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An Enabling Innovation Ecosystem to Accelerate Agriculture Breakthroughs

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Highlights

Climate shocks to agriculture are threatening food security, especially in developing countries. Poverty and malnutrition are rising rapidly. Therefore, we must urgently transform our agricultural systems to be productive, sustainable, and equitable, and to contribute fully to lowering greenhouse gas (GHG) emissions. This will require a global "Agricultural Breakthrough", defined in the Breakthrough Agenda as: ***"Climate-resilient, sustainable agriculture is the most attractive and widely adopted option for farmers everywhere by 2030."*** How can we achieve this?

The diversity of the agricultural sector demands multiple "game-changing" innovations to escape the business-as-usual path and rapidly deliver outcomes that reach a positive tipping point. Synergistic interactions among multiple game-changing innovations in hundreds of national and local agricultural systems will cumulatively transform global agriculture.

The current agricultural innovation ecosystem is no longer fit for purpose: it is not effective in identifying and promoting game-changing innovations. Reforming the agricultural innovation ecosystem is therefore critical. We use a conceptual framework to analyse five innovation cases to generate lessons learned. These form the basis for four recommendations to make innovation ecosystems more effective in driving agricultural system transformations:

1. *We recommend building on and integrating current partnership initiatives to create a* ***Coalition for Agricultural System Transformation*** *(CAST),* including national, regional, and global research institutions, universities, non-governmental organizations (NGOs), and private firms, to drive innovative game-changing research and to move research from knowledge generation to driving systemic changes.

2. *We recommend redirecting a substantial portion of currently available research and development funds* to provide long-term, stable financial support for developing and rolling out innovations; reforming agricultural subsidies to incentivise the adoption of innovations and support women and those with insufficient resources to invest; creating incentives for the private sector to co-invest; and reforming agricultural credit systems to support the uptake of innovations in developing countries.

3. *We recommend that governments implement the reforms necessary to drive agricultural transformation.* Radical policy and governance reform are necessary, and despite the difficulty, can be achieved. To support this process, we recommend that researchers, NGOs, and civil society organizations use emerging scenario development and foresight analysis methodologies to identify what policy changes are needed and strategies to achieve these goals. These methodologies involve facilitated processes among interested stakeholders; to be effective, they must include specific attention to the role of power in transformations.

4. *We recommend investing in effective monitoring, evaluation, and learning (MEL) systems and integrating them into research programs.* This is increasingly being done by CGIAR and others. Beyond that, we require an agricultural roadmap to 2050 to provide a framework for designing innovation initiatives; research program MEL systems can show how each initiative is designed to contribute to one or more of the roadmap goals.

Transforming our food and agricultural systems to be productive, sustainable, and equitable, and to contribute to lowering GHG emissions is urgently needed. Visionary, effective leadership can enable humankind to meet these challenges, but time is short.

Cover photo credit: Jacquelyn Turner/CCAFS

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List of acronyms

CIMMYT International Maize and Wheat Improvement Center,
DCAS Digital Climate-Informed Advisory Services
DTMA Drought Tolerant Maize for Africa
DTMVs Drought Tolerant Maize Varieties
FAO United Nations Food and Agriculture Organization
GHG Greenhouse gases
IEA International Energy Agency
IITA International Institute of Tropical Agriculture
ISFM Integrated soil fertility management
IWMI International Water Management Institute
MEL Monitoring, evaluation and learning
SSA Sub-Saharan Africa

Background

Climate shocks to agriculture are growing in frequency and intensity, erasing earlier development gains, and putting billions of people at risk of losing their livelihoods, even their lives. We have not reversed the global warming trend and, at currently levels of action, are unlikely to achieve the Paris Agreement goal of limiting temperature increases to under 1.50 C. It is therefore even more critical that the international community comes together to increase the scale and pace of innovation and change (Loboguerrero et al. 2020).

Simultaneously, poverty, food insecurity and malnutrition are rising rapidly, especially in the poorest countries. While other factors such as the recent disruption of the global food supply and rising interest rates play important roles, climate change is the main threat: the rate of agricultural productivity growth has slowed, and floods, droughts, and rising temperatures are disrupting production. This is occurring globally but is felt most acutely in poor and middle-income countries. Urgent action is needed to reverse this trend and meet current and future food demand (Steensland 2022).

Food systems emit some 35% of global greenhouse gas (GHG) emissions, mostly from agriculture and land use changes (Costa et al. 2022). Nearly all countries have committed to reaching net zero GHG emissions by around 2050. However, on current trends we will miss this goal. Achieving it will require a high degree of international cooperation to bring about major structural changes in the world economy and in the global food system, including its production component – agriculture.

At COP26, 45 world leaders launched the *Breakthrough Agenda* to accelerate innovation and rapid deployment of clean technologies and sustainable practices in five GHG-emitting sectors by 2030 (IEA et al. 2022). The target sectors are power, hydrogen, road transport, steel, and agriculture, which represent some 50% of all global emissions. The goal is to make specific transformative innovations the most affordable and accessible options in each sector by 2030.

This Brief discusses actions needed to achieve the Agriculture Breakthrough: *"Climate-resilient, sustainable agriculture is the most attractive and widely adopted option for farmers everywhere by 2030."*

The Breakthrough Agenda Report (IEA et al. 2022) notes that achieving this daunting goal will require purposeful action across four principles of climate-resilient, sustainable agriculture:

- Sustainably increase agricultural productivity and incomes
- Reduce GHG emissions
- Safeguard soil, water resources, and natural ecosystems
- Adapt and build resilience to climate change.

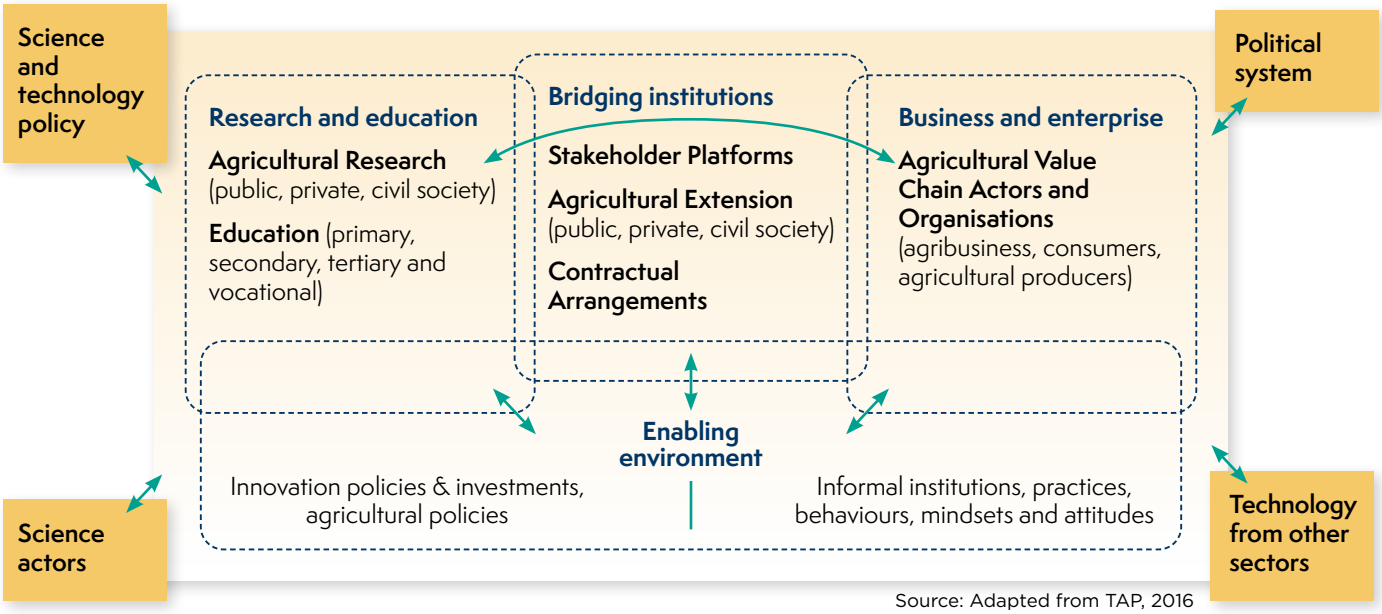
"Climate-resilient, sustainable agriculture is the most attractive and widely adopted option for farmers everywhere by 2030"

