Future-Proofing Food for a Rapidly Warming Planet

Financing Food for the Future

December 2024

NATURE FINANCE

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Our use of Fibonacci sequence imagery is inspired by the association of this unique ratio with the maintenance of balance, and its appearance everywhere in nature- from the arrangement of leaves on a stem to atoms, uncurling ferns, hurricanes and celestial bodies.

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Glossary

AATIF	Africa Agriculture and Trade Investment Fund
AfDB	African Development Bank
BEVs	Battery electric vehicles
CO_2	Carbon dioxide
COP	Conference of the Parties - often refers to the United Nations Framework Convention on Climate Change
CAPEX	Capital expenditures
EEA	European Environment Agency
EU	European Union
EVs	Electric vehicles
FiT	Feed-in tariff
GDP	Gross Domestic Product
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IoT	Internet of Things
IP	Intellectual property
KPI	Key Performance Indicator
NGOs	Non-governmental organizations
NRF	National Research Foundation
NUE	Nutrient use efficiency
OPEX	Operating expenses
PV	Photovoltaic
RAFT	Resilient and adaptive techniques- term created for the purpose of this report
REDD	Reducing emissions from deforestation and forest degradation in developing countries
R&D	Research and development
SBCE	Brazilian Greenhouse Gas Emissions Trading System
SFA	Singapore Food Agency
UNEP	UN Environment Programme
USAID	United States Agency for International Development
VF	Vertical Farming
WFP	World Food Programme

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Foreword

Harnessing the Crisis

In October 2023, in the run up to COP28 in Dubai, NatureFinance published **"Time to Plan for a World Beyond 1.5C"**.[1] The insights piece reinforced the call made by many others to consider more ambitious action to slow down and reverse climate change and nature loss in order to establish viable plans to live in and adapt to a severely climate disrupted world. Crucially, we suggested that the growing realisation that we are failing to remain below safe limits of climate change must catalyse greater will to advance unconventional actions that had to date been considered beyond what is feasible or necessary.

We pointed to examples of such unconventional action in the face of certain types of crises, often in times of war and other disasters, including most recently responses to the 2008 Financial Crisis and the COVID pandemic.

Responses to our provocation were, unsurprisingly, mixed. At one end of the spectrum were those who condemned us for being unhelpfully pessimistic, disloyal to the cause of ambitious action on climate and nature, or worse. At the other end of the spectrum were those who applauded our courage in calling time on the lack of realism about where we are almost a decade on from the auspicious Paris Agreement on climate, and appreciation of linking this recognition with the potential for more radical action on adaptation and resilience.

Common across the entire spectrum was a deep concern that being so far from where we needed to be on climate or nature was already triggering perverse responses, fomenting fear, despair and cynicism, diminishing policy ambition, and empowering those whose interests were not aligned with ambitious action on the climate-nature nexus or solidarity with those most impacted.

Moreover, there was an absolute consensus that such dynamics needed to be resisted at all costs, requiring effective communication about *believable pathways for action in a world warming beyond 1.5°C* rather than just continued statements of hope for what people should do.

Focus on Food

Building on this initial thinking, NatureFinance started to apply a 'beyond 1.5° C' lens to its own work. We chose not to focus on solutions that needed grand political compacts or ambitious international arrangements. Instead, we chose to focus on the potential for unilateral or perhaps plurilateral blends of policy, market, and civil actions borne out of any combination of nature and climate ambition, fear, solidarity, and self-interest.

Food is an obvious candidate to focus on through a 'beyond 1.5° C' lens. Accessible, affordable, nutritious food is a pre-requisite for any just transition. A severely climate disrupted world places food supplies at increasing risk. Most obvious are the physical impacts of climate change on food security. Beyond that are major transition risks, such as policy changes, technology shifts and changing consumer preferences, often with a long tail that brings forward and amplifies future physical impacts into the present.

Fears in food exporting countries of domestic food security problems are already resulting in export restrictions that has snowball effects on the availability and cost of staples in international markets. Such long tail dynamics has a particularly negative impact on low and middle income, food importing countries that cannot afford to buy food at inflated prices on international markets.

The question is 'what is to be done' to ensure food security in a worsening climate scenario, or when markets and policy makers build in expectations of such a scenario into their decision making. Short term measures must include humanitarian food assistance, but the scope and scale of the need is already far outpacing the international community's ability to respond. Today, already more than 350 million people are dependent on food aid. The number in need can only be expected to increase dramatically without radical changes to the global production and management of food.

The trillion-dollar question is what longer term measures could be *initiated now* that might meet the challenges of food security in an increasingly climate disrupted world, and how can we sufficiently scale such measures in advance of a foreseeable crisis? Of course, there is no one silver bullet solution. Many actors are engaged in trying to figure out and implement local, national and international approaches, embracing the complex blend of approaches needed, which range from production, technological, market, policy, and consumption aspects to solutions explicitly focused on equity and solidarity.

This paper seeks to contribute to addressing the existential challenge of advancing food security for all in a severely climate disrupted world. It explores the financial innovations needed to rapidly ramp up capital intensive, climate resilient food systems now in order to deliver affordable nutrition to low and middle-income countries in the years to come. Given the early-stage, speculative nature of the work presented here, we look forward to using it as a basis for continued engagement, debate and experimentation.

Executive Summary

Securing adequate access to affordable, nutritious and sustainable food in a rapidly warming world is one of the most important needs for a just transition.

Scientific consensus is increasingly aligned around the near certainty that the world will overshoot its 1.5°C warming target, with 80% of IPCC scientists putting the number at between 2.5 - 3°C of warming by the end of the century. Extreme drought, heat and heavy rain have dramatically affected the production of crops like soybeans, olive oil, rice, potatoes, and cocoa in regions from the Mediterranean and Eastern Europe to Southern Africa and Latin America.

Across the world, the long-tail effects of severe weather events, shifting growing seasons, trends towards food nationalism, and ongoing geopolitical conflicts are compounding food security challenges. Today's disruptions however are only the beginning. As global warming intensifies, increasing land degradation and water scarcity will continue to accelerate a breakdown in globalised food supply arrangements and diminish local-for-local food production in many parts of the world.

Low and middle-income nations, which are often critical food producers are especially vulnerable to the compounded effects of climate change and nature loss. As their ability to produce food declines, economic fragility deepens, leaving them less equipped to adapt. *Creeping desertification, particularly in vulnerable regions, is already fuelling conflict, creating agricultural pressures, and exacerbating food insecurity as migration and displacement increase*. Globally, extreme weather now accounts for one-third of acute food insecurity shocks, affecting over seventy million people, a number that has more than doubled in five years. These nations are caught in a cycle of vulnerability, at risk of being left behind as food insecurity escalates. In addition, traditional food exporters tend to secure their national security needs first, causing trade disruptions due to pricing hikes and lack of availability.

As the planet edges toward these extraordinary temperature thresholds, the global food system faces mounting challenges from climate change, nature degradation, and geopolitical instability. Addressing these issues requires a dual strategy: scaling innovative food technologies while embracing regenerative farming practices.

Regenerative agriculture is an essential part of the solution, but not sufficient.

Regenerative agricultural practices play a pivotal role in restoring, sustaining and extending the life of food systems by restoring soil health, enhancing biodiversity, improving water retention, and promoting ecosystem resilience. Regenerative agriculture also contributes enormously to climate mitigation efforts by transforming croplands from significant sources of carbon emissions into net carbon sinks. As temperatures begin to increase beyond 1.5°C, regenerative agriculture and related technologies must continue to play a central role in everything from food security and livelihood strategies to climate mitigation, adaptation and resilience efforts.

That being the case, as extreme weather patterns intensify and warming accelerates, the viability of soil-based agriculture will decline in certain parts of the world where reliable access to arable land and water is severely diminished. This is particularly true for the tropical belt countries from the Americas, passing through Africa to Asia. For these parts of the world, regenerative agriculture can be part of a bridge solution, but from a food security and adaptation perspective, these countries will need additional food sources supplied from controlled environment food production systems to meet their basic needs.

Technological innovation on ‘soil-less’ food production will become central to ensuring food security in a warming world.

Resilient and adaptive food production will need to move beyond soil-based regenerative farming to increasingly rely on enclosed and “controlled environment” food production systems such as vertical farming, edible insect farms, and cultivated meat. Such solutions offer the promise of year-round ‘climate independent’ production, stable costs, as well as localised production that improves security of supply and reduces waste and other supply chain costs.

Deploying these technologies is fraught with challenges.

These systems are extremely capital intensive and technologically complex, presenting significant challenges for many low and middle-income countries that are most vulnerable to permanent soil-based agricultural disruption in a world warmed beyond 1.5°C. Such solutions remain technologically immature and expensive and are likely to remain so for some time, resulting in high costs of production, with considerable investor caution given technology transfer or development and other associated risks.

Adopting such solutions is particularly challenging for low and middle-income countries. Citizens' relatively lower purchasing power is a core reason, but this problem is exacerbated by higher costs of capital and under-developed enabling policy, competencies, and hard infrastructure. Moreover, the lack of adequate technology transfer heightens the risk of dependence on high or middle-income countries, raising concerns about technological neo-colonialism. This could lead to situations where low-income nations are compelled to offer access to critical resources in exchange for technology, limiting their sovereignty and making them reliant on external providers. In addition, alongside the specifics of adoption are the broader challenges of transitioning the often large numbers of small farmers and dependent communities away from their current livelihoods. This is especially a concern given that many forms of controlled environment food production are far less labour intensive than traditional soil-based agriculture, and in some instances require a much higher level of technical training. The fragile supply chain infrastructure is another barrier.

Given these challenges, it is likely that controlled environment food production will have the greatest chance of being scaled up in the near term in middle income, climate and nature vulnerable countries such as Brazil, India and South Africa. These countries have enough of the early building blocks to begin pivoting away from reliance on conventional agriculture alone as well as the capacity to serve as regional suppliers for less well-positioned neighbours.

It is essential to quickly bring down the cost of nutrition delivered by capital intensive, climate resilient food systems.

The evolving cluster of soil free, controlled environment food production systems require extensive R&D to drive down costs, alongside the productivity and cost gains from operational learning and economies of scale. NatureFinance has estimated the total R&D investment needed to drive down costs to parity with food costs in higher income countries for a selected set of food technologies to be in the order of US$30-65 billion over the next 10-15 years (see Table 1).This is a modest sum compared to the over US$7 billion in public subsidies that support conventional agriculture each year, or the US$1.3 trillion in explicit fossil fuel subsidies, as reported by the IMF. Notably, when including implicit subsidies—such as unpriced environmental and health costs—the total for fossil fuel subsidies rises to a staggering US$7 trillion annually. Economies of scale might reduce the financing gap needed to drive down costs, especially if middle income countries can become reliable producers not only for domestic but also for regional food production needs. Regulatory frameworks, public policies and trade rules will need to be aligned to incentivise these practices alongside cultivation of transnational solidarity.

Financial innovation will be key to scaling these solutions globally.

Financial innovation will be critical to enable investments to advance at the scale required even during this early period of uncertainty. A comparable example is Germany's use of the feed-in tariff, introduced with considerable controversy, to finance the scaling of renewable energy early in the innovation curve. This instrument lowered the purchase price of green energy by spreading the costs and de-risking investments when they were still high-cost options with considerable associated technology and policy risks.

There is no one-size-fits-all equivalent for scaling capital intensive, controlled environment food production. However, we have identified a cluster of financial instruments, such as nature and carbon credits, performance-linked financing and tax credits, that can be bundled and stacked into standardised financing packages according to specific technologies and contexts. Using such approaches, it would be possible to simultaneously attract scaled private investment, make efficient use of public funds, and lower the cost of delivered nutrition in the context of building out controlled environment food production systems.

Deploying capital intensive, food innovations will require a combination of national strategies and international cooperation.

Financial innovation is needed, but as the case of renewables demonstrates, it is not sufficient on its own. Consequently, there is a critical role for middle and upper-income countries to drive down the costs of these solutions as part of their food security and competitiveness strategies, as well as international cooperation to enable low and other middle-income countries to harness these developments at an affordable cost.

Several technologically developed countries, notably China, but also smaller countries such as Singapore, are already investing heavily in resilient and adaptive food production techniques. Most directly, this is to support their food security goals in the face of growing climate, nature and geopolitical insecurities in global food chains. For China, however, as well as potentially other technically minded countries, these investments and scaled deployment are part of a broader industrial strategy to secure competitive opportunities in future exports of technologies and, more broadly, in climate resilient food production. This opportunity also exists for major food exporters such as Brazil, Europe and the United States. However, these regions face the added challenges of pivoting their massive agribusiness sectors; akin to Germany's challenge of transitioning its automotive industry in the face of policy driven global shifts in mobility technologies.

For climate vulnerable low and middle-income countries, there are significant potential benefits from the national strategies of other countries that drive down the cost and maturity of capital-intensive solutions. International cooperation will, however, remain an essential pillar for such solutions to become a material part of effective food security strategies for low and middle-income countries. Given the accelerating pace of climate change impacts and ecosystem degradation, deployment of these solutions must front-run a decline in the cost curve. Without international co-operation, it will be nearly impossible to secure the affordable transfers of technology, the localisation of technology production, as well as the enabling policy and broader capabilities required to transition farming communities vulnerable to climate-impacted food systems and environmental decline.

