	Business capacity constraints of agri-SMEs	
	Regulatory risks and (dis)enabling environment	

5.2.1. Opportunities

Net-zero motivations

Transitional climate risks arising from consumer demand and reputational risk are a much greater immediate concern to investors than physical climate risks. Transition risks refers to the challenges facing organizations in the move towards low-carbon and climate-resilient economies, mostly focusing on the imperative to massively and rapidly reduce GHG emissions globally (Casey, 2021). Key considerations include:

- reputational risks and changing consumer demands
- national and international policies and regulations
- carbon pricing systems
- technological changes

All the investors interviewed in this study aim to reduce the impact of their portfolio on GHG emissions where possible, and some are starting to set portfolio-level or investee-level emissions reduction targets. No investors cited GHG mitigation and low-carbon growth as barriers to investment. Instead, they recognized the market opportunities being driven by national policies and consumer demand.

> "All the investors interviewed in this study aim to reduce the impact of their portfolio on GHG emissions"

Investors demonstrated a clear interest in decarbonizing their portfolios, and CSA technologies which mitigate GHG emissions were the most frequently cited as demonstrating investment viability.

To increase investments in these technologies, investors highlighted the need for information on the clearly defined mitigation potential of CSA technologies. Being described broadly as ‘green’ or ‘low-carbon’ is insufficient when investors are looking to quantify their GHG emissions reductions, and to help them to identify the most suitable investments for them to achieve net-zero investment portfolios. One finance provider interested in green bonds questioned of CSA technologies:

> *“How do we know the mitigation impact? How can we quantify that? There’s no framework to say ‘this technology used here will save so much carbon per year’. We need that kind of data.”*

For other investors, their focus is on renewable energy and forestry/agro-forestry investments. They see these sectors, with clearly defined GHG mitigation impacts, and established verification, reporting, and certification systems, as being more readily investable for achieving net-zero goals. One investor noted that

> *“We’ve got satellite monitoring for our forestry [investments]. We can’t use that for a biopesticide, or an app. It has to be reliable, verifiable, or we’ll face questions.”*

Productive uses of renewable energy

There is nascent and growing private finance interest in solar-powered CSA technologies, particularly cold storage solutions and drip irrigation technologies, as well as efficient solar dryers. But the primary **interest in renewable energy technologies in post-harvest services** is the advantages they offer over grid energy in many energy-under-served contexts – including lower running costs, improved reliability, and their ability to restart faster following a climatic shock than grid-connected technologies.

Biodiversity and nature-based solutions

Minimizing pesticide use and transitioning to biocontrol products was also highlighted as an area of ‘serious growth and potential’ by two investors. One was focused more on investments in biocontrol producers and distributors, and the other on technologies to improve efficiency in the application of pesticides (chemical and biological) to minimize waste and wider negative ecological impacts. Agro-biodiversity – such as crop rotation, intercropping and agroforestry – were part of some investment portfolios already, being promoted through investments in agro-dealer companies.

Reducing waste can be big business

Avoiding wastage and minimizing spoilage are currently more attractive to investors than production-level technologies. Such **technology solutions range from improved logistics management to rapid processing of lower-grade goods, renewable-powered cold storage, and bio-coatings for fresh produce preservation**. There is no common reason given for this comparative focus, but the fact that **these solutions address customer profitability, food security and value addition, and provide positive environmental impacts**, all play a role in making this an attractive area for investment.

> “Reducing post-harvest losses is an area of real interest among investors”

While not strictly CSA technologies *per se*, these solutions do offer resilience advantages that can form a crucial part of more sustainable and productive agri-food systems, while offering immediate financial benefits to all stakeholders. These technologies can also reduce the avoidable pressure that food losses generate on nature/ecosystems (through necessitating additional production).

Digital platforms address demand-side constraints

The interviewees noted that digital platform technologies – which bundle together various combinations of advisory services, inputs, technologies and financial products – are able to gain greater market traction. This is in part due to there being far smaller transaction costs per user, lower costs for distribution (typically through mobile networks), and revenue generation from commission or other fees paid by service and input providers using the platform to reach farmers. Previous CASA research has identified that a user's willingness to pay increases both with the bundling of additional services, and in particular with the inclusion of financial services in the offering, which can be enough to achieve financial sustainability of the platform technology (Valverde, 2020).

5.2.2. Knowledge needs

Climate risk assessment and management

Investing in CSA technologies is often aligned with a strong understanding and strategic prioritization of physical climate change risks to agricultural production, agricultural value chains, and food supply. All types of investors, from DFIs to commercial banks, are increasingly incorporating considerations of climate change risk in their investment and lending portfolios, but the degree of integration is uneven.

"Investors are increasingly incorporating climate change risk considerations into their portfolio management"

Physical climate risks

Private equity investors lag behind institutional lenders and impact investors in integrating physical climate risks into their portfolio management strategies and due diligence processes. Many private equity investors reported the sentiment conveyed by one interviewee, that:

> *"There are far greater immediate risks to our investments than climate change."*

These include regulatory risks, corruption and volatile market conditions. In three cases, though, private equity investors somewhat contradicted their own points, by later stating that **a main limitation for potential investees is near-term risks of extreme flooding or severe water scarcity**, both of which are highly influenced by climate change.

In contexts where extreme droughts and frequent water security issues are present, such as South Africa, Ethiopia and parts of India, interviewees noted that this played a greater role in their investment and lending considerations. This is primarily driven by tighter regulations around water use, and the higher costs associated with water utilities in those contexts.

Physical climate risks are still poorly understood across the spectrum of investors interviewed by the research team. Even those individuals and organizations that are taking greater strides to consider climate risks in their screening systems noted the difficulties of such activities given the paucity of detailed near-term climate risk metrics available, and uncertainties in how best to factor low-likelihood, high-impact shocks into their risk profiling.

Measuring biodiversity-positive and nature-positive investing

One of the key constraints on greater integration of biodiversity, nature, and ecosystem conservation considerations in investment decision-making is the ability to **monitor and verify changes that are directly attributable to specific investments and technologies**. Investors noted that reliable baselines are scarce and the costs of establishing MRV systems to understand positive or negative impacts of technology use or related activities from investments is prohibitive, particularly in low-margin settings.

All interviewees reported that they aim to apply a 'do no harm' approach, with no negative impact on biodiversity and nature from their investments, but only impact investors and DFIs actively aim to monitor this through key performance indicator reporting mechanisms and project-style monitoring and evaluation services, which are unlikely to be appropriate tools for commercial finance providers.

5.2.3. Bottlenecks and barriers

Farmer finance and affordability

The interviewees highlighted that demand-side activation is critical for transforming the pipeline of investable opportunities in Africa and Asia. The greatest bottleneck faced by CSA technology companies as regards growing and becoming investment-ready is the affordability of services or products for their customers. There is a vast potential market for CSA technologies for smallholders and agribusinesses in emerging markets, but these technologies remain unaffordable for the majority of smallholder farmers.