How can we simultaneously reduce GHG emissions, reverse land degradation, significantly increase production for future food security, and achieve more equitable outcomes? Only by abandoning business-as-usual – that is, incremental adaptation to climate change in favour of radical transformation (Rutting et al. 2022) – and focusing international and local collaboration on achieving significant game-changing innovations in each sector. A *game-changer* is an innovation generating sufficient momentum among a critical mass of key actors to enable them to escape the business-as-usual path and deliver outcomes rapidly, leading to a "positive tipping point". The tipping point is when change is accelerating exponentially, resulting in irreversible systemic change (UNEP 2022; Lenton et al. 2022). At this point, the innovation is

the most affordable and accessible alternative and diffuses rapidly, in turn triggering complementary systemic changes. Recent examples of game-changing innovations include the rapid spread of solar and wind power as these technologies became cost-competitive with alternatives, the exponential increase in the use of cell phones, and, in the 1960s-1970s, the Green Revolution in Asia, where the creation of high-yielding seed varieties combined with the spread of irrigation and use of fertilizer revolutionized wheat and rice cropping systems.

FIGURE 1: Realizing a tipping point towards the agriculture breakthrough will require multiple (bundled) game-changers

FIGURE 2: Agricultural innovation system



Source: Adapted from TAP, 2016

The diversity of the sector demands multiple game-changers

While agriculture is a major contributor to GHG emissions, and agricultural expansion is the leading threat to biodiversity, it is also the only Breakthrough sector with the potential to be a carbon sink through nature-based solutions. But this must be combined with meeting future food and fibre demand. Agriculture is the most fragmented of the five sectors, making achieving the Breakthrough Goal through one single large game-changing innovation along the lines of solar power unlikely. The diversity of the sector demands *multiple game-changers,* which together will lead to climate-resilient sustainable agricultural systems. There is no single transformative agricultural innovation; synergistic interactions among multiple game-changing innovations in hundreds of national and local agricultural systems will cumulatively lead to the transformation of global agriculture: an "Agricultural Breakthrough."

The *Breakthrough Agenda Report* proposes to increase the scale and diversity of international research, development, demonstration, and knowledge sharing. To achieve climate-resilient, sustainable agriculture, it argues that innovations are needed that can reduce food waste, limit emissions from livestock and fertilisers, improve alternative proteins, develop climate-resilient crops and livestock, and protect soil and water resources (IEA et al. 2022).

This Brief therefore focuses on the agricultural *innovation ecosystem* as the key to success. An innovation ecosystem is a network of actors, with supporting institutions and policies, that collaborate to identify and promote innovations, including technologies, processes, or forms of organization (TAP 2016). To be successful, other complementary actions are also needed, such as increased international finance, a level playing field in trade, and agreed international standards for measuring progress (IEA et al. 2022).

The next two sections apply a simple analytical framework to analyse five case studies of applied research and diffusion that, in principle, have the potential to be game-changers. The intention is to identify the gaps and bottlenecks that must be addressed to achieve real breakthroughs. The basic premise is that, to a larger extent than in other sectors, the agriculture sector has special institutional, policy and financial challenges that must be addressed to enable game-changers to emerge. The final sections propose innovations in the agricultural innovation ecosystem aimed at unlocking the potential of agriculture and recommend four key actions to be taken immediately.

Five Focus Areas of the Agriculture Breakthrough Agenda

Conditions conducive to an agricultural innovation becoming a game-changer

The conditions necessary for an agricultural innovation to rapidly scale up or out to large numbers of farmers have been well studied. But rapid diffusion of an innovation will not necessarily transform an agricultural system. That is, it does not, by itself, constitute a "breakthrough" (Milkoreit 2022). Promoting intentional positive tipping points in the agricultural sector, which consists of hundreds of complex unique socio-technical-ecological systems globally, is challenging but feasible (Lenton et al. 2022). The Commission on Sustainable Agriculture Intensification (COSAI) has recently proposed eight "Principles for Agri-Food Research and Innovation" (Zurek et al. 2022). While accepting that all the principles proposed are highly relevant, we concluded that they are not focused on achieving game-changing "breakthroughs" as defined here, and therefore, by themselves, may not lead to breakthrough innovations.

For this Brief, and drawing on multiple sources including COSAI, we identify five critical conditions deemed necessary to enable an innovation to become a breakthrough. While we recognize these are not exhaustive or sufficient by themselves, they enable us to evaluate the case studies of potential agricultural breakthroughs. The five conditions are:

1. Well-functioning, mission-oriented knowledge generation and sharing/communication systems linked to potential users and customers, driven by a clear theory of change. This is very similar to COSAI's Principle 1 (Zurek et al. 2022).

2. Collaboration among multiple local, national, and international partners, including private and public sectors, farmers, researchers, and civil society, all having a shared vision, and preferably operating through multi-sector platforms and/or farmer organizations. This goes beyond, but complements, the knowledge generation and sharing condition.

3. Supportive policies and institutions, including markets, good governance, and strategies aimed at supporting smallholders, women, and youth.

4. Sufficient and affordable long-term financing to generate game-changing innovations and scale them up and out.

5. Market demand for the product and/or potential to substantially benefit adopters, whether producers, customers, or both, through lower costs, higher incomes, or greater resilience compared to the alternatives.

Five case studies of potential game-changers

We drew the case studies from both CGIAR, a global partnership aimed at identifying and promoting transformative agricultural innovations, and ClimateShot, an action agenda to promote agricultural innovation. We deliberately chose cases that represent diverse agricultural system components where game-changers are critical to transforming our food and agriculture systems, where there has been promising progress, and for which there is sufficient experience to learn lessons and draw conclusions. The cases were chosen through consultation among professionals knowledgeable about ClimateShot and CGIAR and represent very different types of interventions and disciplines. They include soil health, crop breeding, water management, support services, and an alternative production method to traditional agriculture. We also considered the case of feed additives to reduce GHG emissions from livestock, but concluded this research, though promising, is at too early a stage to provide good insights.

None of these cases currently represents an actual game-changer, but each is a significant innovation whose experiences reveal what is needed to reach this status.

The cases are:

1. Soil health and reducing fertilizer emissions: Integrated soil fertility management (ISFM)
2. Crop breeding: Drought Tolerant Maize for Africa (DTMA)
3. Agroecological approaches and water management: Solar-powered pump irrigation
4. Digital support services: Bundled Digital Climate-Informed Advisory Services (DCAS), index insurance, and input provision
5. Non-traditional production: Alternatives to meat proteins

TABLE 1: Estimated Potential Contribution of Case Studies to Sustainable Agriculture

Table 1 estimates the potential contribution of each case to the four principles of climate-resilient, sustainable agriculture. No case contributes significantly to all four, another reason why we need multiple game-changing innovations. But each one potentially contributes either to sustainable productivity or to reducing the negative impacts of agriculture.