Low-income countries will suffer the most from climate-elicited food insecurity, having played no role in creating the crisis, and they are least well positioned to respond to it with high-tech, capital-intensive solutions. Prioritising solidarity in the financing of these technologies is of key importance. Financing and technology transfer will, therefore, need to become embedded in the work of multilateral development banks, bilateral and multilateral aid agencies, and potentially new mechanisms like the “global solidarity levies” currently being explored for COP30.

Embracing the implications of beyond 1.5°C warming for food security now is crucial.

A fundamental shift in mindsets is now needed that embraces the lived experience of many countries and communities which acknowledges the scientific consensus that the planet will likely warm well beyond 1.5°C. While the world works towards a best-case warming scenario through mitigation efforts, we must devote equal attention to investments in adaptation and resilience for existentially critical areas like food security.

Beyond the indispensable push on regenerative agriculture, which has value both for mitigation as well as adaptation/resilience, many parts of the world will need more dramatic, non-soil based alternative sources of food to sustain human life in the coming decades. Unlike the energy transition pathway, which will be challenging but is well understood, the food security transition pathway remains dangerously unclear and slow moving. New innovative thinking is needed as the basis for overcoming the current path dependent inertia.

Embracing an Integrated Approach to Financing a Resilient, Adaptive Food Future.

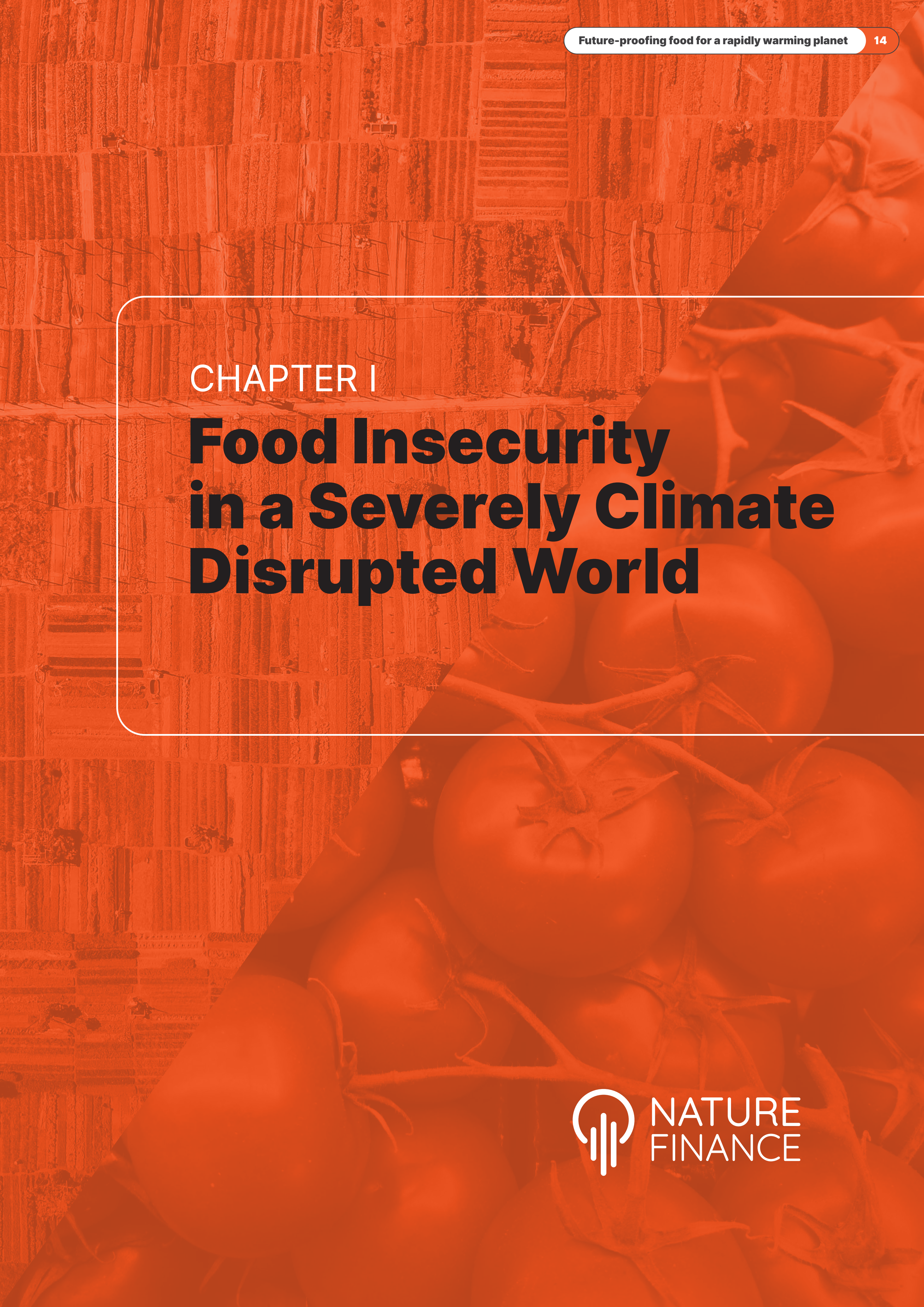
In certain regions, the traditional agrarian model that has sustained human civilisation for millennia may indeed no longer be viable in its traditional form. As extreme weather patterns intensify and resources like arable land and water become increasingly scarce, communities will face significant disruption. While drought-resistant crops and longer growing seasons may offer temporary relief, the shift to controlled environment agriculture will need to be an important part of the toolkit to sustainably address food security globally. This development must be inclusive and adaptable, accounting for the diverse realities and limitations faced by different regions.

This paper seeks to illuminate the pressing need for bold, out-of-the-box thinking to address the unprecedented challenges of food security in a world increasingly disrupted by climate change and nature degradation. While regenerative agriculture has been widely studied and documented, comparatively little work has been done to explore the financial scaling of controlled environment solutions for middle and low-income countries. This stands in contrast to the progress made in advancing regenerative agriculture in these areas. As such, this piece has been created to contribute to this critical discussion that must be brought to the forefront, particularly as we face ongoing climate realities and ecosystem degradation.

The urgent task ahead is to scale up both regenerative agricultural practices, where they remain feasible, and also controlled environment food production systems in regions where soil-based agriculture is no longer reliable. These two approaches are not mutually exclusive; rather, they are **and must remain** complementary, forming the backbone of a resilient global food system. Regenerative practices help restore ecosystems and build climate resilience, while controlled environment systems ensure stable food production in more extreme environments. Together, they represent a multifaceted strategy that responds to the varying impacts of climate change across regions. Achieving this transformation would require coordinated efforts across governments, the private sector, multilateral organizations, and civil society to mobilize resources, drive innovation, and ensure equitable access to solutions.

The worst-case scenario would be for finance to suddenly fetishise the potential of controlled environment agriculture and neglect an equally ambitious and desperately needed drive to scale up regenerative agriculture and related extension services. Both need to happen together, and shifting resources away from regenerative agriculture to controlled environment agriculture would be disastrous for people, climate, and nature.

The future of food security lies in embracing an integrated approach to sustainable, affordable and accessible nutrition—one that balances nature-based solutions with technological innovation, ensuring both environmental sustainability and the capacity to feed growing populations. Today's major food producers—such as Brazil, India, China and the United States—stand to become the main beneficiaries of proactively addressing these transition challenges. Firstly, this is because they have greater access to the substantial capital required to lead a transition of this scale. Secondly, because they have a strong understanding of the related risks and opportunities that will accompany it, and the capacity to deploy meaningful policy and regulatory incentives to address them. Thirdly and finally, they shape the market and play an important orchestration role in the broader global community. Political leadership and international cooperation in the exploration of scalable financial innovations will be crucial. Only through a concerted global effort can we create a resilient, adaptive, and just food system capable of withstanding the mounting challenges of a warming world.



CHAPTER I

Food Insecurity in a Severely Climate Disrupted World

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"How many harvests you have left [is largely dependent on] how we get our food production in tune with the realities of this,"

Dr. Martin Frick

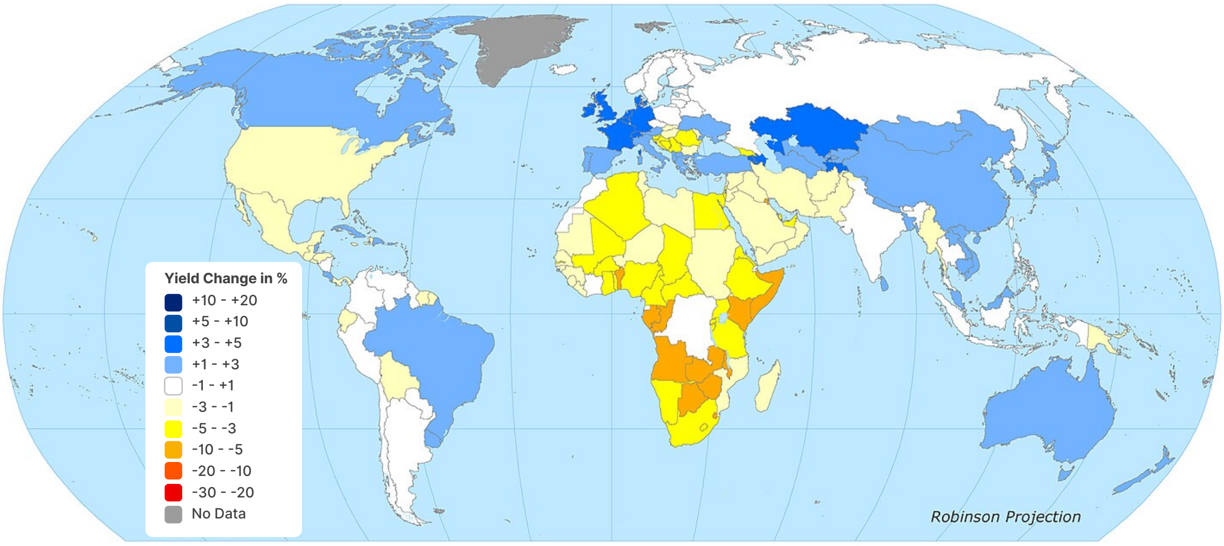
Director, World Food Programme

The world is currently grappling with a severe food security crisis which is being caused and compounded by the combined impacts of climate change, nature degradation, and global political instability.

According to a recent report by the UN Environment Programme (UNEP), the world is on track for a temperature rise of up to 2.9°C above pre-industrial levels by the end of this century[2] — almost double the target set by the 2015 Paris Agreement. An extensive survey of 380 scientific notables reported that 77% of respondents believe global temperatures would reach at least 2.5°C above preindustrial levels, a devastating degree of heating.[3] Almost half of the respondents, around 42%, thought that temperature rise above the benchmark would exceed 3°C. This rapid warming is a major threat to agriculture, one of the most climate-sensitive sectors.[4,5] Rising temperatures and more frequent extreme weather events such as droughts and floods are already disrupting harvests, causing significant shortages in some of the world's most consumed crops.[6,7,8] The evidence remains anecdotal or at least ad hoc, with many challenges in untangling the attribution of crop damage and supply shortages to climate change.[9]

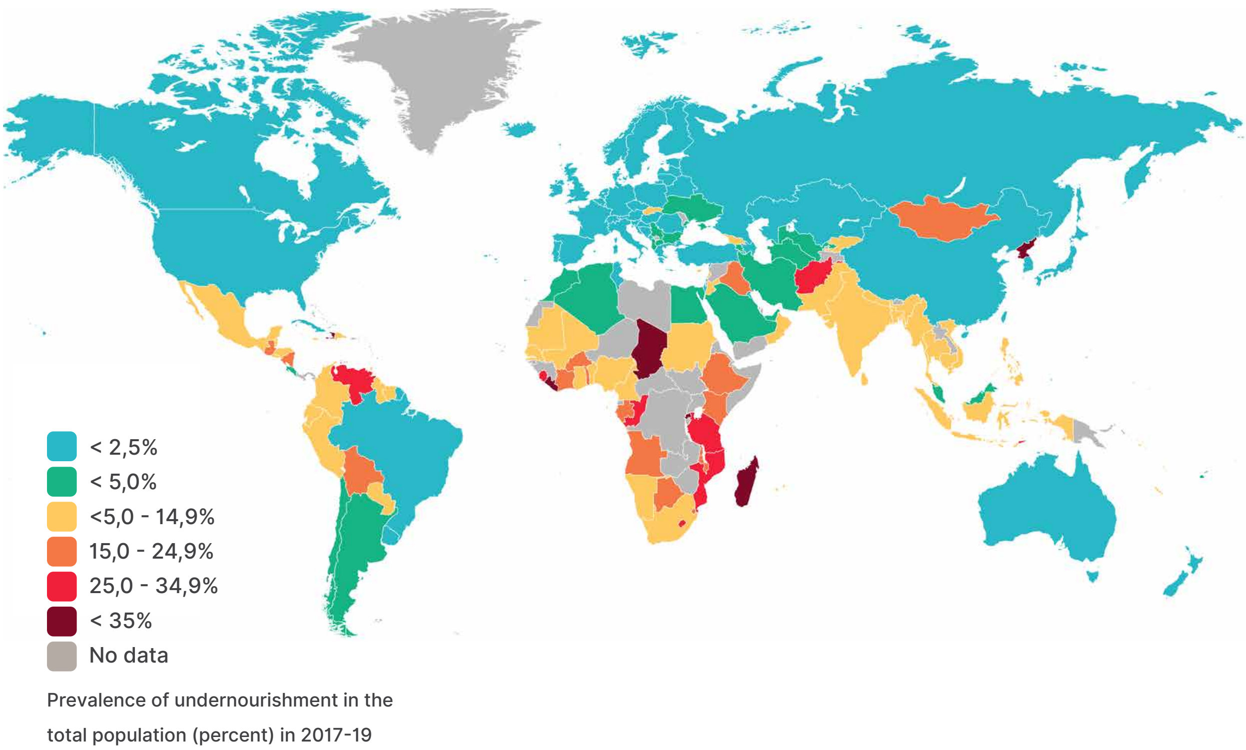
Despite these analytic limitations, the direction of travel is clear. Cocoa prices have hit a global high, especially as crops in West Africa have been impacted by dry weather. Olive oil prices have likewise hit an all-time high, with average temperatures in key producing countries like Spain up by between 2.5°C and 4°C. Rice prices in Asia have soared to their highest levels in more than two years due to expectations of a dry season, whilst heavy monsoon rains in India damaged the country's rice crop.[10]