> "Demand-side activation is critical for transforming the pipeline of investable opportunities in Africa and Asia"

This constraint was expressed by all interviewees in this study. They stressed that if the large smallholder market could be 'activated' in this way, then there would be much less need for supply-side interventions to attract capital flows and financing, as there would be a strong up-tick in the pipeline of investable companies that are able to grow beyond niche offerings in fragile or volatile markets. In India, at $3,000 per unit, the average solar-powered drip irrigation system costs 10 times that of a conventional irrigation system (TERRI, 2019), while typical micro-finance loans for smallholders would only cover around half the cost of such equipment. This situation severely limits the ability of CSA technology companies to reach the scale required to generate sufficient growth year on year to attract equity investments, or to build sufficient collateral and business stability to secure debt finance.

Unfamiliarity with technology

Awareness of CSA technologies and their benefits remains low among smallholder farmers in both continents. This translates into greater marketing costs to stimulate the customer demand, negatively impacting the already small profit margins. Farmers are often reluctant to engage with services where there are limited or no price guarantees for the goods they produce, and particularly in India there is scepticism about services bundled with insurance schemes and private credit services, following recent negative experiences of some providers and news stories of debt-laden farmer suicides across the country.

Unfamiliarity with, and lack of awareness of, CSA technologies is not only an issue among clients, it also affects investors. **Some investors interviewed for this research reported that solar-powered irrigation was the only CSA technology they were aware of**.

Managing and understanding risk for farmers

The interviewees stated that one of the constraints on the demand for CSA technologies is farmers' lack of understanding of how they can address the climate-driven challenges they face, both now and in the future. Four interviewees noted that this holds true as much for farmers in Europe and North America as it does for farmers in Africa and Asia. As one investor highlighted:

> *"Farmers can't 'think green' about long-term sustainability, when they're constantly 'in the red' financially. Addressing the 'now' will always be their greatest priority."*

Another area of commonality between farmers across the globe that limits more rapid uptake of high-impact CSA technologies is 'natural' risk aversion regarding all spending and new technologies and innovations. This was noted by three interviewees, and is also backed up by some recent research in Europe (Dessart, Van Bavel, & Barreiro-Hurlé, 2019).

While no single means of addressing this constraint was identified, according to the interviewees **business models such as subscriptions (for digital services) and leasing (for some hardware products) can help to overcome this risk-averse mentality.**

Technical skills of farmers

More impact-focused investors highlighted that direct technical support to smallholder farmers remains a crucial tool for improving CSA technology uptake. They reiterated that in many cases **farmers cannot make the most effective use of CSA technologies without first getting fundamental aspects of sustainable and productive farming in place**.

One private finance investor highlighted that, for their investments in food crop value chains in Ethiopia and Zambia with processing and value addition companies, most smallholders they source from have never received any extension service training and support. This means that technological improvements to supply chain resilience and storage have less impact than basic skills training for, and sharing information with, smallholders.

Other **investors noted the potential for digital advisory services to be effective in reaching more smallholders**, but cautioned that this would not be a commercially viable opportunity given the limited ability and propensity to pay among such farmers, as is echoed in the literature (CTA, 2019).

Regulatory risk and enabling environment

Another area limiting investment in some countries is the regulatory risks involved in foreign direct investment in countries with weak capital protections, weak or opaque rule of law, or serious political instability. These issues were raised by private and impact investors and DFIs alike. Both Ethiopia and Tanzania were singled out by more than one investor as countries where regulatory risks prohibit investment opportunities. **Such challenges are not unique to CSA technology investments.**

One investor noted that agribusinesses seeking investment now regularly set up shell companies in third-party countries as a means of being able to receive investment. However, such practices are often forbidden by investors, particularly impact investors and those with strong ESG screening mechanisms, further restricting available finance sources and starving those nations of critical tax revenues.

Pipeline constraints

Private equity, impact, and development finance investors alike identified that critical business planning and practices are absent from many potential investees, which fail to sufficiently formalize or modernize after an initial growth stage. This is often matched by the difficulty faced by such companies to recruit the necessary talent to fill key team vacancies as the firm expands, leaving them short of both technical and financial capacities.

Agri-SMEs typically require support across five dimensions – access to talent, access to finance, access to markets, access to knowledge, and a wider ecosystem of support – and **the need for support grows as the company grows** (Agridius, 2021).

One investor based in East Africa noted that while there was a multitude of incubators and accelerators available in the region for ideation-stage innovative technology businesses, they were **not aware of any services which help small enterprises to mature and develop beyond the initial ideation stage**. This has left a large technical capacity gap as regards taking those enterprises to the next level and enabling them to become investment-ready.

One DFI noted that, even with their technical assistance support, on average it takes over 18 months to get a promising business investment-ready. This is a significant amount of time, which implies a clear financial burden, one that most commercial venture capitalists and growth equity investors are unlikely to take on, which creates a blockage in the pipeline of investable CSA technology businesses.

"On average, it takes over 18 months to get a promising business investment-ready"

6. Conclusions and recommendations

This research has obtained the views and insights of investors and other stakeholders in order to identify the emerging investment opportunities in CSA technologies in Asia and Africa. It has found that there are a number of promising business models that help to overcome demand-side constraints, and it identified eight exciting CSA technologies addressing climate and environmental issues that have the potential for commercial viability.

No single CSA technology alone will be sufficient to address the risks and pressures of climate change and sustainable production, but when used in combination with climate-smart practices, and strong supporting services, such technologies can play a crucial role in enhancing adaptive capacities and boosting low-carbon productivity in smallholder agriculture contexts.

6.1. Emerging CSA technology investment opportunities

This report profiles eight technologies identified by the interviewees as showing promise for growth, investment viability, and relevance to the emerging markets in Africa and Asia for smallholders and agribusinesses. Products and services that demonstrate potential for adaptation and mitigation include the following:

Solar-powered micro drip irrigation systems, which are able to help farmers in arid and drought-affected areas to sustainably increase yields and crop resilience, with minimal use of scarce water resources and no ongoing energy costs. **Pay-as-you-go models for such systems are flourishing**, helping to overcome the capital expenditure costs for some farmers, with companies such as SunCulture recently securing $11m in (concessional) loans, and Azanga raising $13.5m in Series B equity investments from both private and impact investors.

Biocontrol products and precision applicators enable farmers to minimize the inputs they use for crop protection in their responses to increasing plant health threats driven by climate change. As market and consumer demand for more environmentally friendly food increases, **investors have identified biocontrol products and precision applicators as key technologies in the transition to nature-positive agricultural production**.

Solar-powered cold storage solutions help to prevent food wastage and spoilage, particularly in increasingly humid conditions and extreme temperatures, as well as helping to **ensure that produce can be sold at an optimal time in prime condition, maximizing income for farmers and returns for investors**. Innovative business models in this area are leveraging stored produce as collateral for brokering access to affordable credit for farmers, simultaneously addressing both a key demand-side constraint as well as diversifying revenue streams.

Digital platforms that bundle together climate-smart advisory services with other complementary products and services are **helping to minimize transaction and marketing costs for companies** and providing a more integrated and holistic offering to farmers. Building on existing trusted relationships, successful platform technologies enable farmers to access stress-tolerant inputs and climate information services alongside financial products and services.