Cases ▼ Principles-climate-resilient, sustainable agriculture ▼	Sustainable increase agricultural productivity, incomes ▼	Reduce GHG emissions ▼	Safeguard natural resources ▼	Adapts, builds resilience to climate change ▼
ISFM	Medium to High	Low to Medium	High	High
DMTA in SSA	High	Low	Low	High
Solar irrigation	High	Medium to High	Low	High
Bundled DCAS insurance-services	High	Low	Low to Medium	High
Alternative proteins	Medium to High	High	High	Medium to High

Source: Authors' estimates

CASE STUDY 1: Integrated soil fertility management (ISFM)[1]

Soil health is a prerequisite for sustainable agricultural production. Declining soil health is a major threat to food security. ISFM is a package of components which vary based on the farming system and farmer preference. It has been developed and disseminated largely in Sub-Saharan Africa (SSA), though its principles are widely applicable. It seeks to maximise input efficiency by combining high potential seed varieties with using both organic inputs (manure, crop residues, cereal-legume combinations), precise amounts of industrial fertilizer, and a variety of soil and water management practices, preferably combined with relevant local knowledge (Vanlauwe et al. 2010; Kihara et al. 2022; Bekunda et al. 2022). Its main aim is not soil health *per se,* but to enhance agronomic efficiency (Vanlauwe et al. 2010). It is often, not always accurately, associated with conservation agricultural practices such as no-till. Because of the extreme variability of African soils, its use must be adapted to the specific soil and other local conditions as what works on one plot may not work on the next one (Vanlauwe et al. 2015). Implementation is invariably stepwise and usually partial: farmers adopt improved seeds plus some fertility management practices, depending on their farming system and access to inputs. Since its full efficacy is a function of synergies among its elements, the impact of partial adoption on productivity is often limited. Adoption of organic fertilizers often reduces the need for industrial fertilizer – a potential cost saving and contribution to reducing GHG emissions. In addition, healthy soils can also act as carbon sinks.

ISFM can reduce the need for industrial fertilizers, saving costs and GHG emissions, and contribute to creating carbon sinks through healthy soils

Most studies confirm that even partial ISFM adoption increases yields and resilience; but its contribution to improving profitability and household welfare is highly variable as it is associated with higher input and labour demand (e.g., Kihara et al. 2022; Bekunda et al. 2022). This is likely a result of partial adoption combined with limitations in local input and output markets. Recent evaluations of the actual uptake of natural resource management practices in nine countries, focusing on conservation agriculture, fertilizer trees, alternate wetting and drying of rice, ISFM, and micro-dosing of fertilizer, found low adoption rates in all the focus countries (Stevenson et al. 2019). Because of the high level of soil variability, effective implementation requires considerable agronomic understanding to adapt it to specific soils.

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ISFM tends to be more widely adopted, and more beneficial, in humid than in dry farming systems, though there are exceptions. The equity impacts are poorly understood; there may be negative social and human impacts related to labour shortages and unequal access to land and other resources (Bekunda et al. 2022). Roobroek et al. (2016) and Stevenson et al. (2019) list multiple reasons why the level of adoption is low. Despite its critical importance, there is no evidence of ISFM being scaled out on a large scale outside development and research projects. If it were scaled out, we estimate it would make major contributions to sustainably increase productivity, safeguard natural resources, adapt to climate change, and make low to moderate contributions to reducing GHG emissions.

1. We are grateful to Bernard Vanlauwe, interviewed on 27 January 2023, for providing his insights on this section. He also kindly reviewed an earlier draft and offered very useful comments, most of which have been used. However, the authors are responsible for the content.

CASE STUDY 2: Drought Tolerant Maize for Africa (DTMA)

Anne Wangalachi/CIMMYT

Maize is the staple crop for some 300 million people in SSA. It is primarily a rainfed crop. Climate change is increasing the incidence and severity of droughts, significantly reducing maize yields and threatening food security. About a decade ago, two CGIAR centres, CIMMYT and IITA, began developing new drought tolerant varieties. They were successful, and DTMA varieties were adapted and disseminated in many SSA countries. Many studies have documented its benefits: its adoption has increased yields significantly (over 150% in Northern Ghana), and reduced variability (Martey et al. 2020; Simtowe et al. 2019; Wossen et al. 2017; Lunduka et al 2019). A few studies have found that adoption is inequitable: for example, in Uganda, male farmers are far more likely than women farmers to adopt, and poor young women household heads are especially unlikely to adopt drought tolerant maize varieties (DTMVs) (Fisher and Carr 2015). In Nigeria, the adoption of DTMVs has an especially positive impact on poverty and welfare when adopted by poor farmers (Olagunju et al. 2020), showing the potential benefits of effective targeting. DTMA has been scaled out to thousands of hectares in many countries with substantial benefits and no serious downside mentioned in the literature. There is no evidence on its impact on GHG emissions or safeguarding natural resources; but it scores high on sustainable productivity increase and climate change adaptation. Whether DTMA by itself is a game-changing breakthrough is a separate issue discussed further below; but breeding new varieties for resilience, productivity and nutrition is a fundamental requirement for the future.

Studies have shown that DTMA has significantly increased yields while reducing variability

CASE STUDY 3: Solar-powered irrigation

The purchase price of solar photo-voltaic irrigation pumps has dramatically declined in the past decade, and their availability has rapidly increased as more firms are manufacturing and marketing solar pumps. Their capital cost is still somewhat higher than diesel or electric pumps using electricity from the grid, but the difference is declining rapidly. The operating cost of solar pumps is close to zero while the cost of fuel and maintenance of diesel pumps can be high, and fuel usually must be imported. Therefore, in most circumstances, the longer-term cost of solar irrigation is substantially lower than diesel pump irrigation (Xie et al. 2021; Lefore et al. 2021). Further, diesel pumps generate high GHG emissions, solar pumps none at all. The World Bank (2022) estimates solar pumps have already saved 640,000 tonnes of CO2e in SSA, equal to taking 138,000 cars off the road.

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Therefore, many research institutions, development agencies, finance institutions, governments, and private firms are actively promoting solar irrigation. In India and Bangladesh, governments are making major investments to subsidize a shift to solar irrigation. South Asia's irrigation is in the throes of a solar pump revolution. Research demonstrated their many benefits, and governments, especially in India, have responded by promoting their scaling out. Solar pumps are green, potentially saving enormous amounts of GHG emissions; reduce the oil import bill; reduce the cost of subsidizing rural electricity from the grid; and offer low-cost uninterrupted daytime power to farmers (Shah et al. 2018).

SSA countries are at an earlier stage, with growing interest by governments and a growing presence of pump manufacturers and marketers. IWMI and other research organizations are working with private firms and governments to strengthen market chains, develop innovative financing mechanisms such as "pay-as-you-go" (rent to own), and identify how to make them available to women and poorer farmers (Lefore et al. 2021).