Figure 1 Projected % change in weighted average yield for grain crops – (1970-2000 baseline to 2080)



Source: NASA's Earth Observing System Data and Information System (EOSDIS)[11]

Figure 2 World hunger map - If current trends continue, the number of hungry people, as defined by the World Food Programme, will reach 840 million by 2030



Source: The World Food Programme (WFP) Hunger Map[12]

Compounding the food security crisis are unpredictable political and economic factors that further drive food instability.[13, 14] The Ukraine/Russia war, a conflict between two major global food producers, has drastically reduced agricultural exports, pushing up food prices, as well as the price of fertilisers many producers rely on to grow food.[15, 16, 17] The World Food Programme (WFP) recently reported an unprecedented crisis of 309 million people facing chronic hunger in 71 countries, the primary drivers of which are global conflict, extreme weather, rising fertiliser prices and trade disruption.[18]

Climate change and food scarcity are already driving nations towards food sovereignty measures. In 2023, India implemented a ban on non-basmati rice exports, driven by concerns that the combined effects of El Nino and global warming could disrupt production. This embargo significantly affected supply chains, exacerbating food insecurity in countries such as Indonesia that depend on imported rice. Such measures highlight how weather extremes can trigger sudden policy change, often with little or no notice and deeply harmful consequences for dependent nations.[19, 20]

The detrimental impacts on agriculture caused by the interlinked climate and nature crises, combined with geopolitical conflict, are most evident in the Global South, where food security affects millions of lives (Fig. 1 and 2). For instance, the ongoing drought in the Horn of Africa is jeopardizing food security for over 23 million people.[21] Globally, extreme weather now accounts for one-third of acute food insecurity shocks, affecting over 70 million people—a number that has more than doubled in five years.[22] In addition, creeping desertification shifting down from the Sahel is driving conflict, creating additional pressures on agriculture in West & East Africa as well exacerbating risks for food security because of migration.

As the world grapples with the twin challenges of climate change and global supply chain disruptions, often exacerbated by agroecosystem decline, ensuring that everyone has access to healthy, affordable food is becoming increasingly complex.

The agriculture industry has made notable strides in boosting efficiency, with advances in technology and regenerative farming methods (see Box 1) leading to higher yields and a smaller environmental footprint.[23, 24, 25] Maintaining or even increasing our efforts in the development of climate resilient soil-based agriculture – whether via technology or regenerative practices – remains an absolute necessity. However, the current rate of improvement may soon prove insufficient, particularly in regions where water and arable land are becoming ever scarcer.[26, 27, 28]

The looming threat of resource depletion—particularly for climate and nature vulnerable countries in the global south—demands not just innovation but a comprehensive rethinking of how we approach food security on a global scale.

Box 1. Prioritizing Regenerative Agriculture alongside newer Resilient and Adaptive Food Techniques

Regenerative agriculture is increasingly recognised for its transformative potential to enhance ecosystem health, boost productivity, and foster economic prosperity. Wide-ranging benefits include:

Climate Mitigation: One of the standout advantages of regenerative agriculture is its capacity to reduce greenhouse gas emissions. By employing techniques such as no-till farming, cover cropping, and agroforestry, these practices turn farmlands into carbon sinks, effectively capturing CO_2 from the atmosphere. Research indicates that regenerative farming can sequester between 1.5 to 2 tons of CO_2 per hectare annually.[29, 30] This carbon capture potential can significantly contribute to global emission reduction targets, potentially offsetting emissions equivalent to those produced by millions of cars. Additionally, the improved soil structure resulting from these methods enhances resilience against climate shocks such as droughts and floods, making crops more robust in an era of increasing climate unpredictability.

Enhanced Soil Health: Regenerative farming methods dramatically improve soil health, which is crucial for sustained agricultural productivity. By increasing biomass production, these practices replenish soil organic matter, preventing degradation and erosion. Studies show that regenerative agriculture can enhance soil organic carbon levels by up to 20%,[31] resulting in healthier soil. The preservation of soil health is not just a sustainability imperative but an economic one, as it reduces the need for chemical fertilisers and intensive soil management, cutting long-term costs for farmers.

Resource Use Efficiency: Resource efficiency is a hallmark of regenerative agriculture. Higher nutrient use efficiency (NUE) optimises land use, improving crop yields and reducing input costs. Importantly, water use efficiency is significantly enhanced, reducing stress on freshwater reserves—an increasingly critical issue in many regions. Farms employing regenerative techniques can see water retention in soil increase by up to 40%,[32] a crucial adaptation as water scarcity becomes a more pressing concern worldwide.

Boosting Biodiversity: The emphasis on crop rotation and reduced pesticide use creates environments that support richer biodiversity. This approach fosters diverse plant and animal life on farms, which helps restore ecological balance and improves overall farm resilience. Pollinator species, which are essential for many crops, can increase up to 400% under regenerative practices compared to conventional farming.

Economic Prosperity for Farmers: The economic benefits of regenerative agriculture are profound. By reducing reliance on chemical inputs and enhancing yields, farmers can lower costs and increase profitability. This, coupled with the improved quality of produce and enhanced resilience to climate-induced crop failures, strengthens farmers' livelihoods. Regenerative practices also pave the way for new revenue streams, such as payments for carbon capture and storage, opening pathways to diversified income sources. These opportunities support long-term economic stability for farming communities, making regenerative agriculture not just an environmental strategy but a pathway to rural prosperity.

In conclusion, regenerative agriculture is a multifaceted solution to some of the most pressing challenges in modern agriculture including aligning ecological sustainability with economic viability, offering a model where productivity, environmental stewardship, and farmer welfare go hand in hand. The shift to regenerative practices is not only an investment in the environment but a step toward a more resilient and prosperous agricultural future.

The development of regenerative agriculture is essential for addressing both the climate-biodiversity crises and global food security. Although scaling regenerative practices presents financial challenges—particularly in terms of access to credit and insurance products designed for transition risk—its broad benefits to society and the environment make it an invaluable approach. Regenerative must continue to receive the adequate support to become the new norm of conventional agriculture, while we also look to supplement and, in some cases, replace it with newer technologies and approaches where it becomes impossible as a primary production source.

Financing Technological Innovation for Food Security in a World beyond 1.5°C

As the planet edges towards higher rises in temperature, the global food system faces mounting challenges from climate change and biodiversity loss, resource depletion, and geopolitical instability. Addressing these issues requires a dual strategy: scaling innovative food technologies while embracing regenerative farming practices.

Cutting-edge solutions like vertical farming, lab-grown proteins, and precision agriculture promise to boost yields, reduce resource dependency, and adapt to shifting climates. However, these technologies are capital-intensive and require significant policy-backed investment to achieve global scale.

Regenerative agriculture, meanwhile, restores ecosystems by improving soil health, increasing biodiversity, and sequestering carbon. These practices make farms more resilient to extreme weather and provide sustainable livelihoods for rural communities.

Together, these approaches form a resilient food security framework. High-tech systems address urban demands efficiently, while regenerative methods safeguard rural agriculture and ecological balance. To succeed, this model demands international cooperation and targeted financing to scale innovations and support sustainable farming.

In a warming world, this dual strategy is essential to securing equitable and sustainable food systems. By combining technological advancements with nature-based solutions, we can turn the challenges presented by climate change and nature loss into opportunities for global resilience and prosperity.

This paper explores ways to overcome this vicious cycle by introducing suitable policy supported financing arrangements. Financing is clearly not the only challenge to overcome. However, as the case of renewables illustrates, having the right financing arrangements in place to drive scaling up early in the technological maturity curve, can be a keystone in overcoming other challenges. What this paper does not explore are the merits of diverse possible food production technologies. In this sense, the proposition is restricted to the three-part hypothesis that:

Scaled capital intensive solutions of some kind will be needed.

These solutions need to be scaled up now in advance of the anticipated significantly worse climate and nature disruptions to come.

Policy-enabled financing innovations will be needed to make this possible.

The following sections therefore offer a:

Brief review of the evidence concerning the magnitude of climate disrupted food production including long tail transition effects.

Highlights of some of the more radical food technology solutions that might need to be deployed in parts of the world largely devoid of useable soil and water for food production.

Consideration of the bundles of financial instruments that might be standardised and used in supporting the early scaled use of such food production technologies.

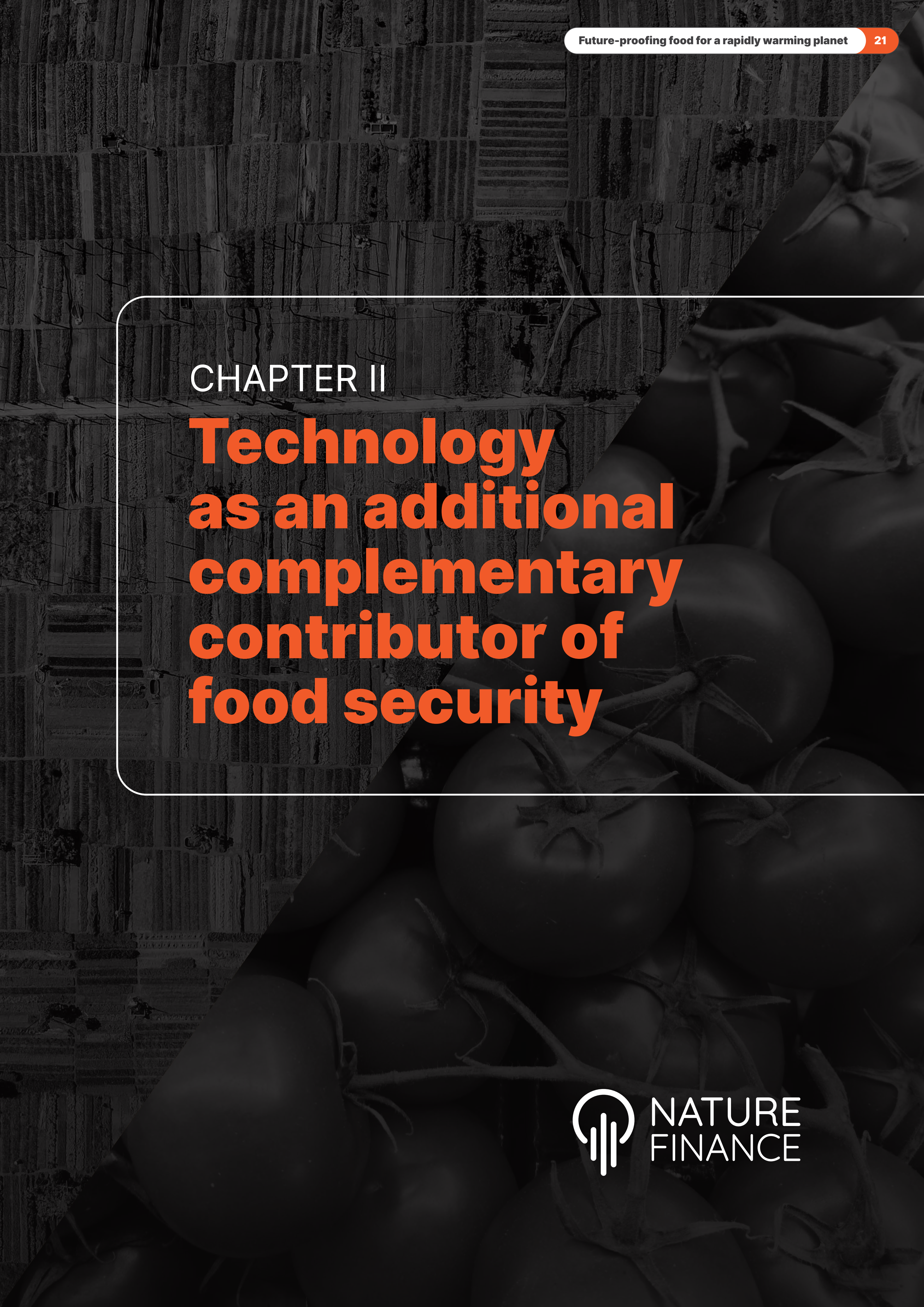
Concluding remarks and recommendations on the implications of this work and possible next steps

Technological innovations in food production have a contentious track record. On the one hand, they have at times delivered significant nutritional gains which have benefitted many. On the other hand, they have been marked by shortfalls in delivery, perverse outcomes, and increased farmer and community dependency on expensive technology and corporate interests.