Smart irrigation involves the coupling of sensors, control instruments, and irrigation machinery with computer models and meteorological information for real-time farm management. Business models that reduce the investment risks to end-users are **demonstrating commercial viability when targeting horticulture users and innovative payment models, with no upfront costs**.

Biodigesters make use of crop and livestock waste to produce biogas and rich organic inputs for crop farming. Emerging business models involve bundling financial services with product sales. For example, one manufacturer has partnered with a financial technology (fintech) company to enable livestock farmers to purchase equipment on long-term low-cost credit, and is generating additional income from retailing both the biogas and biomass outputs from its product.

Bio-coatings make use of organic inputs for the natural coating of fruits and vegetables, which can lengthen their shelf-life. Bio-coatings can be particularly useful in preserving fresh goods under climate-related stresses, such as increased heat or humidity. **Companies with operations in Africa and Asia have shown interest in working with exporters to use these products in their supply chains.** This reflects the influence of both regulations and changing consumer preferences.

Solar-powered processing equipment enables perishable products to be stored and eaten out of season, reducing pressure on other commodities, and the need to import products, and maximizing the value of the goods by making it possible to sell them when there is a supply shortage. Solar dryers can also achieve this, enabling lower-grade produce that cannot be sold fresh to still have value once processed. **These technologies have relatively short payback timeframes, and are already demonstrating scale and growth in India.**

6.2. Findings and recommendations for investors

6.2.1. Sliding scale of impact investment focus

The traditional distinctions between impact investing and commercial investing are becoming increasingly blurred. There are now examples of fully commercial but climate impact-focused private equity investors. Such companies and individuals are helping to crowd in further climate finance, driven not only by the pursuit of profits but also by the need to respond to the risks and opportunities posed by climate change in agriculture, and beyond.

As global and national policies continue to shape sectors towards low-carbon and climate-resilient pathways, there will likely be more investors operating with a climate-focused approach to their portfolios. CSA technology investments relevant to smallholders and agri-SMEs in emerging markets will be able to capitalize on this growth in impact-aligned investing if there is enough awareness of these technologies among target clients and investors alike, if there are sufficient sources of accessible and patient capital and debt, as well as pre- and post-investment technical assistance aimed at early-stage enterprise development, which will help agribusinesses increase their investment readiness.

Recommendation

Bringing together the expertise of these pioneer investors, alongside impact investors and climate experts, could help investors to share positive examples of how other commercial investment vehicles can pivot towards impact focus in their portfolios.

6.3. Findings and recommendations for governments

6.3.1. Climate risk

Improved guidance, standards and common datasets are required to help all types of investors to better integrate physical climate risk assessments into their investment decision-making and management processes. There is a need to fully understand climate risks if CSA and adaptation actions and technologies are going to be prioritized in innovation, business decision-making, and investment strategies (IGCC, 2017). If risks are unknown, then the technologies designed to address them will face much greater hurdles in attracting investment and building market demand.

There is a strong need to ensure CSA technologies have a clear link back to business resilience and the bottom line, and to demonstrate the (medium-term) commercial opportunities from enhancing adaptive capacity through innovative technologies. Without this, the business case for investing in CSA technologies may remain a fringe, niche area of investment interest.

Recommendations

Formalized data and benchmarks to help lower the costs of establishing and running impact-focused commercial investment funds, and standardized climate risk reporting protocols, are two ways in which public and private financial institutions alike could work together to improve physical climate risk management systems (Dalberg, 2021a).

National governments could provide more detailed climate risk assessments of agro-ecological zones that are usable by financial institutions.

Establishing global guidelines on how to practically consider low-likelihood, high-impact climate-driven shocks would help investors understand how best to identify investment opportunities and areas of potential maladaptive practices.

6.3.2. Biodiversity and nature

Biodiversity and nature considerations are not integrated into decision-making processes by most investors, and few have a clear idea of value propositions in nature-positive investments or the types of technologies required to support sustainable production methods which enhance biodiversity.

Impact investors are leading the way in this area, with nature and biodiversity goals and metrics already an integral part of most of their systems. Sometimes this is done at an organizational/portfolio level, with key performance indicators tracked across all investments, while others take a more tailored approach, developing specific metrics for each investment to best capture the specific changes a company may make.

Recommendations

Public actors can promote action and investment from the private sector in nature-positive and regenerative agriculture by raising the awareness of investors on the value propositions, business resilience, profitability benefits, and commercial opportunities, and by supporting the development of accessible, standardized MRV systems and technologies.

Unless and until climate and nature/ecosystem benefits can be costed, public finance should be focused on technologies and practices that cannot be viably addressed by market mechanisms, recognizing their public good benefits, biodiversity impacts, risk reduction outcomes, and the immediacy of the need for resilience and adaptation for smallholders.

6.3.3. Awareness of CSA technologies and investment opportunities

Awareness of the plurality of CSA technologies and familiarity with their benefits and business models was generally low among interviewees. Governments and donors could help to improve knowledge of these technologies, and their promising business models.

Recommendation

Governments and climate-focused international institutions should work with communities of investors to increase their knowledge and understanding of, and familiarity with, CSA technologies relevant to smallholder contexts, and the ways in which such technologies can also improve supply chain climate resilience for many food trade businesses.

6.4. Findings and recommendations for concessional finance providers

6.4.1. 'Missing middle' of investment

To drive forward greater access to CSA technologies at scale, there needs to be a viable pipeline of investment-ready enterprises. Given the risks and challenges involved in the sector, this will require greater capital investment from impact investors at the early stage.

The greatest private financing gap is the lack of resources for widespread diffusion of small-scale technologies. Targeting smaller business requires a focus on different financial instruments, moving from a few large allocations of finance to growth-stage companies, to many small applications of working capital loans, lines of credit, venture capital and affordable farmer finance. Impact investors are currently the only ones engaged in this level of activity, but their comparative funding capacity is small compared to both the scale of the challenge and the wider investment market.

The costs of establishing and managing innovative finance funds for agribusinesses can be as high as 44% of the total available finance, with costs increasing the earlier the financing stage and the smaller the ticket size (Dalberg, 2021a). This is too high for private finance providers; management costs need to shrink before they can engage at this level.

Recommendations

The public good nature of CSA technologies should be recognized: thus, to reach the $100bn climate finance goal, DFIs and other public finance funders should look to shoulder more risk in investing directly in early-stage CSA technology innovators, to allow them to grow, explore their market potential, and pivot as required towards sustainable, scalable and replicable business models, including revenue diversification. Returnable finance of this type is vital for preventing promising innovations falling into the 'valley of death' while demand-side constraints limit their ability to rapidly grow.

DFIs typically have ticket sizes in the millions of dollars, but should look to lower the minimum investment threshold in specialized CSA technology funds to enable promising CSA technology ventures to scale. Support through concessional finance, subsidies and grants is likely to be required across the board to speed up the adoption of these CSA technologies, and to accelerate their development into investment-ready ventures.