192 million smallholder rainfed farmers could benefit from adopting solar irrigation

The World Bank (2022) estimates some 192 million smallholder rainfed farmers could benefit from adopting solar irrigation. While the potential benefits are enormous, there is also a major potential downside: indiscriminate pumping of groundwater in many places will drain aquifers and threaten long term sustainability unless managed effectively (Lefore et al. 2021). Therefore, policies need to differentiate among regions: in areas with abundant groundwater, rapid expansion can be encouraged; where aquifers are limited, incentives are needed to limit over-pumping. An example is linking solar panels to the grid and encouraging farmers to sell excess power, thus earning money by not pumping.

Nevertheless, solar irrigation appears to be a potential game-changing innovation. Its contributions to sustainable productivity increase, reduced GHG emissions, and climate change adaptation are high. Its contribution to safeguarding natural resources is mixed: intensification of production will reduce the need to expand into forests, but aquifer management is a major challenge.

David Brazier / IWMI

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CASE STUDY 4: Bundled Digital Climate-Informed Advisory Services (DCAS), index insurance and inputs[2]

For several decades, researchers in partnership with insurance companies and others have been investigating how to provide affordable, attractive crop insurance to smallholder farmers. Recent advances in processing satellite data have led to the development of index-based crop insurance, dramatically lowering the cost of insuring smallholders' crops. With index-based insurance, pay-outs are made based on a rainfall or vegetation index using satellite data for a particular season or period: if rainfall in the insured area falls below a threshold, or in the case of flood insurance, above a threshold, insured farmers (including livestock herders) are automatically compensated. Satellite technology combined with new algorithms has also made provision of real-time weather information to farmers possible, thus enabling them to adapt their cultivation plans. More recently, IWMI and other CGIAR partners, among others, have been pilot testing bundling of insurance, weather forecasts, and provision of agronomic inputs and advice (Amarnath 2019). This work has been carried out in Bangladesh, India, and Sri Lanka (Kramer et al. 2019; Amarnath 2019; Amarnath et al. 2021; Aheeyar et al. 2021); and has begun to make headway in SSA as well (e.g., Bulte et al. 2020; Syll 2021).

Returns on investments for bundled DCAS providers and farmers can be substantial: 1-to-10 to 1-to-70 for providers, and productivity and income gains of 30% or more for farmers

Bundling and cross-selling index insurance with other value-added services is key to driving uptake amongst farmers

Bundling is a recent innovation with promising prospects; indeed, bundling and cross-selling index insurance with other value-added services is key to driving uptake amongst farmers (GSMA 2020; Ferdinand et al. 2021). Returns on investments for bundled DCAS providers and farmers can be substantial: 1-to-10 to 1-to-70 for providers, and productivity and income gains of 30% or more for farmers (Ferdinand et al. 2021). We estimate bundling DCAS with insurance and other services can make a major contribution to sustainable productivity increases and adaptation to climate change; it may contribute somewhat to safeguarding natural resources (by increasing intensification), but by itself contributes little to reducing GHG emissions unless specific incentives for reducing GHGs are included. There is no data on including ISFM practices in these bundles, and minimal data for DTMVs in maize-based systems (Awondo et al. 2020), but the benefits are likely to be substantial.

2. The bundled DCAS discussion has benefitted from inputs by Giriraj Amarnath of IWMI, during an interview on 13 January 2023. However, the authors are responsible for the content.

CASE STUDY 5: Alternatives to meat proteins

Livestock, including fish and aquaculture, account for 40-50% of global agricultural GDP. The livestock and fish industries face serious sustainability challenges and livestock production is a major contributor of GHGs; in many regions, its expansion is causing deforestation and land degradation, increasing GHG emissions. On the other hand, millions of smallholder farmers depend on livestock production, and such systems are often highly productive and involve recycling resources (IPES-Food 2022).

Sustainable intensification and climate-smart agriculture practices that improve productivity while reducing emissions will help reduce traditional agriculture's footprint. However, this may not be enough without radical, complementary alternative innovations (Godfray and Oxford Martin School 2019). One option is replacing a large percentage of meat, fish, and dairy products with alternative proteins. These substitutes, if they reach a large scale, offer substantial environmental and nutritional benefits (Morach et al. 2021) while also presenting important social and economic challenges.

Several ways now exist to produce meat substitutes: insect-based, fungi-based, plant proteins, single cell bacteria-based, and lab-grown alternatives

There are now several ways to produce meat substitutes: insect-based, fungi-based, plant proteins, single cell bacteria-based, and lab-grown alternatives (in some cases, from cells derived from livestock cells). Lab-grown beef substitutes are already being marketed and are widely available in high- and middle-income countries. While not yet price-competitive, costs are coming down as quality improves, production is scaled up, and new innovations are applied. Several studies, including Godfray and Oxford Martin School (2019) and Smith et al. (2021), predict a potential "tipping point" to becoming a mainstream food in the next decade. Improved quality combined with policy interventions by governments and growing private investments may accelerate the change. On the other hand, there are trade-offs as well, given the large number of people dependent on livestock for their livelihoods. Alternative proteins are unlikely to completely replace meat and dairy (Lusk et al. 2022); indeed, it may open new opportunities for small-scale producers of indigenous crops (FCDO and CCAFS 2021), but over time, may force livestock producers to specialize in premium products and to adopt livestock management practices that reduce their carbon footprint.

Insects can be mass produced using minimal amounts of land, water, fertilizer, pesticide, feed, energy, and other resources. They are therefore promising potential alternatives for both livestock feed and human food, but the research is at an early stage (Dossey et al. 2016). Insect-based food products are available in the market, but data on their nutritional quality is sparse (Churchward-Venne et al. 2017). While some westerners may resist these, they may find easier acceptance in countries where insects are seen as acceptable food.

Alternative proteins can make major contributions to lowering GHG emissions and safeguarding natural resources; and moderate to potentially high contributions to sustainably increase productivity (e.g., by switching to producing insects at scale) and adaptation to climate change (by reducing damage to the environment by expanding meat production). They are not a "silver bullet" and are unlikely to replace livestock production; but they are likely, over time, to reach a high level of production and consumption.

Achieving Agriculture Breakthroughs: Impediments and Bottlenecks

The five cases vary in terms of the presence and strength of the conditions conducive to becoming game-changers – that is, arriving at a tipping point at which they become an attractive and widely adopted option; but none have all the conditions in place. Table 2 offers an estimate of the strength of the five conditions for each of the case studies, as "strong,", "moderate," or "weak." These are qualitative judgements based on the available literature. **ISFM** is the only case with no "strong" presence of an important condition, which may at least partly explain why it has not taken off. In both the **ISFM** and **DTMA** cases, researchers are focused primarily on the technologies themselves, while in the other three cases, researchers address, at least to some degree, both the technology and the conditions required for scaling out – indeed, the CGIAR **solar pump** researchers are primarily focused on the pathways to uptake. The rest of this section discusses the presence and strength of the five conditions, drawing on the five cases.