Severe climate disruption will necessitate technological solutions even when considering and notwithstanding the potential of low-tech, regenerative production solutions in some parts of the world. For most low and middle-income countries, climate change is already delivering damaging extreme weather events and exacerbating water scarcity and accelerating ecosystem degradation - impacts which are expected to increase in the future. In such circumstances, domestic, climate resilient, food production will be dependent on protective and productive technology.

Local food production in certain regions, such as sub-Saharan Africa, will face significant challenges due to the adverse impacts of climate change on natural environmental conditions as illustrated in Figure 1. As a result, traditional, open-environment agricultural systems are increasingly unable to sustain production in these areas. To address this, capital-intensive and disruptive food production methods, such as controlled environment agriculture (e.g. vertical farming) and lab-grown protein, will become essential.

There are multiple challenges in deploying such food production technologies, all the more so in low and middle-income countries. Today, they are in the main immature and high cost, much as renewable energy technologies were two or more decades ago. This can and is likely to change, but it requires overcoming the vicious cycle of high perceived risk and societal resistance that in turn restricts scaling up and maintains high costs. This can further constrain the take-up and evolution of societal acceptance, whilst lowering investor interest in advancing the maturity of the technologies themselves.



CHAPTER II

Technology as an additional complementary contributor of food security

NATURE FINANCE

Capital intensive food production solutions no longer reliant on soil, ample water and stable weather conditions are needed to ensure food security in a severely climate disrupted world.

Resilient and Adaptive Food Techniques (RAFT, see Box 2) has the potential to play a critical role in addressing the growing food security crisis, by relieving at least some of the pressure on the food system. RAFT encompasses various technologies and methods designed to minimise the environmental footprint of food production while ensuring sustainability and resilience. This includes vertical farming (hydroponics, aquaponics, aeroponics), alternative proteins (such as edible insects and microorganisms, and cultivated and plant-based meat), and other innovative agricultural practices that either minimise soil and water use, decrease pollution, or lower CO_2 emissions.

This paper does not seek to tout the benefits of deploying specific RAFT solutions in specific regions in the context of a severely disrupted climate future. Instead, we take as a given that some forms of RAFT will be essential to building more resilient and adaptive food systems in many climate and nature vulnerable countries. Our focus is on exploring the financing challenges and opportunities that exist to scale these approaches in time to meet anticipated needs.

Box 2. Definition of Resilient and Adaptive Food Techniques (RAFT)

Resilient and Adaptive Food Techniques (RAFT) is a term created for the purpose of this report. It refers to a range of approaches to food production which are typically technology driven and capital intensive. This includes vertical farming techniques (such as hydroponics, aeroponics and aquaponics) and alternative proteins (such as edible insects, microorganisms, cultivated meat and plant-based meat), as well as other current and future innovative practices, the requirements of which are characterised by high capex. Our definition of RAFT refers specifically to disruptive or non-conventional approaches to food production, and therefore does not include other technological solutions such as digitalization of agriculture, IoT, new seeds, genetic modification or regenerative agriculture. While recognising the importance of developing these methods and technologies, they are not included under RAFT because they represent a continuation of conventional agriculture, notably relying heavily on the extensive use of soil and water and being dependent on 'open weather' conditions.

Vertical livestock farms or "landless livestock system" are deliberately excluded from this definition, as they are inherently inefficient in terms of feed-to-product conversion ratios, rely on off-farm livestock feed production, as well as other off-farm inputs such as antibiotics, and are associated to unethical animal treatments.

The expansion of RAFT technologies could play a complementary role by preserving limited areas of viable land for ecosystem restoration. By reducing the reliance on extensive agricultural land, these technologies can ease pressure on natural landscapes, enabling ecosystem restoration and mitigating some of the more extreme impacts of climate change and nature loss.[33]

There is rightly a robust debate surrounding the advantages of RAFT technologies.

Notably, and considered below, are the downsides of higher cost, negative potential employment effects, increased dependency on adopted, often imported technologies, the disconnect with culturally specific consumption patterns and norms, and the impacts on the broader social, cultural and economic conditions of existing food production ecosystems.[34, 35]

RAFT also have potential benefits, notwithstanding potential downsides.

RAFT technologies typically offer year-round production regardless of climate, ecosystem and weather conditions.

The security of supply of this type of production is reinforced by being located close to high-density populations, which can reduce transport costs/ impacts as well as both production and consumption related food losses.

RAFT approaches are also widely considered to reduce the environmental impacts of agriculture, reducing land degradation and land clearance for conventional agriculture, water usage, destruction of biodiversity and ecosystem services and carbon emissions.[36, 37, 38]

Moreover, RAFT is not dependent on specific habitats or environments and can be used to produce food more or less anywhere. It therefore has the potential to mitigate risks associated with export restrictions and geopolitical tensions by reducing reliance on international supply chains and strengthening local food sovereignty.[39, 40]

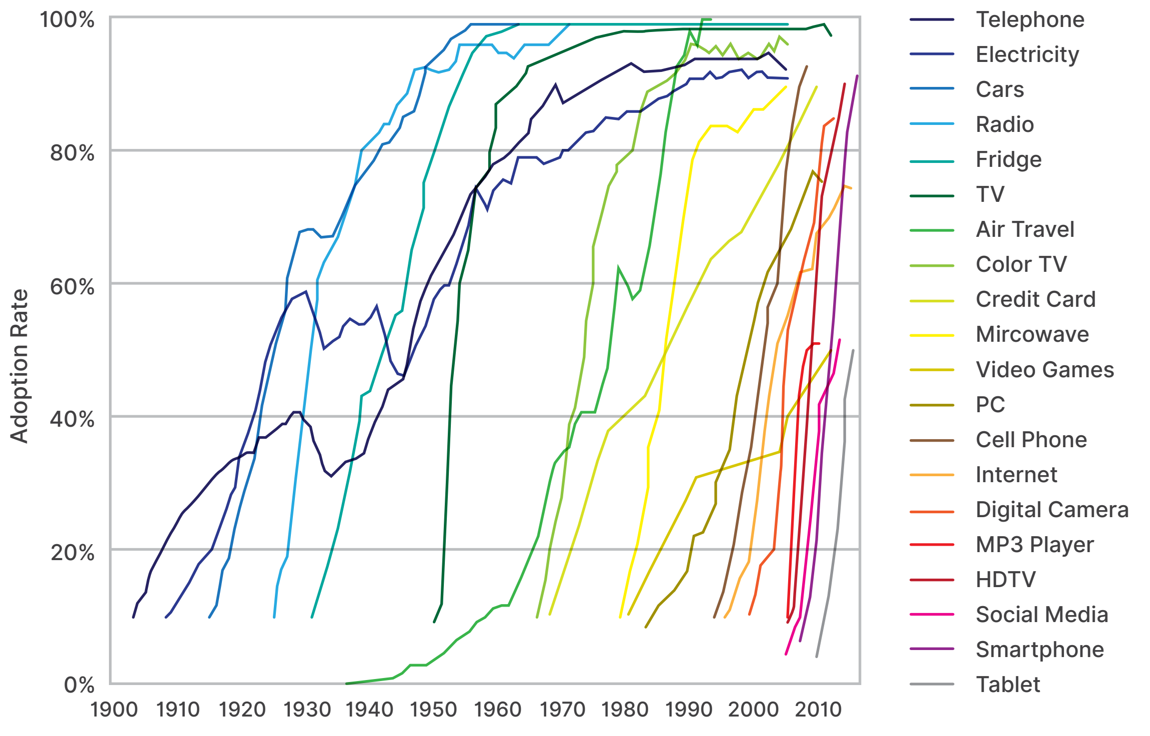
Despite such potential benefits, there are significant barriers to the useful adoption of RAFT, notably the high upfront costs and the resulting higher cost of nutrition. So far, most of these methods remain in the early stages of development and are not mature enough to compete with traditional agriculture on either cost or scale.[41, 42] Costs will fall over time as a result of innovation, efficiency gains and economies of scale. However, achieving price parity between RAFT and conventional food production would require billions of dollars in annual investments, far exceeding current funding levels.[43, 44]

RAFT: A Phase Shift in Innovation and Uptake

RAFT technologies have the potential to contribute to a healthy, sustainable diet and global food security.[45, 46, 47] Indeed, such approaches may be an essential part of the food security mix in a severely climate disrupted world. However, for RAFT to become a key part of the food security mix, barriers need to be overcome to make it a viable option to be used as a complementary solution. Notably, production needs to reach cost parity with conventional agriculture, including in low and middle-income countries.

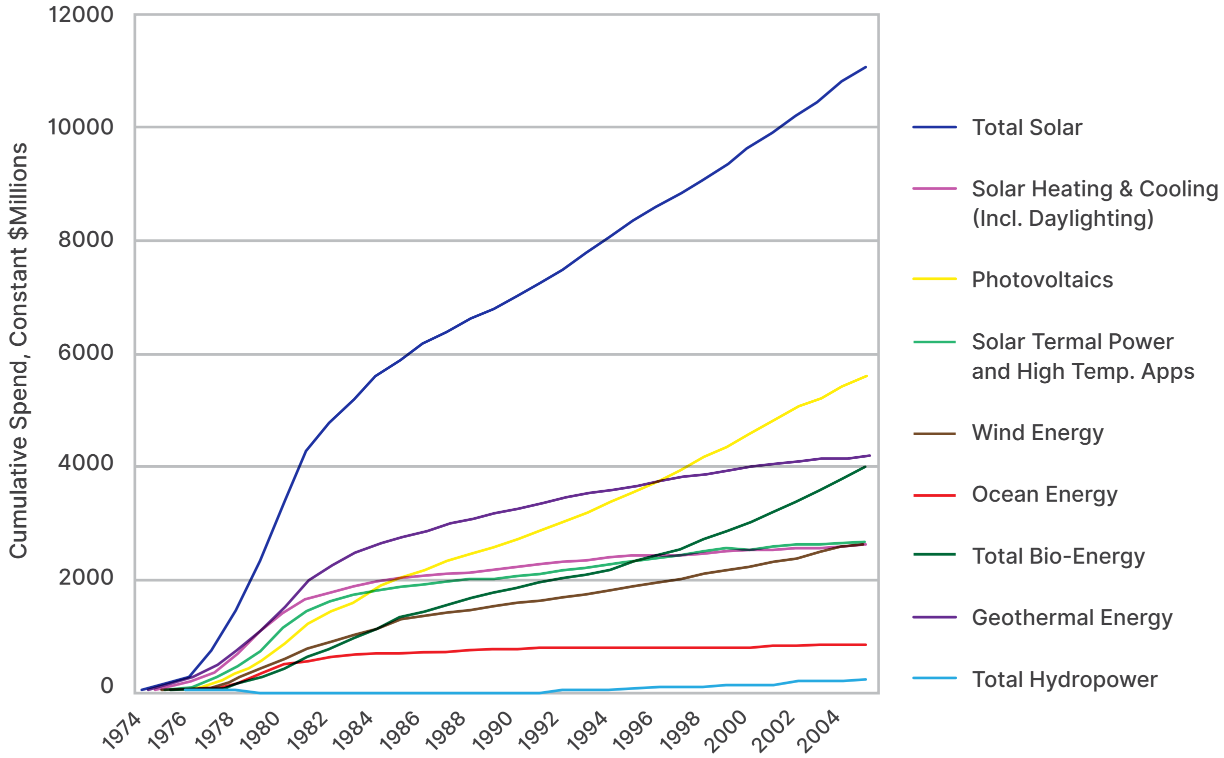
The good news is that progress towards this goal is underway, driven by significant market traction and investment in the RAFT sector.[48] The cost of cultivated meat for example – currently one of the most expensive forms of RAFT – has reduced significantly in recent years. Meanwhile the costs associated with producing more established RAFT technologies such as plant-based meat, vertical farming and edible insects, are also reducing, in some cases nearing cost parity with conventional agriculture. Yet, whilst RAFT costs can and will reduce significantly, this is not happening fast enough to meet the most pressing food security needs.[49]

Figure 3 Technology adoption rates



Source: Asymco, BlackRock[50]

Figure 4 Cumulative historical R&D funding of renewable energies by governments of Canada, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, UK and US



Source: M.A. Schilling, M. Esmundo / Energy Policy[51]