6.4.2. 'Missing middle' of technical assistance

This 'missing middle' is also fundamentally one of technical capacity and support. Business management capacity is often a key constraint when assessing the bankability of agri-SMEs – strong internal organization, financial management and good governance can more than triple the likelihood of receiving a loan or investment (AGRA, 2021).

Agri-SMEs typically require support across five dimensions – access to talent, access to finance, access to markets, access to knowledge, and a wider ecosystem of support – and the need for support grows as the company grows. Yet in practice the availability of such support shrinks as SMEs develop beyond their initial start-up phase (Agridius, 2021).

Technical capacity constraints for companies at the interface between early stage and growth stage are a major bottleneck for the investment pipeline. Patient capital provision from concessional finance providers, such as DFIs and impact investors, faces constraints at this point. The long timeframes and 'handholding' required to get enterprises investment-ready is a major deterrent to private capital investors.

Recommendation

Public, private and philanthropic providers of business development technical assistance should shift their focus away from ideation and initial innovation stage support to focus instead on enhancing the capacities of CSA technology enterprises to develop into investment-ready operations. This will require longer-term engagement, supporting companies through each stage of growth, adjustment and development to become investment-ready (Rokitzki & Hofemeier, 2021).

6.5. Findings and recommendations for technology innovators

6.5.1. Demand-side development

The main bottleneck for investment is the main constraint on CSA technology business growth – limited demand. That is not to say that there is no demand for such products and services, but rather it should not be assumed that the demand can be met by farmers and small agribusinesses themselves without the ability to pay for the CSA technologies. Addressing affordable, appropriate and transparent smallholder and agribusiness finance is one of two fundamental areas which need to be addressed to unlock the potential of CSA technologies across Asia and Africa.

> “Affordable finance is one of two fundamental areas which need to be addressed to unlock the potential of CSA technologies across Asia and Africa”

The second fundamental area is that of farmer-level skills and knowledge. ‘Getting the basics right’ may not be the most ground-breaking or exciting topic, but it remains critical for both improving climate resilience and adaptive capacity, and giving farmers the best possible footing to maximize the benefits of CSA technologies. Farmers cannot ‘leapfrog’ to more advanced technologies without basic support for good agricultural practices first.

Recommendation

Focusing on innovative models to enhance access to appropriate credit and information services will likely have a greater effect on private finance investments in CSA technologies than any supply-side intervention. Business support organizations and public bodies should look to innovative business models – such as the example of the cold storage company leveraging warehouse receipt financing – to address the dual, interdependent challenges of climate change and financial exclusion. CSA technology providers need to build business models around trusted relationships and transparent trade-off considerations with farmers.

6.5.2. Business models

The right business model is highly dependent on the nature of the business, the technology, and the context in which it is operating, but it is clear that there is a need to bundle services and products, and for client and revenue diversification.

Commercial viability of enterprises in a nascent market area should not be expected so early, particularly in emerging market contexts. Even in North America, where venture capital activity in climate-smart technologies is increasing, most start-up companies *“are still a long way from returning capital to investors”* (Glasner, 2017). Until there is a transformation in the financial inclusion of smallholders and small agribusinesses, some level of subsidy will likely be required to enable them to access CSA technologies. As the pressures of climate change rise, waiting until the situation changes will already be too late for many famers.

Recommendation

CSA technology innovators should explore opportunities for bundling with other technologies and services, and the potential opportunities for revenue diversification and pivoting towards alternative service provision models in different contexts. Further analysis of successful examples of CSA technology business models will play an important role in demonstrating such value propositions.

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Annex 1 – List of interviewees

In total, 120 individuals were contacted by the research team to request interviews. 70 were commercial finance providers; the remaining 50 comprised impact investors, DFIs, technology innovators, and ‘enablers’, such as staff from innovation hubs and SME incubators.

Name	Organization	Category
German Vegara	Tiserin Capital	Investor
Rebecca Mincy	Acumen	Investor
Danny O’Brien	SVG Ventures	Investor
Satya Sagar	Omnivore Investments	Investor
Arjan Ruijs	Actiam	Investor
Bon Tjeenk Willink	DOB Equity	Impact investor
Dr Henry Kisembo	DALI	Investor and enabler
Serena She	Lightsmith Group	Investor
Nidhi Pant	S4S Technologies	Innovator
Michiel Botman	Versis Investments	Investor
Gaetan Hendrickx	BIO-invest	DFI
Melissa Tickle	Finca Ventures	Impact investor
Seth Silverman	Factor[e]	Impact investor
Mariah Grubb	Kampani	Investor
Roux Wildenboer, Abrie Rautenbach	Absa	Bank
Hannah Wood	UBS	Bank
Matt Shakhovskoy	ISF	Enabler
Brian Frimpong	Zebu Investments	Investor
Pedro Carvalho	KTN	Enabler
Maxine Barnett	Acorus Capita	Investor
Atsuko Toda	African Development Bank (AfDB)	DFI
Tanja Havemann	Clarmondial	Impact investor
Hortense Tafforeau	Creadev	Investor
Bram Thuysbaert, Martijn de Groot, Charlotte van Andel	FMO	DFI
Fallon Casper	Incofin	Impact investor
Sarah LaHaye	One Acre Fund	Social enterprise
Lize Lubbe	Phatisa	Investor
Mauricio Benitez	ResponsAbility	Impact investor

Annex 2 – Context for CSA technology investments in Asia and Africa

Agriculture is the sector of the global economy that is most vulnerable to the impacts of climate change, particularly in low-income countries. Climate change represents a serious threat for the world's 475 million smallholder farms. Rising temperatures and seasonal shifts are being observed across Africa and Asia (IPCC, 2021). Climate-driven natural hazards, such as droughts, floods, pests, invasive plants and diseases, are increasingly impacting yields and damaging the natural resource base upon which farmers' livelihoods depend.

Actors along agriculture value chains are also impacted by climate change, including issues of storage, transport and resilience of supply. Becoming resilient to both long-term climate shifts and short-term shocks will require rapid access to, and adoption of, CSA products and services (Acumen, 2021).

Agriculture depends on the proper functioning of natural ecosystems and use of natural resources, but, globally, agriculture is the primary driver of deforestation and biodiversity loss, accounting for 70% of deforestation, and also the main user of freshwater for irrigation (IPBES, 2019).

While being extremely vulnerable to climate change, agriculture is one of the largest contributors to global GHG emissions, accounting for around a quarter of all emissions annually (IPCC, 2019). Unsustainable practices are leading to pressures on nature and leading to the degradation of functional ecosystems. These practices include over-use of chemical fertilizers and pesticides, and the clearing of forests and native grasslands for agricultural expansion, which contribute to reduced soil quality, depletion of scarce water resources, and the destruction of habitats for a wide range of beneficial flora and fauna.

The agricultural sector faces significant challenges to meet the growing demand for agricultural goods with a rapidly increasing global population, while not undermining the natural resource base upon which it depends, and being able to cope with the increasing impacts of climate change, including slow-onset hazards and extreme weather events.