Prashanth Vishwanathan

TABLE 2: Estimated Strength of Conditions Critical for Breakthrough

	Knowledge generation-sharing ▼	Partner collaboration ▼	Policies, institutions ▼	Finance ▼	Market demand/ return on investment ▼
ISFM	Weak to Moderate	Weak to Moderate	Weak	Weak	Weak
DTMA in SSA	Weak to Moderate	Moderate	Moderate	Moderate	Moderate to Strong
Solar irrigation	Strong	Strong	Strong in South Asia Moderate in SSA	Strong in South Asia	Moderate to Strong
Bundled DCAS insurance-services	Strong	Moderate	Weak to Moderate	Weak	Moderate to Strong
Alternative proteins	Strong	Moderate	Moderate	Strong	Moderate to Strong

Note: These estimates are based on the authors' judgement and are intended to be illustrative.
Strong, i.e., the conditions are fully in place to promote the innovation to become a breakthrough
Moderate, i.e., the conditions are present or emerging but need strengthening to achieve breakthrough
Weak, i.e., the condition is very weak and must be the focus of attention to achieve breakthrough

Mission-oriented knowledge generation and sharing

Well-functioning, mission-oriented innovation ecosystem

We define this condition as involving a well-functioning, mission-oriented innovation ecosystem that is generating, sharing and communicating new knowledge linked to potential users and customers and driven by a clear theory of change. This condition is especially important in the earlier stages of developing, testing, and validating an innovation.

The **ISFM** and **DTMA** cases both represent the traditional agricultural research and extension theory of change for generating and disseminating innovations, especially in their early stages. However, this model has evolved over the last two decades to involving farmers from an early stage through "participatory action research" by collaborating with extension staff and farmers in testing innovations. In recent years, other partners have become involved as well. Both ISFM and DTMA were driven by CGIAR centres working with national research institutions and farmers. But neither case involved an innovation systems approach; as Hellin and Camacho (2017:112) note, an innovation ecosystem "shifts the focus from technologies in and of themselves, to a more nuanced one that recognizes the important of knowledge, collective action, and the organisational context." There is also no clear evidence of deliberate attempts to make these two innovations available to poor farmers or to women.

The other three cases, **solar irrigation**, **DCAS** bundles, and **alternative proteins**, have not followed this traditional research to extension model. All three involve collaboration among traditional researchers and private firms that stand to benefit from production and marketing of the innovation, making their theory of change more robust. The solar irrigation and DCAS bundles cases also involve government officials, extension services, NGOs, and farmers; and in both cases, attempts were made to inform and involve many other stakeholders as well, for example through workshops, thus creating effective innovation ecosystems (Minh et al. 2020). The level of participation in solar irrigation of the different actors varies among countries; for example, government officials are more actively involved in Ethiopia than in Ghana.

The **alternative proteins** case involves collaboration among researchers and private firms producing and marketing the products, with funding from venture capitalists as well as some public sources. In the **solar irrigation** and **DCAS** bundles cases, researchers have deliberately focused on how to make the innovations available and affordable to poor smallholders and especially to women.

Strong cooperation among multiple partners

Collaboration among multiple partners, including private and public sectors, farmers and researchers, and civil society, all having a shared vision

This condition involves collaboration among multiple partners, including private and public sectors, farmers and researchers, and civil society, all having a shared vision, and preferably operating through multi-sector platforms and/or farmer organizations. It is clearly related to, but goes beyond, the mission-oriented knowledge generation condition as it includes the demand partners as well, such as private firms or public agencies which will take the innovation to scale.

All five cases involve collaboration among multiple partners, but to varying degrees. We rate **ISFM** as "weak initially but moderate more recently" because, except for fertilizer companies and more recently, firms interested in legume inoculation to enhance the availability of organic resources, there is no evidence of private sector or civil society involvement in the early innovation process. It has been driven largely by international and local researchers, governments, and donors. Indeed, it is difficult to see a major role for private firms other than those marketing industrial fertilizer as

there is no other "product" to sell, and ISFM may reduce demand for industrial fertilizer. **DTMA** has involved private seed companies at the production stage in most countries, in addition to researchers, governments and donors: the seed companies play a critical role in producing and marketing the new seeds.

The private sector is a major partner in the other three innovations; solar pump manufacturers and sellers have a strong incentive to increase their sales, while insurance companies are interested in finding ways to tap the potential of the crop and livestock insurance market. In SSA, there are also cases of start-up private firms developing climate and weather information services and providing them to farmers as a service. In Zambia, CGIAR is testing helping weather service providers bundle other inputs and services, including weather information, into packages; one is focused on targeting women (e.g., Munyangeri et al. 2022). NGOs have also played important roles in promoting **solar irrigation** and **DCAS** bundles to smallholders in both Asia and Africa.

The **alternative protein** sector is very different from the other four cases. International agencies, NGOs, and in some cases governments, have begun urging citizens in middle- and high-income countries to avoid over-indulging in meat, especially beef. This has probably contributed to raising consumer interest. Researchers and private start-up firms developed and began marketing alternatives to meat products. Their business remains a niche market, but its growth has attracted more established firms as well as venture capital and more start-ups to enter the market. This in turn is stimulating more research and favourable publicity, which is attracting government interest. Governments are especially interested in the health benefits of replacing at least some meat consumption with alternatives, while international organizations continue to raise awareness of the impacts of meat production on the climate and biodiversity. Smith et al. (2021) make a strong case for public co-investment in alternative proteins. As the market develops, there will be a need for regulation as well. IPES-Food (2022), however, warns of the dangers of powerful multinational firms dominating and distorting the market for their own benefit.

Supportive government policies and institutions

Effective markets, clearly supportive government policies, good governance

This condition includes effective markets, clearly supportive government policies, good governance, and strategies aimed at supporting smallholders, women, and youth. Currently, government policy support for targeting innovations specifically to poor farmers and women is weak or absent, despite researchers', donors', and others' interest. We rate government policy support for bundled **DCAS** as "weak," though it may be improving. **ISFM** per se is generally weakly supported by policy, except that in some SSA countries, industrial fertilizer is subsidized. In South Asia, researchers found that local government institutions often did not work together. Nevertheless, the Indian Ministry of Agriculture plans to bundle DCAS services into its crop insurance scheme. For ISFM, some governments subsidize industrial fertilizer but not organic fertilizer, undermining a primary objective of ISFM. Some governments support watershed management projects that include elements of ISFM with donor assistance, but there is no evidence of strong policy support for the ISFM model.

Similarly, despite the interest of researchers, extension agencies and insurance companies, in South Asia successful pilot studies of bundled **DCAS** continue but have not scaled out, largely because of government indifference. However, donors are now interested; for example, in Sri Lanka, two major donors are looking at bundling DCAS, insurance, advice and input support through rural enterprises; multiple government departments are now collaborating. In SSA, CGIAR researchers and

others are engaging with governments and advocating reforms, suggesting there is potential for stronger support to emerge soon.

We rate government policy support for the other three cases as "moderate" but insufficient to achieve major breakthroughs. An exception is India's and Bangladesh's generous subsidies for **solar irrigation** as part of broader efforts to reduce dependence on diesel fuel imports, reduce deficits of electricity distributors (in India), and reduce GHG emissions. Some SSA governments, such as Ethiopia, have also reduced taxes on imported solar equipment. In all five cases, there is clear scope for increasing policy support to kickstart a transformation process. Although smart public-private interventions could also help accelerate a new **alternative protein** economy (Godfray and Oxford Martin School 2019; Smith et al. 2021), even more important will be government regulation to assure safety and nutritional value and to create a level playing field to enable innovative new firms to prosper.