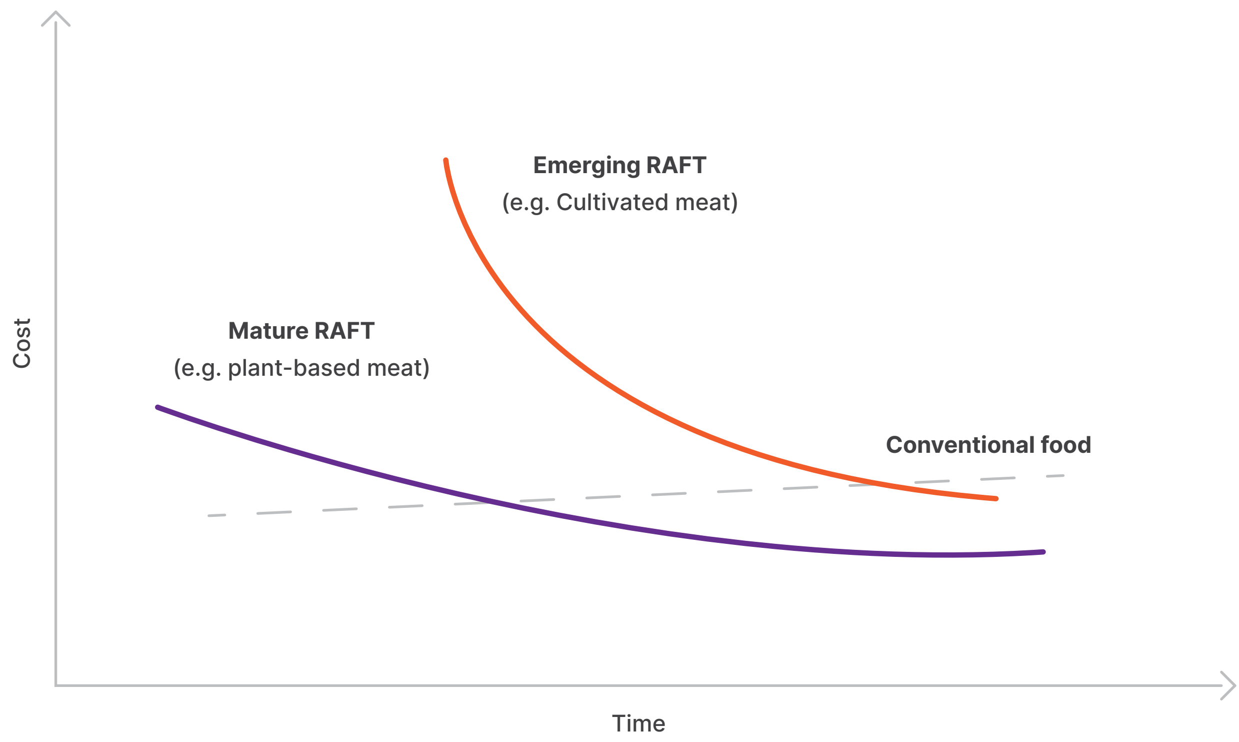
Cost parity convergence is also being driven by the rising costs associated with conventional agriculture, driven by a wide range of factors.[52]

A changing climate and nature degradation are diminishing crop yields, particularly in the Global South[53, 54, 55] Political instability and trade restrictions are complicating market dynamics.[56] In addition, climate change and political instability are leading to a rise in fertiliser prices, which has traditionally played a key role in mitigating diminishing yields.

The emergence of necessary, yet financially challenging, sustainability regulation is also increasing financial pressure on conventional agriculture.[57, 58] For example, Denmark's 'flatulence tax' scheme, designed to curb carbon emissions from beef and dairy has contributed to rising costs in conventional agriculture, despite being met with industry wide support. From 2025, dairy farmers in Denmark, will expect to pay an annual tax of 672 krone ($96) per cow, a cost that will inevitably be passed on to consumers.[59]

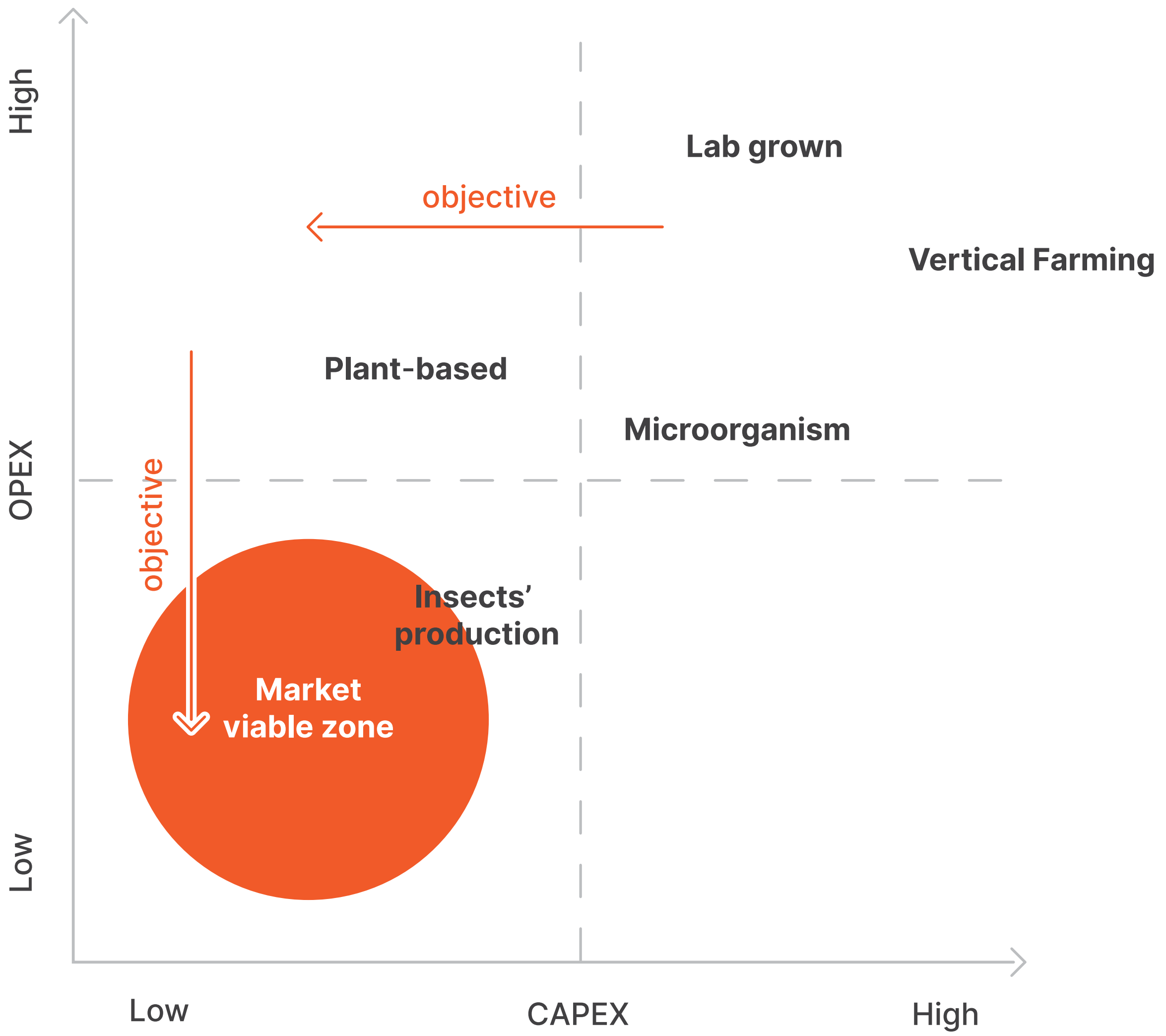
With falling RAFT costs and rising conventional agricultural costs there may be some price convergence. NatureFinance has created some estimated cost trajectories for protein-focused RAFT. Summarised in Figure 5, they compare predicted cost trajectories for cultivated and plant-based meat as well as the rising trajectory of meat produced by traditional agriculture. These estimates incorporate many uncertainties and should therefore be considered as providing directional rather than quantitative, insights. The point at which the curves intersect is dependent on multiple factors, but finance will likely be the most important variable when it comes to achieving cost parity, driving down CAPEX and OPEX for RAFT technologies (Figure 6).

Figure 5 The price of RAFT products is falling while the cost of conventional agriculture rises



Source: NatureFinance

Figure 6 CAPEX and OPEX for main RAFT technologies relative to market viability



Source: NatureFinance

As the gap in production costs narrows, momentum builds for what some have termed a "fifth agricultural revolution,"[60] heralding a potential future where global food systems reduce their dependency on natural resources such as water and soil, and increase their dependency on technology and renewable energy systems. The stakes are high, and time is running out as we strive to redefine the very nature of how we cultivate food and strengthen global food security.

RAFT's contribution to the Food Security Nexus is dependent on producing affordable outputs for all.

Modest investments in R&D have the potential to bring the delivered cost of food from capital intensive, food security solutions down to parity in higher-income markets, notwithstanding other challenges to overcome in low and middle-income countries.

Over time RAFT-related market and technology developments are likely to deliver more affordable nutrition but may prove too little too late.

Continued R&D will likely drive down technology costs, whilst also reducing perceived technology risks and lowering the cost of capital. Operational learning, often under-estimated, will likely improve the use of technology and further drive-up productivity and lower costs. As the technologies move up the adoption curves (see Figure 3 and 4), there will likely be economies of scale in the production of the technology that further drives down capex requirements and the resulting cost of nutrition.

It remains unclear at this stage just how low production costs and associated food prices are going to fall. There will be major differences between different food technologies and new ones will emerge tailored to specific contexts. That being the case, these developments - if entirely reliant on technology and direct market developments - are likely to unfold quite slowly. More specifically, without serious government intervention, they are unlikely to happen fast enough to enable RAFT to be a meaningful part of the food security mix, especially in the low and middle-income countries that are being more rapidly impacted by the climate and nature crises, and have lower capacity to pay for food.

The Investment Needed to Achieve Cost Parity

In our analysis, we have focused only on examining R&D costs of these technologies and have not included the potential positive effects on cost gained from economies of scale and efficiency improvements. As a result of this limitation, our estimates are therefore likely to be higher than the actual investment needed to achieve cost parity.

At the same time, we have restricted our analysis to the cost of food in developed countries, which tends to be higher than in low and middle-income countries. In consequence, even higher investment will be needed to bring RAFT to scale in developing countries.

Table 1 Comparative table of current and needed investment levels for main RAFT technologies

	Cost parity date	Current level of investments (USD)	Required investment (USD)	Water/ soil economy per calorie/ protein	Development Phase
Cultivated meat	2035	0.5b to 1b[61]	20b to 30b[62]	95% soil and 80% water use reduction compared with beef[63]	R&D Phase
Plant-based	2025	1.5b to 2b[64]	5b to 10b[65]	99% soil and 80% water use reduction compared with beef[66]	Commercial Expansion
Fermentation	2030	0.5b to 1.0b[67]	8b to 12b[68]	60% soil and 99% water use reduction for milk proteins[69]	Commercial Expansion
Vertical Farming	2030	1b to 1.5b[70]	10b to 15b[71]	99% soil and 90-95% water use reduction agriculture[72]	Start-up
Edible insects	2040+	300m to 500m[73]	3b to 5b[74]	99% soil and water use reduction compared with beef[75]	Start-up

Source: NatureFinance (estimate based on several publications)

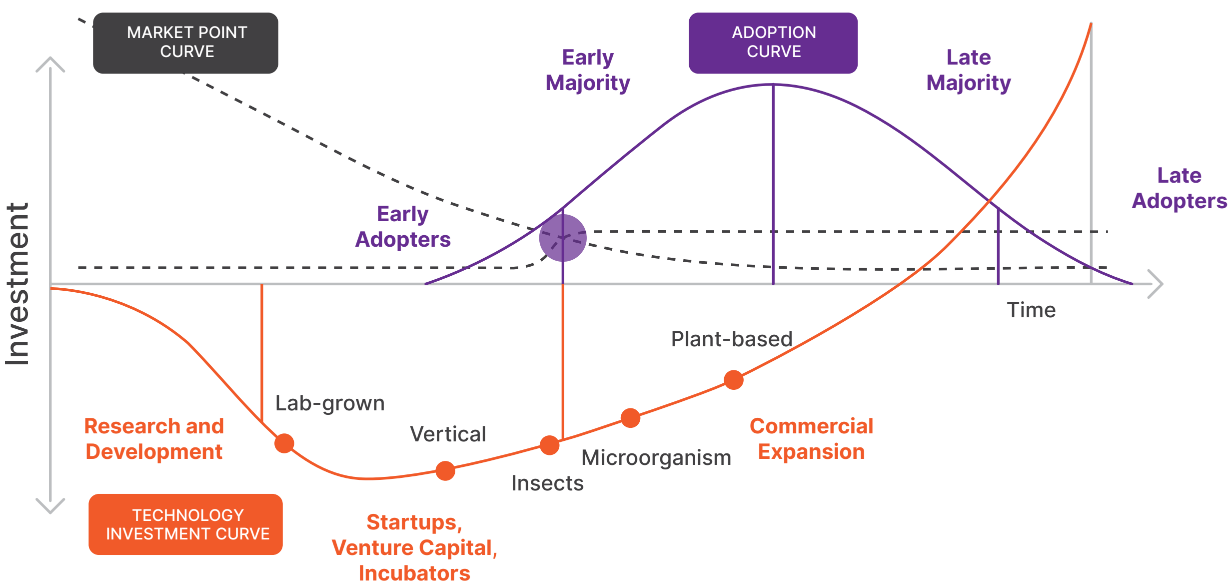
With these limitations and cautions in mind, we have considered five key RAFT technologies and estimated the financing shortfall which must be addressed to enable them to reach cost parity. These estimates are summarised in Table 1, using the current position of each technology on a typical technology investment curve as shown in Figure 7, which also enables us to make an estimate of the date at which cost parity might be reached under business-as-usual technology, finance and market conditions. NatureFinance estimates that cost parity for edible insects will come later compared to others as most of the market is currently dedicated to animal feed, and the process receives less attention from investors.