6.6. The need for CSA technologies

To meet the challenges of decarbonizing the agriculture sector, enabling it to adapt to climate change and to function in a nature-positive way, technology innovations can play a critical and potentially catalytic role in the transition to low-carbon, resilient and environmentally sound farming systems. These range from 'hard' technologies, such as seeds and solar-powered irrigation systems, to 'soft' technologies, such as climate information services and hazard early warning systems (UNFCCC TEC, 2014).

Nature-based solutions are also critical for addressing these challenges in ways which enhance and optimize the use of nature, rather than degrading and depleting it. Nature-based solutions are actions that involve the protection, restoration or management of natural ecosystems and working lands, such as croplands or woodlands (NbS Initiative, 2020). Technologies which facilitate nature-based solutions and improve their efficiency and effectiveness will be crucial in responding to the dual issues of climate change and biodiversity loss in the agriculture sector.

6.7. Technology investment challenges

Many barriers to developing and commercializing CSA innovations exist, particularly in regard to smallholder farmers' uptake. Issues of affordability, poor supporting services, literacy, and technology relevance commonly limit commercialization. Risks associated with the agriculture sector and with working with low-income customers often deter investors and can stifle innovation (Rockefeller Foundation, 2012), or shift the incentives of agribusinesses towards only serving the higher end of the market. The diversity and complexity of agriculture also presents a significant challenge for technological innovation in the sector for both hard and soft technologies.

There are often greater challenges in realizing a strong or rapid return on investment in adaptation technologies compared to mitigation technologies. The benefits of adaptation technologies and resilience-building measures are generally realized over the medium term (IGCC, 2017). However, some technologies can result in more immediate gains, such as stress-tolerant seeds and early warning systems for pest or weather risks (UK Space Agency, 2021).

While technologies which help improve resilience to climate-driven shocks and stresses may create significant positive cost–benefit ratios in terms of avoided losses, these do not always translate into commercial viability for innovators and investors. The financial benefits of adaptation and resilience technologies and activities do not necessarily translate into direct returns on investment for private finance providers, but rather avoided costs for users and governments, and wider ecological benefits, often over long-term timeframes (World Bank, 2021).

In general, mitigation measures can result in more rapid returns on investment and immediate cost savings for users. For example, renewable energy and energy efficiency technologies have seen enormous growth through pay-as-you-go models (Moore, 2019) (GSMA, 2020), in part because of the direct impact of these technologies on end-user energy bills, and access to clean, efficient and reliable energy that is more rapidly deployable than grid-based systems (Practical Action, 2019).

Mitigation measures in agriculture may only lead to improved incomes where input use is lower or cheaper, or where there is some form of ‘compensation’ for lower emissions production: for example, through carbon credit schemes or premium pricing of products. While it is necessary for both governments and businesses to ensure they prioritize low-carbon growth and development, it should be recognized that the burden of responsibility for mitigation does not lie with smallholder farmers, who have contributed the least to global GHG emissions, and their share of global emissions remains negligible.

6.8. Climate finance

At COP15 in Copenhagen in 2009 global leaders committed to mobilizing and providing at least $100bn per year in climate finance for developing countries by 2020. However, it appears that this target has not been met (Harvey, 2021). As the host of COP26, the UK Government has set its ambitions on rallying support to deliver on that target as soon as possible (UK Gov, 2021) (COP26 Presidency, 2021).

The United Nations Framework Convention on Climate Change (UNFCCC) Standing Committee on Finance defines climate finance as *“finance that aims at reducing emissions, and enhancing sinks of greenhouse gasses and aims at reducing vulnerability, and maintaining and increasing the resilience of human and ecological systems to negative to negative climate change impacts”* (UNFCCC SCF, 2018).

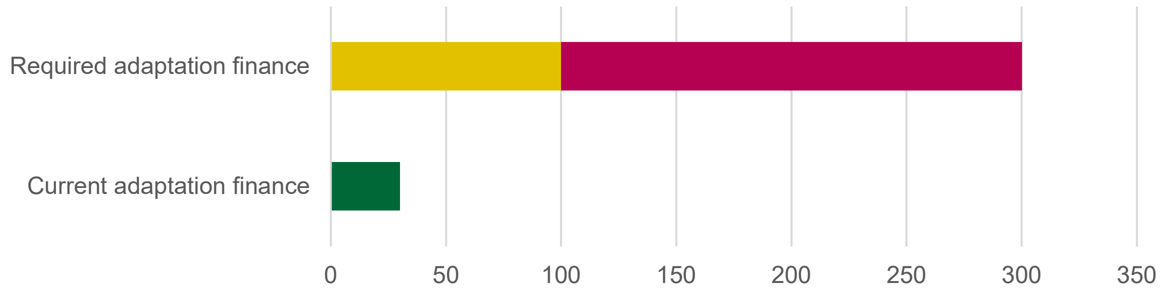
Climate finance takes many forms, including grants, loans, equity investments, insurance, in-kind payments, and various forms of blended finance arrangements. Although most climate finance globally takes the form of debt and equity instruments, primarily financing renewable energy technologies and energy efficiency measures, there is a growing pool of grant funding and concessional loans targeted at climate actions in developing countries, particularly in agriculture (CPI, 2019).

6.8.1. The climate finance gap

Despite a series of commitments by developed economies that there should be an equal balance between mitigation and adaptation finance, the reality is that approximately 95% of all climate finance (all types) remains targeted at mitigation, primarily renewable energy and energy efficiency measures (CPI, 2019).

Current estimates put the cost of climate adaptation in low-income countries at between \$100bn and \$300bn per year (UNEP, 2020). Current funds and investments come nowhere close to that level, at around \$30bn per year, although the trend is one of growth (GCA, 2021). The Global Commission on Adaptation (GCA) found that investing \$1.8tn in early warning systems, climate-resilient infrastructure, improved dryland agriculture crop production, global mangrove protection, and water resource resilience over the next 10 years could generate \$7.1tn in total net benefits (GCA, 2019). However, not all of these net benefits accrue to the investor, as they include avoided damage costs, ecosystem services, and other public good benefits (World Bank, 2021).

Figure 6: Adaptation finance gap

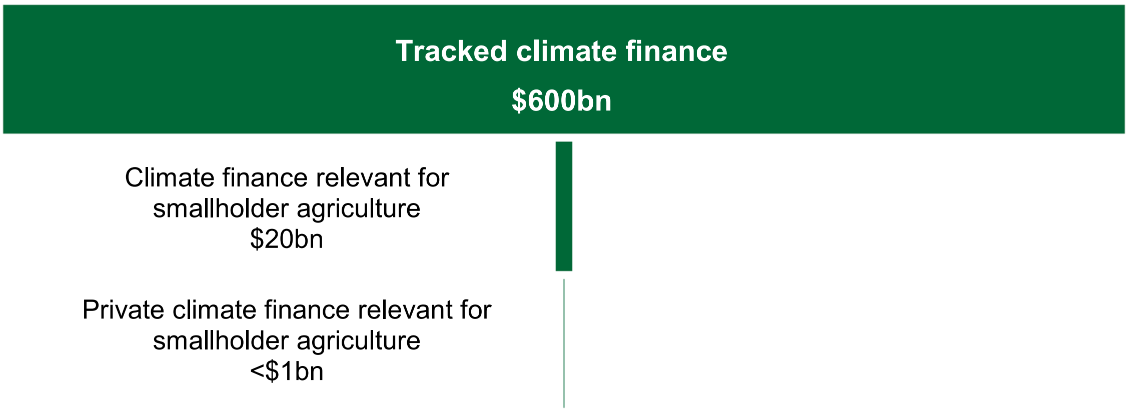


Most investors tend to approach climate challenges from the perspective of ESG screening, looking first at risk and starting with a ‘do no harm’ perspective, rather than seeking to identify solution-oriented technology investments (BCG, 2021). But bridging the private climate finance gap requires a shift towards the proactive identification of climate-smart investment and financing opportunities. Increasing private financial flows to emerging and developing economies needs to be supported by connecting available capital with investable opportunities and encouraging new market structures (Carney, 2021).