Sufficient finance readily available

Affordable long-term financing to scale innovations up and out

Under this condition, affordable long-term financing to scale innovations up and out is available, including mechanisms to target financial support to poor farmers and women (or to poor consumers in the case of alternative proteins). The **DTMA** and **alternative protein** cases, and more recently the **solar irrigation** case in India and Bangladesh, have been supported by long-term finance. **ISFM** and bundled **DCAS** have, to date, depended largely on time-limited project or program funding from donors to develop and test the innovation. Longer-term funding for scaling agricultural innovations in developing countries is rarely available, a major reason why many promising innovations remain "on the shelf." We have noted ISFM is usually beneficial in terms of production and sustainability, but rarely sufficiently profitable for farmers to continue after researchers have left. It is unlikely to reach a "game-changer" scale without substantial long-term support from governments to farmers, including targeted subsidies. This support can be justified because soil health is a public good since the benefits accrue to the entire watershed and even beyond (Stevenson et al. 2019). Scaling it out will also require investing in capacity development of farmers so they understand its complexities and nuances, and in the use of big data, advanced analytics, and satellite-based tools to inform farmers on the appropriate mix of practices given local soil conditions (Vanlauwe et al. 2015).

Public support for bundled **DCAS** will also be required to reach a critical mass of customers. Private firms are unlikely to bear the costs of continuing to test and disseminate it without government support: it is ripe for public-private partnerships, which may emerge from current World Bank and other donors' investments. For example, in Zambia, CGIAR researchers are collaborating with small and medium enterprises (SMEs) to test an aggregator business model which now reaches 75,000 farmers. USAID has expressed interest in scaling out this program. There is evidence from an index-based livestock insurance program in Kenya that temporary subsidies can be used to introduce a new product, and once its benefits are clear, people will pay the full price to continue (Carter et al. 2022).

In South Asia, the financing available for scaling out **solar irrigation**, in the form of government subsidies and farmer investments, is substantial and likely sufficient, if continued, to transform the water-food-energy nexus there. However, we anticipate that this will further exacerbate inequities in rural areas, as there appears to be no effective large-scale effort to target poor farmers or women. It may also exacerbate threats to aquifers in some areas. In both South Asia and SSA, NGOs and researchers

are experimenting with ways to make solar irrigation available to poor smallholders and farmers, for example, through focused marketing, "pay-as-you-go", and provision of irrigation as a service by private firms. But these efforts have not attracted the level of finance needed to scale out. There is currently insufficient long-term finance available to reach a tipping point in the use of solar irrigation in SSA.

Finally, finance is not a major constraint for expanding the **alternative proteins** sector in middle- and high-income countries. Venture capital is available for new firms, while legacy firms are also beginning to invest, potentially hastening scaling but possibly at the expense of reduced competition. Finance is weak in low-income countries where it is most needed.

Strong incentives, including market demand and/or cost reduction

Strong market demand for the product and/or a potential to substantially benefit adopters

There is strong market demand for the product and/or a potential to substantially benefit adopters, whether producers, customers, or both, through lower costs, higher incomes, or greater resilience compared to the alternatives. **ISFM** is simply not profitable for farmers unless they are able to adopt a full package to enhance agronomic efficiency, while consumers are indifferent. Without subsidies, it will never become a game-changer, despite its undoubted environmental benefits. **DTMA** varieties, on the other hand, are often profitable for farmers and increase their resilience to drought, which is why they are widely grown. There is good evidence that the demand from farmers for **solar irrigation** and bundled **DCAS** is also strong as it is clearly beneficial to them. Solar irrigation is nearly always cheaper than diesel irrigation, more reliable than electricity from the grid, less labour-intensive than manual bucket irrigation, and, especially when replacing rainfed agriculture, very profitable. Real time DCAS, like weather forecasting, is attractive to farmers as it strengthens the basis for crop and input investment decisions; when bundled with agronomic advice, quality inputs, and index-based crop insurance, it reduces the likelihood of serious loss and enhances the potential for higher production and higher incomes for farmers, insurance companies, and service firms.

Firms involved in producing and marketing **alternative protein** products are either already profiting or anticipate substantial future profits. Consumers in middle- and high-income countries are increasingly aware of its nutritional benefits and the environmental costs of livestock production. As the products improve in texture and taste and diversify from beef to other meats, many predictions are highly optimistic. Godfrey and Oxford Martin School (2019) predict the next decade will see a "potential tipping point" while Morach et al. (2021) predict that by 2035, it will account for 10% of meat, eggs, and dairy around the globe. A concerted effort will be required to profitably produce and market alternative protein products in lower income countries. Alternative proteins will not completely replace meat and dairy products; rather, the expectation is they will reach a scale that accounts for a very large but unpredictable percentage of the protein market.

Innovating the Innovation System to Unlock Breakthroughs

Transformational research cannot be done effectively in the framework of a three- or five-year project

Currently, most agricultural research is aimed at improving existing agricultural systems' productivity, sustainability, or profitability. While this is valuable and should continue, by itself, this will not be adequate to meet future demand sustainably, as in most cases it is not focused on achieving game-changing breakthroughs. It is therefore critical to increase investments in, and the effectiveness of, research and development aimed at system transformation (Vermeulen et al. 2018; Hall and Dijkman 2019; Zurek et al. 2022; IEA et al. 2022). This will require a substantial increase in research on agricultural systems to identify how to break the path dependency of under-performing systems, promote major shifts in governance and resource allocation for equity, and commit to long-term, focused investments (Vermuelen et al. 2018). Transformational research cannot be done effectively in the framework of a three- or five-year project. In other words, we must transform the innovation ecosystem itself, including how it is financed, to achieve the game-changing innovations required to meet future food demand.

We have used five necessary though not sufficient conditions to analyse the potential for five innovations to become game-changers. In this section, we focus on the agricultural innovation ecosystem itself and use these conditions to identify actions needed for innovations to become game-changers that cumulatively contribute to achieving the Agricultural Breakthrough. They are based on lessons from the five case studies, complemented by the literature. The five actions are: 1) develop a vision and theory of change focused on critical potential game-changers; 2) promote strong collaboration among multiple partners and related research initiatives; 3) increase long-term financing, from research through implementation; 4) advocate for evidence-based policy reform to support innovation; and 5) implement systematic, iterative monitoring, evaluation, and learning (MEL).

A necessary condition for any innovation to become a game-changer is incentives to adopt. This is implicit in the definition of a breakthrough – it must be the "most attractive and widely adopted". Market demand can be created through demonstration and advertising for which effective communication is key.

Focusing on potential game-changing innovations based on a vision and robust theory of change

In all cases, effective communication of the benefits is critical

ISFM and **DTMA** are examples of research aimed at improving the productivity and sustainability of existing agricultural systems. This type of research is certainly valuable, but it is not always transformative and therefore will not, by itself, lead to "game-changers". In contrast, the **solar irrigation**, bundled **DCAS**, and **alternative protein** cases are potentially game-changing innovations. The work has been based on relatively robust theories of change, driven by a vision of creating profitable new businesses that in turn will both benefit consumers and result in transformation of productivity, diets, and agricultural systems. In all cases, effective communication of the benefits is critical, whether through advertising, advisory services, or other media.

As the production and consumption of **alternative proteins** reaches a large scale globally, it will have profound implications for the future of the meat, fish, dairy, and poultry industries as well as diets. Similarly, as **solar irrigation** and bundled **DCAS** reach a large scale, they will transform not only the production system but the availability and cost of food.

Collaboration among multiple partners

Effective innovation ecosystems will need to enable hyper-collaboration, involving a wide range of diverse partners

In the private sector, many innovative firms now recognize that multiple partnerships with a wide range of other actors is the key to achieving game-changing innovations. "Hyper-collaboration" is based on the belief that individual companies will not deliver novel solutions that open new markets. Effective innovation ecosystems involving a wide range of diverse partners is critical (Kolk 2018). The five "pillars" of effective hyper-collaboration are vision, strategy, navigation, engagement, and fulfilment. Fulfilling the potential of hyper-collaboration will require transformation of most organizations' governance, processes, and mindsets.