Our estimates suggest that achieving cost parity between RAFT products and conventional agriculture requires investments in R&D of an estimated US$35-60 billion over the next 10-15 years.

This investment is modest compared to the over US$600 billion in public subsidies currently supporting conventional agriculture,[76] or the US$7 trillion allocated to support the fossil fuel industry. [77]

Making such investments is crucial for lowering production costs, enhancing efficiency, and expanding operations. Without this investment, the full potential of RAFT technologies cannot be fully realised, and a vital opportunity to address food security challenges will be lost.

Figure 7 Typical investments and adoption dynamics for new technologies and where the different technologies stand



Source: NatureFinance

CHAPTER III

Financing food security in a world beyond 1.5°C

NATURE FINANCE

National experience and a decade of sustainable finance innovations provide the basis for assembling standardised and repeatable and scalable ways to finance the rapid deployment of capital intensive, climate resilient food productions solutions.

Learning from Practice

Realizing the potential for early-adoption RAFT solutions to enhance the resilience of food systems and food security requires smart financing solutions. The design challenge is to figure out what financing instruments are best suited to this challenge and opportunity. Early-stage national experiences such as those highlighted in the next section provides important clues as to what might be the smartest financing approaches.

More broadly, RAFT is in a similar position to renewables twenty years ago,[78] and there are many lessons that can be learned from the financial mechanisms and strategies that were employed by governments and businesses to accelerate the renewable transition. These strategies included things like strategic investment into R&D, stimulation of market demand through tools such as Feed in Tariffs (FiT) and effective marketing.

Three strategies in particular are highlighted here that can be employed across the different stages of development to accelerate the journey down cost curves.

1

Support R&D through strategic investment. Technological progress reduces the CAPEX required for new technologies. Therefore, targeted R&D investments can reduce costs at various stages of the value chain.

2

Stimulating market demand with procurements, long-term offtake agreements and penalties. These strategies have the potential to stimulate market demand for RAFT technologies by creating guaranteed consumers for products. Doing so will also de-risk investment from other sources.

3

Targeted marketing to change public perception towards RAFT produced food. Investing in marketing which emphasises the sustainability and nutritional benefits of RAFT can increase demand, leading to further reduction in cost.

Lesson 1

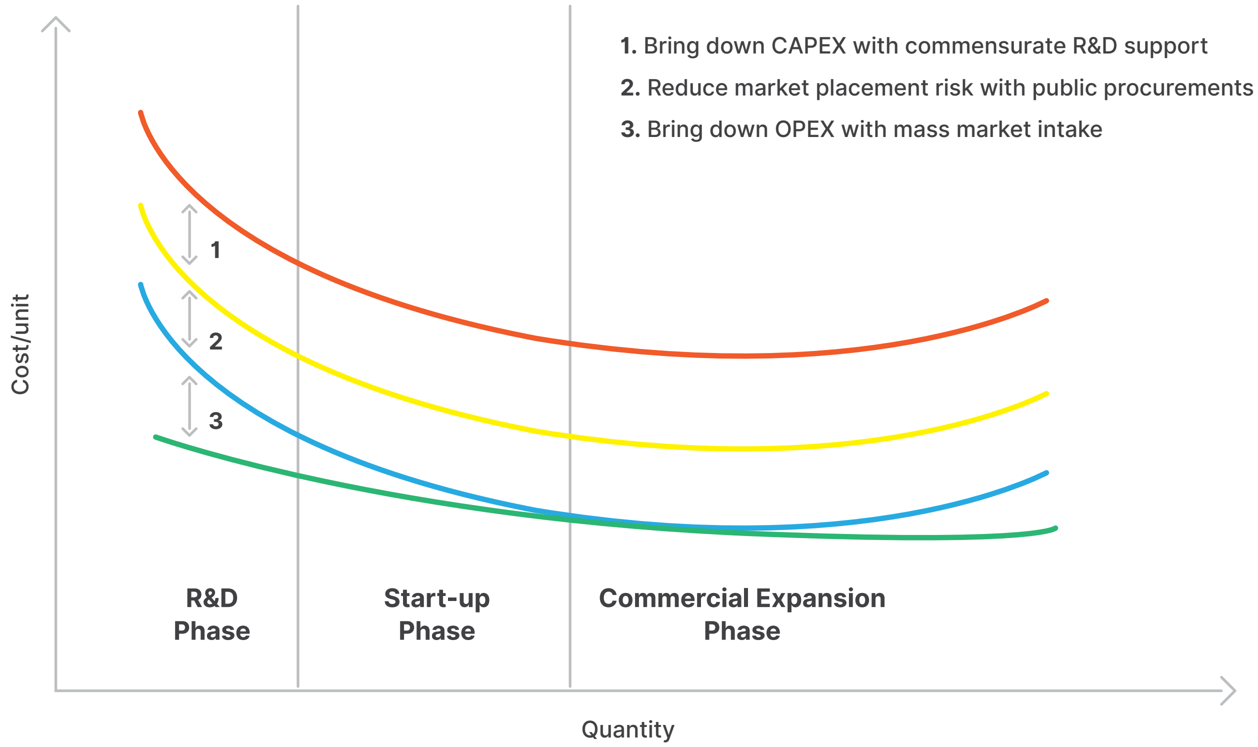
Robust 'technology push' to transition from technically possible to commercially viable

In 2022, global funding for RAFT research and development reached approximately US$3 billion, doubling from previous years, but still only a small fraction of the estimated US$60 billion required to revolutionise the sector (see Table 1).

Countries such as the Denmark, China, and the United States are at the forefront, employing direct funding and tax incentives to stimulate private-sector innovation.[79] The aim of these fiscal strategies is not only to provide innovation capital and foster growth, but also to help reduce capital expenditures and operating expenses for RAFT companies.

Investment in research and development can significantly reduce the costs associated with new technologies,[80] making them more accessible and affordable. The United States, for example, has implemented substantial tax credits and direct funding to support RAFT-related research, encouraging private companies to innovate and bring new products to market.[81, 82] Similarly, China has integrated RAFT technologies into its Five-Year Economic Plan, ensuring sustained investment and development.[83]

Figure 8 How three different strategies would reduce and flatten the cost curves associated with development and implementation



Source: NatureFinance

Lesson 2
Reduce risk by stimulating demand

There are several financial strategies that can be employed to stimulate market demand and reduce costs as a result. Commercial expansion and market growth lead to reduced costs as increased production generally leads to economies of scale and increased efficiencies. Quantitative models using learning rates or experience curves, show that for new technologies, increased production typically results in falling production costs. For example, in renewable energy, learning rates for solar PV have been observed to be around 20-22%, meaning costs drop by this percentage with each doubling of production volume.[84]

Public procurement – public procurement strategies are one way of stimulating demand by offering guaranteed procurement; these strategies reduce the risks associated with developing and introducing new technologies to the market.[85, 86] As Table 2 shows for EVs in China, IT in America and organic food in Denmark, public procurement strategies and partnership-based instruments have often played a pivotal role in bringing new technologies to market, accelerating their uptake and commercial viability. Introducing RAFT products into public sectors, such as school or government cafeterias, is one-way public money could be used to stimulate market growth, reducing operational costs and enhancing market penetration.

Long-term corporate offtake agreements can play a similar role to procurements but driven by the private sector. These agreements provide financial stability, encouraging investment in new technologies and reducing market risks.[87, 88] For low-income countries, they can stimulate local economies by creating jobs and fostering skill development. Moreover, corporations can assist in technology transfer and capacity building, ensuring sustainable practices take root. By securing reliable, sustainable supply chains and aligning with their social responsibility goals, corporations not only bolster global food security but also strengthen their own operations.

Table 2 Quantifying the impact of public procurement on technology costs

China	USA	Denmark
The Chinese government's procurement program for electric buses[89]	The U.S. government's bulk purchasing agreements for IT hardware and software.[90, 91]	The Danish government set the goal to achieve 60% organic food in public institutions by 2020.[92]
The Chinese government's large-scale procurement of electric buses significantly lowered costs. Between 2010 and 2017, the cost of lithium-ion batteries, a key component of electric vehicles, dropped by approximately 80%. [93]	Government procurement agreements have historically driven down costs in the IT sector. For example, the GeneralServices Administration (GSA) bulk purchasing agreements have been shown to reduce costs by 20-30% compared to market prices.	Denmark has one of the highest market shares of organic food in the world, with organic products making up over 13% of the total food market. Also, the program significantly increased the conversion rate of conventional farms to organic farms, with organic farmland in Denmark comprising over 10% of total agricultural land.

Source: NatureFinance

In essence, long-term corporate offtake agreements are a win-win: they can drive the adoption of RAFT, promote economic development in vulnerable regions, and help corporations meet their sustainability commitments. As the world faces mounting environmental and geopolitical challenges at lower costs, fostering these partnerships could be key to transforming how we produce and consume food.

Fines and penalties – Fines, penalties and regulation are an effective way of promoting sustainable practices. For example, CO_2 emission penalties in the EU automotive sector, discourage unsustainable practices and encourage the adoption of environmentally friendly alternatives. Impacts are listed and quantified as an illustration in Table 3. Applying similar restrictions and penalties to agriculture, whether emissions-based or nature-based, could accelerate the adoption of new technologies.

Food labelling – Introducing robust health and environmental food labelling regulation alongside effective marketing can also increase demand by influencing consumer preferences.[94, 95] Such initiatives directly communicate the benefits of RAFT products to consumers, driving adoption even when products are not yet at cost parity.

Table 3 Impact quantification of penalty systems on the development of EVs. Applying similar restrictions and penalties to agriculture, whether emissions-based or nature-based, could accelerate the adoption of new technologies.

Impact	Quantification
Increased Production of EVs	According to the European Automobile Manufacturers Association (ACEA), the share of electric cars (battery electric vehicles, BEVs) in the EU increased from 3.0% in 2019 to 10.5% in 2020.[96] This significant growth is largely driven by the need to meet CO_2 targets.
Technological Advancements	The average cost of batteries, a major component of EVs, has fallen from around $1,100 per kWh in 2010 to approximately $137 per kWh in 2020. This cost reduction is partly due to increased investment and economies of scale driven by regulatory pressure.[97]
Consumer Incentives and Market Growth	In 2020, the EU saw a record 1.4 million new electric cars registered, a 137% increase compared to 2019, according to the European Environment Agency (EEA)[98] - demand also fed by government subsidies, further boosting market growth.
Reduction in Average CO_2 Emissions	The average CO_2 emissions of new cars in the EU fell from 122.3 g/km in 2019 to 107.8 g/km in 2020, a reduction of 14.5 g/km, according to the EEA.[99] This decrease is significant given the regulatory targets and associated fines.