6.8.2. Agricultural finance gap

Agriculture in particular has struggled to attract sufficient climate finance investments to date. Agriculture’s share of climate finance has actually decreased over the last two decades (FAO, 2021). This is despite its significant role in global GHG emissions, its severe vulnerability to the impacts of climate change, and its important role in the economies of most emerging economy countries. The Climate Policy Initiative (2020) found that a mere 0.085% of tracked climate finance was from private sources targeted at smallholder agriculture. The proportion of this negligible amount targeted towards CSA technologies is not known. Although there are caveats to this figure – specifically that only a small portion of private climate finance is traceable – it nevertheless paints a stark picture of the need to rapidly change the status quo of investment flows for vital CSA products and services. This is also reflected in the Climate Bonds Initiative’s (CBI’s) analysis that agriculture and land-use sectors account for only 2% of climate-aligned bonds, most of which are targeted towards North America and Europe (CBI, 2021).

Figure 7: Climate finance for smallholder agriculture



A recent report estimates there is a $11.2bn annual investment gap for sustainable agriculture technologies in developing and emerging markets, with an additional $2.1bn per year gap in investment required to counter the impacts of climate change on food security and hunger (IFPRI, 2021). Across Africa alone, the African Development Bank (AfDB) finds there is a need to invest $45bn per year to enable the agriculture sector to adapt to climate change and develop in a low-carbon way. At present, only $7bn per year is invested in the sector across public and private sources (AfDB, 2018), while less than 1% of commercial lending on the continent goes to agriculture (FAO, 2018). Alliance for a Green Revolution in Agriculture (AGRA) research suggests that there is an annual financing gap estimated at $65bn for agri-SMEs in sub-Saharan Africa, with financing needs per enterprise between $25,000 and $1.5m – the 'missing middle' of SME and climate finance (AGRA, 2021).

6.9. Private climate finance landscape for CSA technology

Overall, the data availability on private finance in CSA technology is patchy at best: for example, a UNFCCC report found no sufficient available information on research, development and demonstration of private finance for adaptation technologies (UNFCCC TEC, 2017). A recent United Nations Development Programme (UNDP, 2020) report on the ecosystem of private investment for climate action states that:

> *"Tracking private climate finance flows is also more challenging than tracking public flows. Difficulties may arise when distinguishing the origin of private finance, encountering confidentiality clauses related to private sector data, and facing a lack of data collection systems. As a result of this complexity, the landscape of private investment, and the ways in which the private sector considers the threats and opportunities presented by climate change, is often less well understood."*

Where data does exist, it rarely gives a complete picture of key metrics, such as total size, investors, investees and type of finance; and very rarely does it give an indication of the technologies (if any) that are being targeted – the exception being those related to renewable energy technologies for use in agriculture.[4]

This is not yet a mature area for investment, and the wide breadth of potential technologies, types of finance, and limited reporting, combined with the often-broad definitions of CSA technologies, means there is little consistency in the data identified.

[4] A parallel study on investments in renewable energy technologies in agriculture is being conducted by Shell Foundation, RMI, and Duke University.

Table 12: Ecosystem of private climate finance

<table>
<tr><th colspan="2">Type</th><th>Description</th></tr>
<tr><td colspan="2">Seed funding</td><td>Individuals investing their own funds (e.g. angel investors, or specialized funding organizations)
High risk, but also high potential returns
Opportunity to shape company growth strategy</td></tr>
<tr><td colspan="2">Venture capital</td><td>Individuals investing their own funds, or pooled funds from individuals and institutional investors
Includes follow-on investments from angel investors
High risk but high potential returns</td></tr>
<tr><td rowspan="3">Growth equity</td><td>Mezzanine financing</td><td>Quasi-equity – a hybrid of equity and debt. Used by established companies in need of growth finance but without the collateral or ability to obtain sufficient loan finance, or unwilling to further dilute ownership
Allows lenders to share some profit growth potential and protection for investors, as well as more favourable loan terms for companies</td></tr>
<tr><td>Minority stakes</td><td>Companies requiring cash injections for growth, while maintaining overall ownership
Challenges for investors to secure minority ownership rights and influence over business strategy</td></tr>
<tr><td>Controlling interest</td><td>Often used in conjunction with debt finance (leveraged buy-out)
Exits often conducted via public offerings or to strategy buyers with minority or controlling stakes</td></tr>
</table>

Source: (UNDP, 2020)

Only $1.3bn to $2bn of private equity finance is invested in agriculture technology development in the Global South each year, primarily targeted at large-scale farm machinery, rather than climate-smart technologies (Dalberg, 2021). This represents a small fraction of the $1.4tn of private equity investments made each year globally.

In Africa, the agri-tech sector is developing in an uneven manner, with spikes and dips in finance for start-ups and growth-stage companies. Agri-tech start-ups received just 8.6% of start-up finance ($60m) across the continent in 2020, and made up just 4% of the total number of start-ups receiving investment; and two companies accounted for nearly 80% of that funding, both receiving follow-on seed funding, and both targeted at downstream retail and distribution markets (Disrupt Africa, 2021).