The **ISFM** and **DTMA** cases can be seen as "business as usual" approaches to research, involving a more limited set of partners than the other three cases. Recognizing the limits of this traditional approach, CGIAR is investing in broadening its partnerships. For example, a new CGIAR Initiative on Accelerated Breeding seeks to transform the crop breeding process to be more focused, include a wider range of partners, and increase the effectiveness of partnerships. This is a welcome change. The **solar irrigation**, bundled **DCAS** and **alternative protein** cases include a larger range of partners in the development, testing and scaling process than the other two cases and are indeed forcing the research institutions and other partners involved to change the way they do business.

But the four CGIAR cases share a critical limitation: to a large extent, they have been working in silos and have not fully explored potential synergies of broader collaboration. For example, combining **ISFM**, **solar irrigation**, and **DCAS** bundles most likely would produce higher returns and be more attractive to farmers than adoption of one innovation. Combining these with **DTMA** varieties in dry maize farming systems would likely enhance productivity and returns significantly. Each of these innovations has been driven by one to two specialized CGIAR centres, or in the case of DCAS bundles, a small subset of centres. Through the new One CGIAR reform process, expanding and diversifying CGIAR partnerships is underway and already creating more cross-disciplinary and multi-institutional partnerships. However, it has not yet reached the level of "hyper-collaboration."

Long-term finance

Financing research by itself is not sufficient; the entire sequence, from developing and testing an innovation to scaling it out requires adequate long-term support

Financing research by itself is not sufficient; the entire sequence, from developing and testing an innovation to scaling it out requires adequate long-term support. For some innovations, subsidies are necessary, especially if the benefits accrue to the society at large as well as to private producers or consumers. For all five cases, funding of the research per se appears to have been adequate. However, a major reason **ISFM** has not scaled out is that for most farmers, the benefits are not sufficient incentive, at least in the early stages of adoption: while production may increase, profits often do not. Further, many of the benefits of ISFM and watershed conservation accrue to individuals over too long a time horizon to be attractive to poor farmers. Therefore, there is a strong case for offering subsidies to smallholders to implement these practices. This has only rarely been done.

DTMA is sufficiently profitable for both farmers and seed companies to have gone to scale. Long-term funding enabled the research and then sharing of new varieties, and capacity building of extension staff and farmers. **Solar irrigation** in SSA and bundled **DCAS** everywhere are at a stage where, to go to a sufficiently large scale to reach a tipping point, they need far more public and private financing. Once they reach a critical level, they are sufficiently profitable to both service providers and farmers that, except for subsidies aimed at greater equity, private finance should be sufficient. In the case of **alternative proteins**, it is currently largely driven by private investments. Modest, targeted public investment could bring the sector to a tipping point faster in high- and middle-income countries (see Smith et al. 2021); but substantial public investment will be needed to complement private investment in low-income countries.

Most of the additional funding needed could be generated by re-allocating existing innovation funding

Finally, Zurek et al. (2022) note that most of the additional funding needed could be generated by re-allocating existing innovation funding. Governments could also offer incentives and partnerships to generate more private capital: there is a high potential for public-private partnerships in mission-focused transformational research (Spielman et al. 2007; Hartwich et al. 2007). The One CGIAR process is hampered because the Initiatives, as critical as they are, are being funded for just three years at a time. This forces researchers to spend scarce human and financial resources preparing proposals for the next stage.

Evidence-based policy reform

Effectively implemented government policies can make or break potential game-changers

Well-designed, effectively implemented government policies can make or break potential game-changers. Until recently, for example, most SSA countries assessed high customs duties and taxes on imported solar pumps. Relaxing or removing these after research showed the potential benefits have lowered costs significantly, thus reducing a binding constraint on uptake in Ethiopia (Lefore et al. 2019) and Ghana (Gebrezgabher et al. 2021). Evidence from pilot studies of **solar irrigation** in India, including testing a program enabling farmers to sell excess solar power to the grid, has led to major investments in subsidies by the Government of India. The PM-KUSUM program is investing billions of dollars to promote solar pumps, including replacing polluting diesel pumps, to increase productivity. Selling power to the grid creates a new revenue stream for farmers and reduces subsidies provided by state electricity entities. In neighbouring Pakistan, the government has not offered incentives for solar pumps. As a result, far fewer are being purchased, and those that are, are only purchased by larger scale farmers (Shah et al. 2018).

These examples suggest the value of supportive government policies in scaling out innovations to a game-changing level. **ISFM** has had no specific policy support, while support for **DTMA**, bundled **DCAS**, and **protein alternatives** is moderate at best.

Systematic MEL

Well-designed MEL systems monitor the innovation ecosystem itself: what is working, what are the bottlenecks, and what adjustments are needed

Until recently, CGIAR and other research institutions under-invested in systematic, timely monitoring, evaluation, and learning (MEL). Efforts were focused largely on the innovation itself and not on the process of producing, testing, and promoting the innovation. This has changed; current CGIAR Initiatives budget for MEL specialists and systematic collection of data. The data is used not only to monitor progress toward goals, but also to learn lessons as a basis for outcome and impact evaluation and making course corrections. These lessons can be valuable in developing scaling strategies (Vermeulen et al. 2018). Well-designed MEL systems monitor the innovation ecosystem itself: what is working, what are the bottlenecks, and what adjustments are needed, for example in relationships among partners, to achieve the planned outcomes.

There is little evidence on the MEL arrangements in two of the five cases (**ISFM**, **DTMA**); they appear to have depended on ex post impact evaluations. The **solar irrigation** and **DCAS** bundled research do involve more robust MEL arrangements. The **alternative protein** case is driven by the private sector, which invests in market surveys and tracking costs and benefits, including nutritional value.

Beyond strengthening MEL of agricultural innovation ecosystems, a consortium of investors has requested FAO to prepare a clear roadmap for the "Agriculture, Forestry, and Other Land Use" sector to achieve a sustainable, zero-GHG-producing global food system by 2050 (FAIRR 2022), along the lines of an IEA (2021) roadmap for the energy sector.

Effective MEL is clearly a critical tool to enhance the potential to achieve breakthroughs.

Actions to Achieve Game-Changing Agriculture Breakthroughs by 2030

We must overcome the current path dependence and push production systems into new trajectories. This means changing not only what is done, but how things are done

Given the urgency of transforming agricultural production systems, the current agricultural innovation ecosystem is no longer fit for purpose. At all levels, from local to global, our research systems are highly integrated into the current food system and are not as effective in identifying and promoting game-changing innovations as is needed. We must overcome the current path dependence and push production systems into new trajectories. This means changing not only what is done, but *how* things are done (Zeppenfeldt and Dinesh 2023). Given the high level of inequality characterizing our agriculture and food systems, technological innovation by itself is not sufficient: bundling of mutually synergistic technologies, policies and institutions aimed at transforming the power structure itself, will be required (Barrett et al. 2020).

The following four recommendations propose actions needed for innovation ecosystem transformation, aimed at driving transformation of food and agricultural systems.