Source: NatureFinance

Lesson 3
Marketing for commercial expansion

Marketing will have to play a critical role in influencing consumer behaviour and reshaping consumer preferences.[100, 101] This is particularly important for products such as alternative proteins which may be unfamiliar to consumers. Campaigns highlighting the health and environmental benefits of food, such as those currently conducted for organic, regenerative and generally responsible agriculture, have been shown to be effective at enhancing consumer awareness and facilitating market penetration.[102, 103] One recent example is the effectiveness of campaigns promoting plant-based diets which have led to significant increases in consumer demand for such products.[104]

Despite the power of effective marketing, many challenges remain when it comes to changing consumer preferences. Much of the food and retail market is dominated by cheap, processed food, which many experts consider to be addictive. These products are often backed by well-financed advertising campaigns which can be difficult for public campaigns to compete with, and many countries' populations face rising obesity linked to the marketing and availability of unhealthy foods.[105, 106] In emerging economies, increasing individual income is leading to a growth in meat consumption globally, placing further strain on environmental resources.[107]

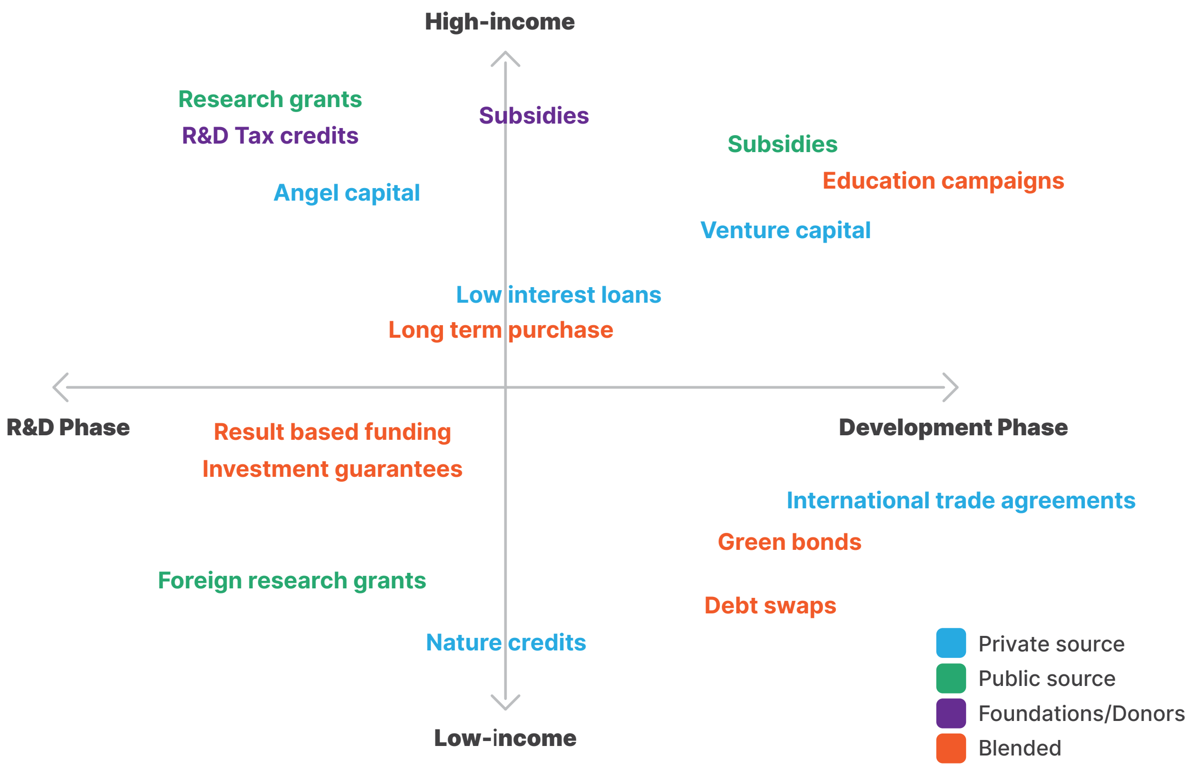
A strategic and comprehensive public communication strategy is crucial to shift global dietary trends towards RAFT. This strategy should include a mix of campaigns and incentives designed to foster a global shift towards RAFT, illustrating the urgent need to transform how we think about and consume food. For instance, public awareness campaigns, educational programs, and collaborations with influencers and celebrities can help change consumer habits and promote sustainable eating.[108, 109]

Flexible financial policies for diverse contexts

The transition to RAFT demands a sophisticated financial strategy that leverages various instruments tailored to different technological and economic contexts. Numerous financial instruments have been identified to support the scaling of new food technologies and existing literature extensively analyses their benefits and limitations. When it comes to strategizing how to accelerate RAFT development and associated cost reductions, it is helpful to map these instruments against three criteria as illustrated in Figure 9.

1. Availability for different country income levels
2. Relevance to the stage of technology development
3. Source of financing

Figure 9 Multi-dimensional chart of available financial mechanisms



Source: NatureFinance

As Figure 9 shows, there is no universal solution, but by combining subsidies, venture capital, and blended financial solutions it is possible to tailor financing strategies for different countries and different RAFT technologies.

For instance, low-income countries may not have access to the same amount of capital or financing options as high-income countries, such as R&D tax credits and venture capital. These can often be useful in the development phase and start up phases respectively.[110, 111, 112] Low-income countries may therefore have to rely on alternative financing options such as foreign research grants and nature credits to fill this gap.

Furthermore, the specific contexts and food security requirements faced by different countries and regions must be considered. Table 4 compares the three case studies covered in chapter 4 and outlines how different financial solutions have been tailored to different challenges specific to each country.

Rwanda, for example, is a low-income country which is already heavily impacted by climate change and nature loss. Its food security relies on smallholder farmers and therefore government policy is aiming to support producers to transition towards vertical farming, however finance is largely reliant on donors and NGOs.

Brazil, with abundant agricultural land and large-scale industrial farming, is under internal and external pressure to prevent deforestation. Whilst RAFT presents an opportunity to tackle these challenges, it must be balanced with the need to conserve Brazil's own conventional agriculture industry as it is a major global exporter.

Table 4 Different country profile with adapted needs and opportunities

	Rwanda	Brazil	Singapore
Country profile	• Low income country • Food security pressure • Small-holder farmers	• Middle income country • Leader of global food exports • Large, industrialised farmers	• High income country • No available land for agriculture • Technological leader
RAFT relevance	• 30% of the GDP relies on agriculture and is at threat from climate change	• Need to limit deforestation caused by land clearing for agriculture	• Political strategy to source locally 30% of its food
Current solutions	• Investing in urban VF, supported by donors and NGOs • Focusing on decentralised farming for small holders	• 30% to 40% of leafy vegetables are hydroponically grown • Export plant-based meat in over 30 countries	• Already leader in wastewater reuse • Large amount of public funding available for RAFT • First legislation on cultivated meat
Future opportunities	• Access to food sovereignty and climate independent food production system with RAFT	• Leverage capital and experience about agriculture • Transform agriculture leadership to RAFT • Anticipate forthcoming environmental regulations and import rules	• Continue R&D to reduce costs • Export technology and position as leader • Increase market penetration

Source: NatureFinance

The Global South can leverage natural assets to finance sustainable agriculture. Global RAFT financing strategies must consider the weaknesses but also the strengths of the Global South which remains largely excluded from RAFT development due to a lack of access to financing. There are several potential opportunities whereby countries in the Global South can leverage their natural assets, and the biodiversity and ecosystem services provided by them, to fund RAFT development.

Nature and Carbon credits - One proposal, for example is to establish a nature-type credit market – similar to carbon trading but also encompassing biodiversity/nature credits – facilitating financial flows from wealthier nations to less affluent but nature-rich counterparts.[113, 114, 115] The aim of markets such as this, which are not without their critics, is to enable high-income countries to compensate for environmental impacts that they cannot mitigate for internally by protecting natural assets in the Global South. For example, companies could purchase credits which are then used to finance RAFT development, so long as it can be shown that development prevents nature destruction. RAFT could be used to generate carbon credits for non-emission, or so-called carbon avoidance projects which prevent additional greenhouse gas emissions from entering the atmosphere by reducing sources of emissions. However, to guarantee significant investments, long-term off-take agreements must be implemented to ensure guaranteed revenue and de-risk investment.

One notable example of a successful carbon/nature credit project is Kenya's Kasigau Corridor REDD+ Project, a conservation programme which aims to prevent land clearance and deforestation whilst simultaneously supporting sustainable agriculture.[116] Funded by Wildlife Works and partners, this project is funded through sales of credits to entities in high-income countries, including major retail corporations like Kering. The project illustrates one approach that low-income countries could use for generating finance for sustainable economic development and food security whilst protecting natural assets.

Green bonds - The growing demand for so called ‘green bonds’ offers another potential avenue for financing RAFT in emerging economies. These bonds are financial instruments designed to fund projects that have positive environmental benefits, such as renewable energy or sustainable agriculture. By issuing green bonds specifically targeted at funding RAFT projects, countries in the Global South could finance ambitious undertakings such as vertical farms or bioreactors for cultivated meat production.[117, 118] The African Development Bank has issued several green bonds as part of its broader strategy to support climate change mitigation, nature restoration and adaptation efforts across the continent.[119]

Leveraging sustainable development to attract investment - Countries in the Global South can also use the sustainable development potential of RAFT to attract impact investors and foster public-private partnerships. Investors drawn to sustainable ventures offering both environmental and social returns could inject much-needed capital into RAFT initiatives – which could be used to underwrite innovative startups and infrastructural endeavours, supported by equity investments, low-interest loans, credit guarantees, and flexible repayment terms.

The Africa Agriculture and Trade Investment Fund (AATIF) for example, is a public-private investment fund that finances agriculture and food security projects in Africa. Established to address the need for increased investment in Africa's agricultural sector, the AATIF focuses on improving food security, enhancing agricultural productivity, and creating economic opportunities within the agribusiness sector across the continent. Initiated by a consortium of European development finance institutions, including the African Development Bank, the AATIF targets projects that promise both economic returns and positive impacts on food security and rural development.[120]

RAFT trade agreements - Trade diplomacy could be vital for creating market incentives for RAFT products globally.[121, 122] Net exporters of RAFT products could forge bilateral trade agreements that provide access to their unique natural resources. This would increase demand for RAFT and de-risk local food security by increasing supply sources.

China has been a major investor in the Global South in recent decades, financing many development infrastructure projects based on reciprocal trade and access arrangements. This includes several bilateral agreements in African nations, including Zambia and Angola where support for food security has been provided in exchange for facilitated access to natural resources.[123, 124] These agreements often involve provision of significant infrastructure development and agricultural support in exchange for access to natural resources like land and minerals. Chinese financing as well as technology and expertise has resulted in increased food production and has had broader economic benefits related to job creation, improved logistics and market access. However, these agreements are also controversial and regarded as exploitative by some.[125] They therefore require careful oversight to ensure long-term sustainability and equitable benefits.

Putting pressure on wealthy nations to raise finance – Many argue that there is a moral imperative behind financing sustainable development and food security. Wealthy nations have contributed disproportionately to the global environmental and food crises, and therefore have a responsibility to mobilise the capital and resources necessary to integrate low-income countries into the RAFT revolution. By doing so, they not only help secure food sovereignty for these regions but also contribute to a broader global political and environmental stability that is in the interests of all.

Global implementation of RAFT technologies requires a nuanced strategy integrating ambitious long-term targets, proactive policy and a suite of adaptive financing options. The aim of these measures should be to speed up the transition from high initial implementation and operational costs to economically viable and competitive solutions. If public and private investment can successfully raise the necessary capital to catalyse development, then there is potential to create a virtuous economic cycle in which growth in the RAFT sector continues to drive down prices, in turn stimulating further growth.

Given the level of investment required, public finance alone is almost certainly insufficient to drive RAFT development at the speed necessary to strengthen food security in a rapidly warming world. Public finance, policy measures and targeted trade arrangements can however play a key role in de-risking investment and accelerating development to boost private finance.

Financing solutions must be adapted to local needs and contexts and understanding the specific finance requirements will be essential when developing strategies for different countries and regions. Additionally, international collaboration and coordination will play an essential role in helping to create effective marketplaces, trade arrangements and financing for RAFT products. Table 5 provides a multidimensional picture of the types of financial instrument and the sources of funding required for different income countries at different phases of RAFT development. Understanding this big picture can help strategists and policymakers target public and private investment to support the development and global integration of RAFT (Table 5).

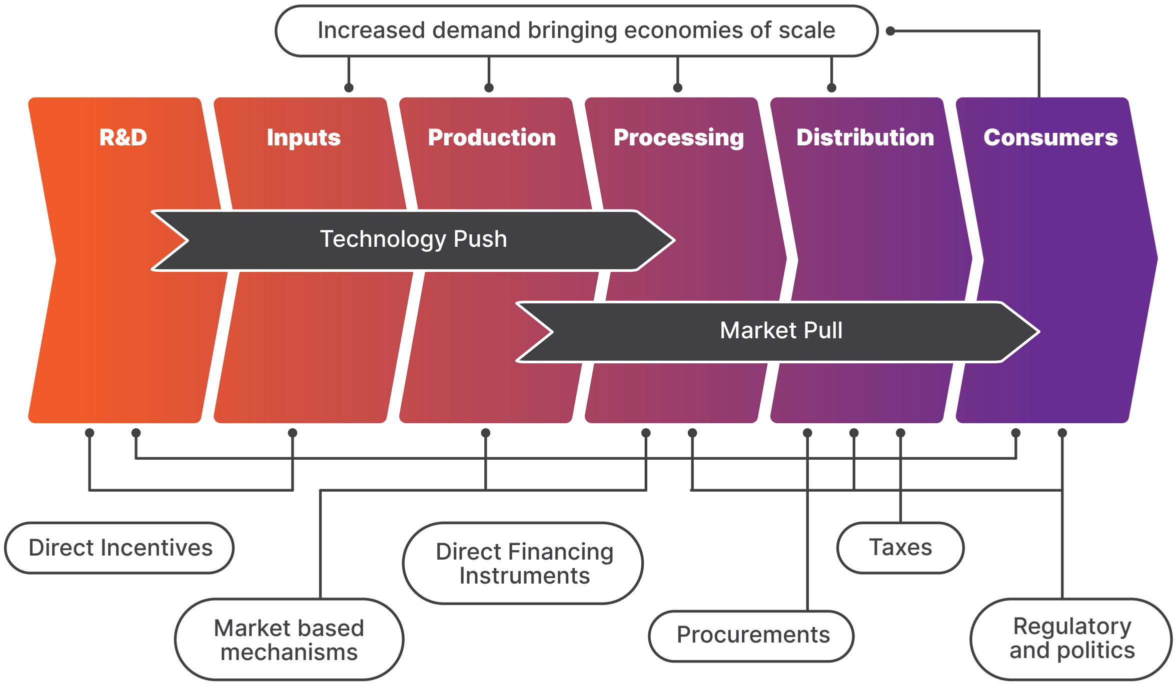
Financial instruments can accelerate development at different stages of the value chain of RAFT development, as summarised in Figure 10, leading to a virtuous economic cycle whereby growth in the sector stimulates further technology-driven cost reductions, efficiency gains and economies of scale, leading to reductions in CAPEX and OPEX, leading to further sector growth.