Kenya attracted 60% of agri-tech investment in Africa in 2020, highlighting the important role that technology incubators in Kenya play in taking businesses from concept stage to start-up enterprises. From the database of investments covered by Disrupt Africa, only one could be considered to be related to CSA – a drone company developing analytics tools for large-scale fruit farming.[5]

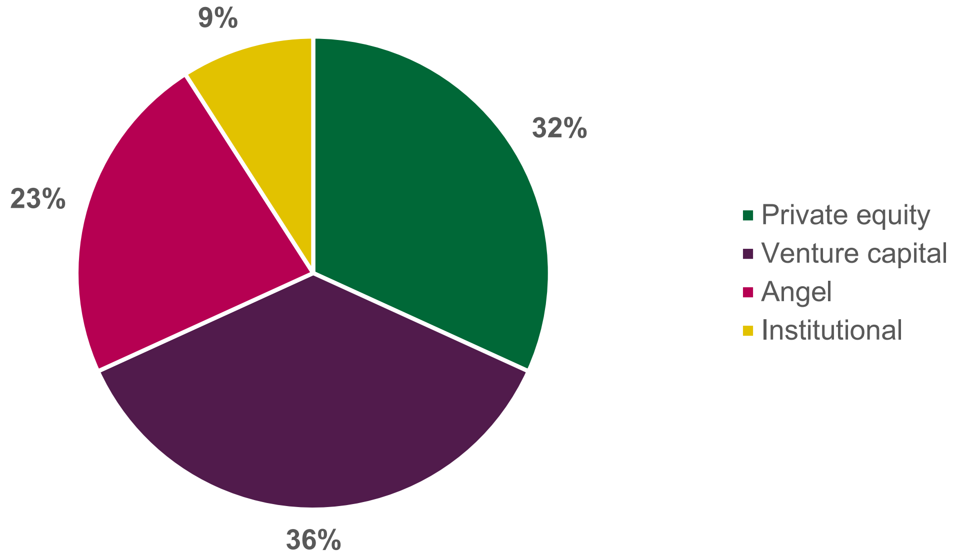
Earlier research commissioned by CASA found that in most countries in Africa there are typically fewer than 10 viable agribusiness firms that could have a minimum deal size that would be suitable for most impact investors, let alone private equity investors (Jayne, Ferguson, & Chimatiro, 2020).

[5] This is unlikely to be of relevance to smallholders, and the climate-relevance of the technology is questionable as there are no references to climate change in any published materials from the company.

6.10. Investor database analysis

The Shell Foundation has collaborated with the CASA programme to develop a database of over 200 investors engaged in the agriculture sector in Africa and Asia.[6] A comprehensive and systematic methodology was used to identify relevant investors, and this includes all investors with a demonstrated interest (active or aiming to be active) in agricultural technology financing in sub-Saharan Africa, as well as Asia and beyond (Shell Foundation, 2021).

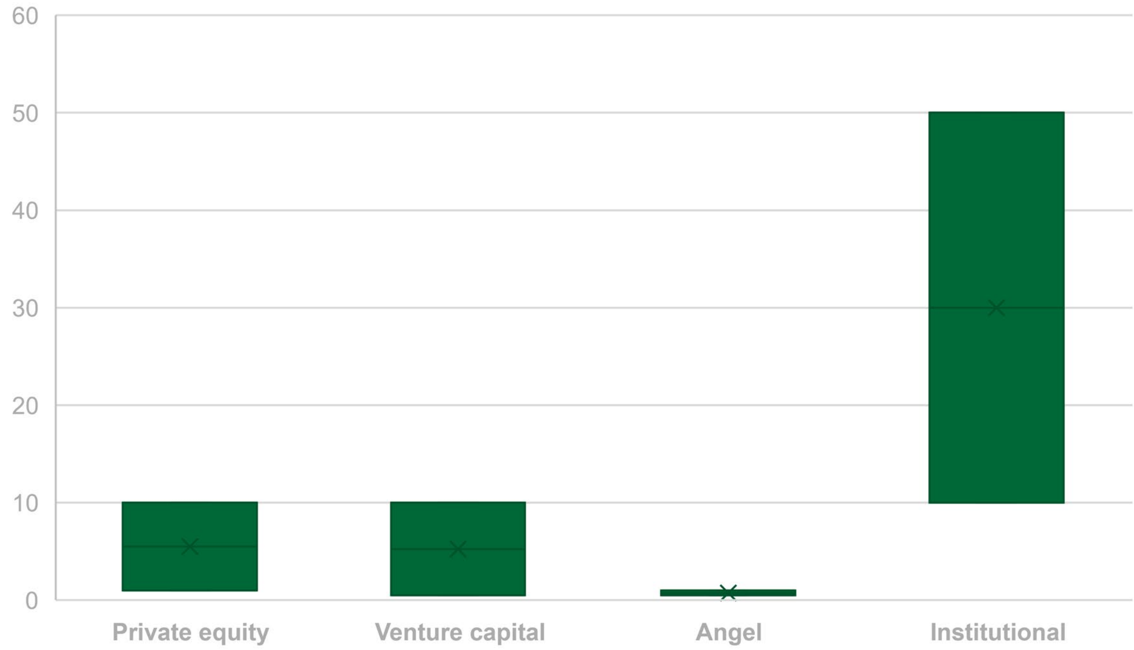
Figure 8: Agri-tech investor types from Shell Foundation database



Within the database, there are 22 commercial finance providers targeting agri-tech investment and finance opportunities. Of those, seven are private equity investors, with typical investment sizes starting at $1m, and rising to $10m in growth-stage enterprises. Eight venture capital investors, five angel investors, and two institutional investors make up the remaining organizations covered by the database that are engaged in agri-tech finance. Four of the five angel investors are focused on sub-Saharan Africa, each providing finance of less than $0.5m in early-stage enterprises. One angel investor focused on the India market has a wider range of financing, of up to $1m. The venture capital providers are all focused on portfolios in sub-Saharan Africa, with a wide range of ticket sizes at this stage, from lower than $0.5m to over $10m.

[6] Available at https://www.casaprogramme.com/investors-database/

Figure 9: Range of finance from investor types, $ million



However, across all 13 of the angel investor and venture capital investor portfolios, there are only three portfolio investees identifiable as CSA technologies, of which only one is targeted towards the smallholder and agri-SME markets. This demonstrates the paucity of investment in the sector among commercially oriented investors. It highlights that there is a greater need for understanding and identification of the CSA technology investment opportunities in emerging markets, and actions to increase the pipeline of investment-ready CSA technology enterprises.

6.11. Technologies

This section provides a definition of CSA technologies, and a typology that helps identify certain specific areas of technology innovation. Crucially, it aims to also link these CSA technologies to the specific climate-related risks and challenges they seek to address in primary and secondary agriculture markets.

6.11.1. CSA technology

The agriculture sector is divided into the traditional upstream, midstream and downstream components of the value chain, which are then broken down into smaller parts: production, processing and transportation innovations, efficiencies, and risk diversification (Village Capital, 2020). CSA technology here refers to technologies which can be used upstream to implement and achieve CSA systems in commercial smallholder farms.

The term technology can often encompass a very broad range of things in CSA, including physical tools, plant genetic materials, machinery, digital information services, infrastructure, land and ecosystem management practices, farming techniques, and livestock rearing practices (UNFCCC TEC, 2017). There are also a range of other technologies which support climate-smart smallholder agriculture that leverage technologies, such as market information platforms, financial services, post-harvest storage and processing, and transport.

For the purposes of this report, a narrower view of 'technology' is used, referring to those things that could directly utilize commercial finance and investment at the farm production level. These fall into two broad categories: products and services. Products cover 'hard' technologies, such as tools, machinery, plant genetic material, inputs and soil additives (including non-chemical inputs), and remote sensing and testing equipment. Services refers to 'soft' technologies which support the implementation of climate-smart farming practices. These are primarily digital tools and value-added services, such as information and advisory services, early warning systems, precision management tools, and means of monitoring, verifying and reporting on key CSA outcomes metrics, such as soil carbon sequestration.