Coalition for Agricultural System Transformation (CAST)

Partnerships among diverse stakeholders is a key condition for producing and promoting successful game-changing innovations. As the *Breakthrough Agenda Report* (IEA et al. 2022: 156) observes, "international collaboration can accelerate innovation by developing a wider range of options and testing them in a wider range of contexts". Building on and integrating current partnership initiatives, we recommend

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creating a *Coalition for Agricultural System Transformation* (CAST) that will include national, regional, and global research institutions, universities, NGOs, private firms, and governments. The UN High-Level Climate Change Champions, or a similar group focused on food system transformation, the Agricultural Innovation Mission for Climate (AIM4C), and the 45 leaders who launched the Breakthrough Agenda could form the political and financial core of CAST.

Its members must be dedicated to implementing innovative game-changing research and to moving research from knowledge generation to driving systemic changes. This will require a strong mission orientation, effective leadership, and a willingness to take risks and learn from failure. CAST should develop, or encourage its partners to develop, long-term transdisciplinary programs focused on specific potential game-changing innovations. This recommendation is consistent with, but goes further than, the Breakthrough Agenda Report (IEA et al. 2022).

We believe CGIAR could potentially provide leadership to CAST, but only if it undergoes further reform. Specifically, we recommend CGIAR to work with its financial supporters to introduce a set of long-term *Innovation Initiatives* aimed at producing and promoting specific game-changing innovations. These Innovation Initiatives would include an even larger set of partners – hyper-collaboration – along the entire innovation chain than current Initiatives do; and would incorporate private sector entrepreneurs and venture capitalists. They would complement Initiatives aimed at more systemic research; but the latter would also continue to be mandated to identify and pilot test potential game-changing innovations.

CGIAR also needs a mechanism to encourage cross-Initiative synergies: an important lesson is that the four CGIAR-led cases examined would achieve significantly higher impacts if they were integrated. Finally, CGIAR-led Innovation Initiatives should be complemented by others led by other parties, as is, for example, the **alternative protein** case.


C. Schubert (CCAFS)

Strong political commitment combined with sufficient, innovative financing

This includes reforms in how agricultural research and development is financed. Achieving these reforms will in turn require strong political commitment

Root and branch reform of how food and agricultural system research for development is financed and implemented at all levels will be required to achieving enough game-changing innovations to constitute an Agricultural Breakthrough. This includes reforms in how agricultural research and development is financed. Achieving these reforms will in turn require strong political commitment. The signatories to the Breakthrough Agenda have committed to collaborating for a decade; we suggest these countries could lead creating and sustaining a broader and deeper political commitment. Other global campaigns working to create commitment could be harnessed, for example AIM4C and ClimateShot, and can be asked to participate in CAST.

Huge additional sums to support research are not necessarily required; rather, it is crucial to 1) redirect how existing funds are used and allocate a larger portion to support potential game-changing innovations; 2) ensure long term, stable financial support for developing and rolling out innovations; 3) implement major reforms in how subsidies are used, including use of smart subsidies to incentivise adoption of innovations and support women and those with insufficient resources to invest; 4) create effective incentives for both existing and new start-up firms to invest; and 5) reform local agricultural credit systems to support uptake of innovations. This is a daunting agenda, politically challenging in many countries, but essential for success.

Policy and governance reforms to support market-based innovation and achieve social equality

Recommending radical, evidence-based policy and governance reform is easy; it is found in nearly every study related to climate change and agricultural transformation. But radical reforms are fiendishly difficult to implement. Nevertheless, it is a necessary condition to transform the agricultural innovation ecosystem and financing and to achieve equality and social justice goals. Current policies reflect and support the distribution of power: those who benefit most have the strongest capacity to make or prevent changes. Subsidies that benefit vested interests at the expense of the poor and the environment will not be easily reformed.

Food and agricultural systems are inherently complex, and policies enacted by multiple ministries have impacts far beyond their intended target. Therefore, it is not only the ministries in charge of agriculture, climate change and environment whose policies count; those of the ministries in charge of finance, industry, and others may also need to be reformed. For example, the private sector is a critical partner in agricultural transformation. Therefore, policies on taxes and tax exemptions will affect their participation. Similarly, policies made at central levels often need to be adapted to local conditions. Re-aligning public subsidies to accelerate private start-ups and entrepreneurs to invest can support a re-alignment of the balance of power, leading to designing appropriate support services and upscaling of new technologies.

Despite its difficulty, radical policy and governance reform can often be achieved

Despite its difficulty, radical policy and governance reform can often be achieved. It requires considerable political commitment, including a willingness to strategically sacrifice some social capital. But in most instances, imposition from the top will not work. There are multiple techniques that have been shown to be effective in various contexts. Usually implemented by researchers, NGOs, and civil society organizations, these include socially inclusive, facilitated multi-stakeholder processes to imagine possible alternative futures and to inspire action. There is a growing set of scenario development and foresight analysis methodologies that show great promise (e.g., Wiebe et al. 2018). But building future scenarios through facilitated processes among interested stakeholders often fail to pay sufficient attention to the role of power in transformations. "Disruptive seeds" is a recently tested scenario approach that integrates power shifts that are required for sustainable transformation and helps build strategies that directly address power imbalances (Rutting et al. 2022).

These processes may reveal conflicts, but also enable co-production of new policies, or lead to new strategic alliances among parties with a shared interest in system transformation. Success is not guaranteed; as Pereira et al. (2023: 125) note, "it nevertheless remains unclear how issues such as the elite capture of benefits can be addressed, including issues of gender and other socio-economic inequities." But inaction is also not an option.

MEL: Global roadmap to 1.5˚C, nature and nutrition security goals

Building effective MEL into the implementation of research and development is essential. MEL systems must include monitoring progress on the four principles of climate-resilient, sustainable agriculture: sustainably increase agricultural productivity and incomes; reduce GHG emissions; safeguard soil, water resources, and natural ecosystems; and adapt and build resilience to climate change. MEL is required at other levels as well. For example, how will we know whether research programs are on track to contribute to both sustainable food security and reduction of GHG emissions and land degradation? Given the high level of GHG emissions from the food system and the role of agriculture in destroying biodiversity, limiting climate warming to below even 2˚C is not possible without reducing agriculture's roles. This is why a group of investors with USD 18 trillion in assets recently requested FAO to provide a global roadmap for agriculture to 2050 that will mitigate risks and set standards for the industry. FAO is currently working on this; it may be available in time for COP 28 in 2023 (FAIRR 2022). Such an agricultural roadmap could provide a useful framework for designing Innovation Initiatives; their MELs can show how each Initiative is designed to contribute to one or more of the roadmap goals.

Final observations

Humankind simultaneously faces multiple complex challenges, including war, aging populations, unemployed youth, and growing socio-economic inequalities. Underlying all of these are the growing threats to the critical planetary systems that support life as we know it. The challenges facing our food and agricultural systems are related in diverse ways to these challenges. Therefore, transforming our food and agricultural systems to be productive, sustainable, and equitable, and to contribute fully to lowering GHG emissions is a pre-requisite to solving other challenges. We believe visionary effective leadership can enable humankind to meet these challenges, but time is short. With this Brief we aim to raise awareness and inspire action.

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CGIAR:

The CGIAR Initiative on Climate Resilience, also known as ClimBeR, aims to transform the climate adaptation capacity of food and agricultural systems in low- and middle-income countries. Its goal is to tackle vulnerability to climate change at its roots and support countries as they adapt and build equitable and sustainable futures.

Clim-Eat:

Clim-Eat is a think-and-do tank for climate and food. We seek to be a bridge between the food and climate communities, mobilizing knowledge and connecting it to action through policy and practice.

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