This definition excludes practices, techniques and some indigenous technologies. These are all important, valuable and necessary in CSA farming (UNEP-DTU, 2021). However, these do not fall within the scope of this report, which focuses on directly investable technologies.

As identified in much of the literature, there is still a strong case for public investment in these 'knowledge technologies' – as the technologies covered in the proposed definition used by this study are primarily enablers for the more effective and efficient use of those practices, but on their own are typically insufficient to achieve truly sustainable and climate-smart agriculture systems.

6.11.2. CSA technology typology

This section sets out a typology of climate technologies. The typology is informed by a range of sources which each define climate technology in different ways, including the World Bank (2016), UNFCCC (2014) and the United Nations Food and Agriculture Organization (FAO, 2013). The aim of this adapted typology is to make clear the role and purpose of a technology, the impact area it addresses, and the category of technology it falls under, working within the limitations of the technology definition provided above, so that private financiers have a better understanding of the different opportunities and associated impacts.

Aspects such as stage of development, geographic footprint, and cost are not included as part of the typology, as these are all dynamic characteristics of the technology at a point in time and do not define the technology, but rather shape the finance opportunity. These factors will be central to the analysis, but do not form part of the typology.

CSA impacts

CSA technologies should be clearly aimed towards addressing at least one of the three CSA pillars: **productivity and efficiency; adaptation; and mitigation** (FAO, 2013). While it is desirable that technologies address all three pillars simultaneously to a greater or lesser degree, in practice this is not always viable. CSA should be seen as a whole farm approach, where all three pillars are considered, with technologies contributing towards that goal in one or more of the impact areas. CSA products and services enhance climate resilience and adaptive capacities if they enable smallholders and agribusinesses to obtain new climate information, learn improved climate-adaptive skills, identify and appraise climate adaptation options, and sustainably increase productivity and incomes (Acumen, 2021).

CSA issue areas

To achieve these impacts, technologies should be classified in terms of the issue areas they directly respond to. Adapting the UN Climate Technology Needs Assessment taxonomy (UNEP-DTU, 2021a), these issue areas are categorized as:

- crop resilience to stresses
- crop resilience to shocks
- livestock resilience
- livestock GHG mitigation
- water use efficiency
- sustainable and safe inputs
- biodiversity and ecosystem services
- crop GHG mitigation and carbon sequestration
- information and advice for CSA farm management
- MRV
- post-harvest waste and losses

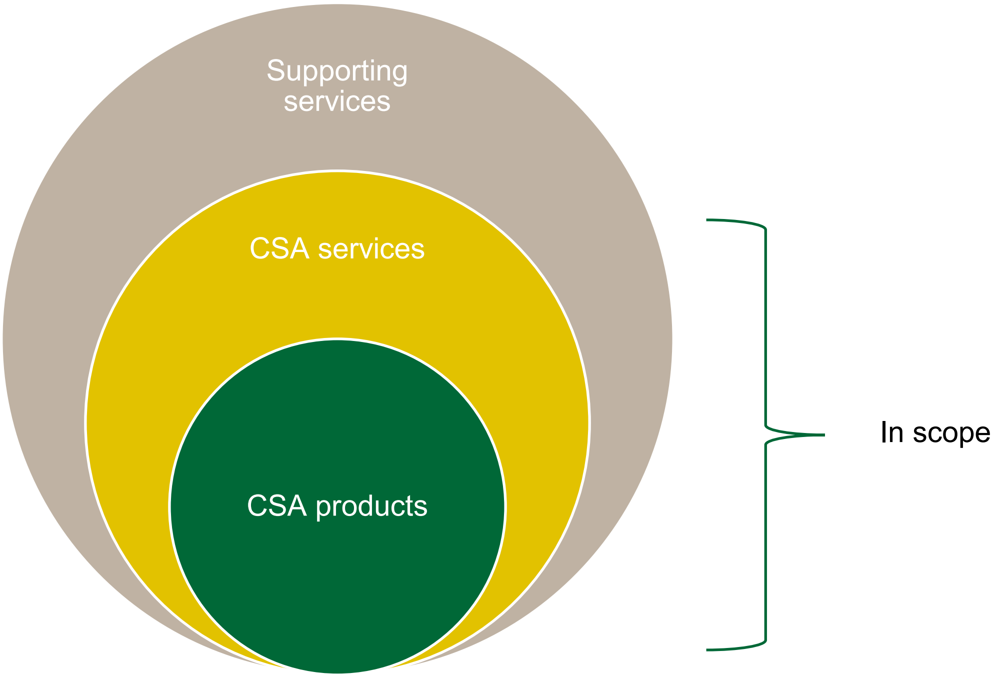
By categorizing CSA technologies by the specific issue(s) they address, we can better understand which issues are being most under-served, and which are gaining traction with technology innovators and financiers. For example, from the initial scan of literature, there are a range of technologies being developed to improve MRV for carbon sequestration through regenerative agriculture systems and attracting private finance, but comparatively few targeted at biodiversity and ecosystem services or adaptation.

Excluded areas

There are a range of other technologies which act as broader supporting services to sustainable, climate-smart agriculture. These include innovative digital market information systems, insurance, smallholder finance, and digital transport management tools, among many others.

While these play an important role in creating more efficient, low-carbon and climate-resilient agri value chains, or indeed ensuring the affordability of some CSA technologies, they do not directly address climate-smart production. These are also technologies for which a significant amount of research has already been undertaken, and where commercial finance is already playing a considerable role. Therefore, for the purposes of this report, these ‘supporting services’ will not be considered in-scope when assessing CSA technologies.

Figure 10: Typology of CSA technology



6.12. Other technologies identified through interviews

In addition to the technologies profiled in the main report, a number of other CSA technologies were identified by the interviewees, but were not chosen for inclusion for the profiles. This is because there was either limited information from investors or externally on the technology, there was minimal relevance of the technology to smallholder farming contexts in Africa and Asia, or because there were no clear CSA benefits.

The other technologies identified during the research included:

- nano-ice crystals for seafood storage
- indoor automated hydroponic systems
- biological and engineered soil additives
- satellite hyper-spectrometry instruments
- ‘Uber style’ tractor rental

All these technologies are receiving some level of private finance from the interviewees engaged as part of this research. However, of these only the biological soil additives and satellite earth observation instruments were identified as having potential relevance to smallholder farming contexts in Africa and Asia. Biological soil additives are not currently commercially available in most of Africa and Asia, and concerns were raised by both some of the interviewees and report authors of their CSA benefits, the scientific basis of their impacts, and their role in substituting out chemical inputs. It was therefore decided that, with no identified business model for uptake among smallholder farmers, this technology would not be profiled.

The high-sensitivity earth observation technology was identified by one investor. However, there is limited information available about this technology, and for confidentiality reasons no further details could be provided by the investor, limiting our ability to accurately profile the technology. It should also be noted that such technologies are not direct CSA technologies themselves, but can play important roles in other CSA services, such as digital CSA advisory platform technologies – which are profiled in this research.

Commercial Agriculture for Smallholders and Agribusiness