Table 5 How different financing options can support each phase of development for low, middle and high-income countries

	Country income level		
Technology development phase	**Low-income**	**Middle-income**	**High-income**
R&D Phase (e.g. cultivated meat)	**Financial instruments:** Research Grants Technological transfers **Source of fund:** Academic funding Corporates Foundations Angel investments	**Financial instruments:** Research Grants Technological transfers R&D tax credits **Source of fund:** Academic funding Corporates Angel investments	**Financial instruments:** Research Grants R&D tax credits **Source of fund:** Public funding Academic funding Angel investments
Start-up Phase (e.g. fermentation, vertical farming)	**Financial instruments:** Investment guarantees Result based funding Long-term purchase Nature/Carbon credits **Source of fund:** Corporates Venture capital International public org Foundations	**Financial instruments:** Long-term purchase Nature/Carbon credits Mezzanine Low interest loans Extended payment terms **Source of fund:** Corporates Venture capital International public org Foundations	**Financial instruments:** Low interest loans Water/energy subsidies Extended payment terms Long-term purchase Energy purchase agreements **Source of fund:** Corporates Venture capital
Commercial expansion Phase (e.g. plant-based meat, edible insects)	**Financial instruments:** Green bonds Nature/carbon credits Debt swaps Public promotion Int. Trade agreements **Source of fund:** Corporates Banks Insurance Consumers Environmental taxations	**Financial instruments:** Labels & Certifications Public promotion Off-takers agreements Subsidies Nature/carbon credits **Source of fund:** Consumers Corporates Banks Insurances Environmental taxations	**Financial instruments:** Labels & Certifications Public promotion Off-takers agreements Subsidies **Source of fund:** Consumers Corporates Banks Insurances Environmental taxations

Source: NatureFinance

Figure 10 How different financial instruments can be used along the value chain to create a virtuous cost reduction cycle



Source: NatureFinance

Given the urgent need to strengthen global food security, further strategic financial and diplomatic interventions may be required to facilitate RAFT development and ensure that the fifth agricultural revolution is inclusive, sustainable, and transformative. We include some radical thinking suggestions below.

Introducing a feed-in tariff (FiT) mechanism for sustainable agriculture – Feed-in-Tariffs are widely understood to have played an essential role in supporting the transition from fossil fuels to renewable energy (Box 3). These tariffs involve guaranteeing an above-market price and long-term contracts for different types of renewable energy. A similar mechanism could be used to guarantee above-market prices for RAFT products, accelerating their adoption. However, implementing a similar mechanism for RAFT may be challenging due to the complexity of supply chains and the range of different commodities produced. Furthermore, it may be essential to find a balance where FiTs do not harm the conventional agriculture industry.

Reforming agricultural subsidies – Agricultural subsidies are provided by governments to farmers and agribusinesses to help stabilise food prices, ensure a steady supply of agricultural products, and sustain agricultural businesses. However, these subsidies often promote environmentally harmful practices over nature-positive agriculture.[126] Furthermore, agricultural subsidies distort food prices in a way that does not account for their impacts on nature, climate and health.

A 2021 Rockefeller Foundation report estimates that the real cost of food is actually three times higher than what consumers pay when these factors are taken into account.[127] Subsidies can also act as a form of protectionism which is harmful to low-income countries whose agriculture industries compete with subsidised produce from wealthier nations. An overhaul of the current subsidies is needed to promote sustainable farming methods like regenerative agriculture and RAFT and reduce the environmental impact of our food system.

Box 3: The success of German Feed-in-Tariffs(FiT) for renewable energies[128]

Germany's Renewable Energy Sources Act (EEG) of 2000 is one of the most successful examples of FiTs. It guaranteed fixed payments for renewable energy producers and required grid operators to prioritise renewable energy. The FiT policy led to a massive increase in renewable energy capacity, particularly in wind and solar PV. By 2020, renewable energy accounted for about 46% of Germany's electricity consumption. The cost of solar PV in Germany fell by around 75% between 2006 and 2014. The policy also created hundreds of thousands of jobs in the renewable energy sector and established Germany as a global leader in renewable technology and innovation. Similar policies have been introduced by countries around the world.

A bold call for nature and food security debt swaps – It is estimated that developing countries spend over USD 400billion annually to service their external public debt,[129] roughly the same amount of capital experts estimate is required to switch to a fully sustainable bioeconomy.[130] Debt swaps are an innovative financial mechanism which could be used to exchange debt for commitments to sustainable agriculture, food security and nature restoration.

A call to action for charitable foundations to lead global food security initiatives – In 2024 U.S. based foundation assets reached a record USD1.5trillion in value.[131] Foundations globally are well-positioned to spearhead transformative changes in global food systems, particularly in the Global South. Allocating a portion of foundation spending towards RAFT could drastically enhance food security and resilience, offering a strategic solution to many of the pressing issues foundations seek to tackle like conflict, hunger, poverty, nature degradation and climate change.

Cap-and-trade compliance program on nature use for food production – Carbon markets employ a cap-and-trade system where governments set a "cap" or limit on the amount of carbon that can be emitted for a given activity. Businesses or countries that exceed their limits are able to purchase credits to offset their emissions.[132] A similar cap-and-trade program for food production could regulate the use of natural resources. Food production businesses that use or damage excessive water or land would need to buy credits from more efficient businesses or pay fines. This would both incentivise transition towards regenerative agriculture and RAFT and provide a further revenue stream for both through the selling of offsets.

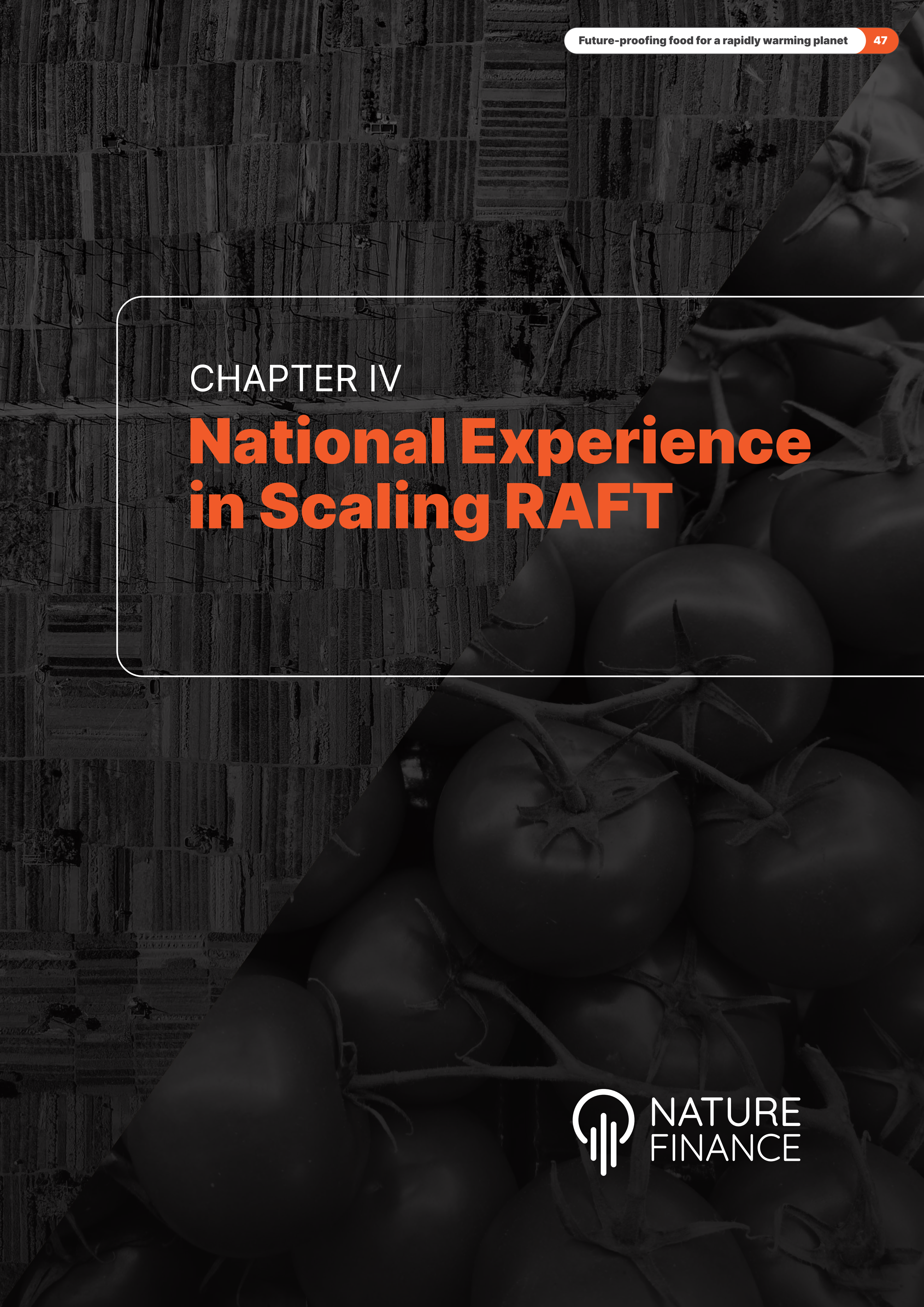
Banning pollution-intensive food production methods – Much like Europe's ban on petrol car sales by 2035, prohibiting polluting food production methods such as fertiliser-intensive farming would force producers to transition to more sustainable practices like RAFT and regenerative agriculture.[133]

RAFT represents a crucial opportunity to address global food security and the environmental impact of agriculture. Financing the implementation and development of RAFT will however require a sophisticated mix of financial strategies and instruments tailored to the diverse needs of different countries and technologies. By building on lessons learned from other disruptive technology transitions, this blueprint provides a framework which strategists, policy makers and other key stakeholders can use to develop a targeted financing strategy, which can accelerate RAFT development, facilitating the creation of an agriculture industry which is more aligned with the urgent demands of our time.

Box 4: Top-Down Approaches and Local Contexts

Philanthropic entities frequently implement top-down strategies, which may not align with the specific needs and cultural contexts of the communities they intend to assist. The Gates Foundation's agricultural programs in Africa, for instance, have promoted the use of mass-produced fertilizers and new seed varieties. Critics argue that this approach fosters dependency on international supply chains and undermines traditional, sustainable farming practices.[134] Such strategies can erode local agricultural knowledge and biodiversity, leading to long-term unsustainable outcomes.

While philanthropic organizations play a crucial role in addressing global challenges, it is essential to critically assess their approaches to ensure they do not inadvertently entrench unsustainable practices. Emphasizing community involvement, respecting local contexts, and addressing systemic inequities are vital steps toward creating sustainable and equitable solutions. By aligning their strategies with the actual needs of communities and fostering inclusive decision-making processes, philanthropies can contribute more effectively to sustainable development.



CHAPTER IV

National Experience in Scaling RAFT

NATURE FINANCE

Here we analyse key areas of progress and innovation to date in various countries and identify where they could use innovative finance and other policy tools to scale and accelerate RAFT further.

National and regional strategies are needed to make climate resilient, soilless, closed-system food security options part of the solution, differentiated across high, medium and low-income countries.

Need for Innovative Financing

There is a need for innovative financing to make RAFT more accessible, to more communities, more quickly. Our estimates of the dates at which cost parity are reached, especially in low-income countries, are simply too late to deploy RAFT at scale to support food security needs, especially in low and middle-income countries whose food security is more rapidly being impacted by the climate and nature loss. It will be necessary therefore to accelerate developments more rapidly than the market alone will deliver. There are multiple steps that can be taken to accelerate needed developments, including non-technology developments such as enhanced nature and climate-linked regulations and standards. One keystone step is to consider innovative financing options that go beyond traditional stand-alone public or financing instruments.

National experiences with innovative finance for RAFT remain at an early stage but already provide notable insights. Before turning in the next section to a high-level review of possible innovative financing approaches, we have given some consideration to emerging national experience in three illustrative contexts, namely:(a) Singapore as a high-income country with little agriculture; (b) Brazil as a middle-income country and highly industrialised agriculture; (c) Rwanda as a low-income country with mostly small holder farmers. Each of these cases are summarised below.

Case Study A
Singapore: defining tomorrow's food supply today

Limited space for conventional agriculture has always been both a challenge and opportunity for Singapore.

With a limited land area of just 728 square kilometres and around 6 million inhabitants, the island city-state of Singapore faces significant challenges when it comes to food security. The nation imports over 90% of its food, making it highly vulnerable to global supply chain disruptions, which have been exacerbated by climate change, habitat loss and geopolitical tensions.[135] In response to these challenges, Singapore has set an ambitious goal to produce 30% of its nutritional needs locally by 2030—a strategy known as "30 by 30".[136]

Singapore has been proactive in implementing RAFT through various innovative projects that leverage cutting-edge technology and practices. RAFT is widely recognised to play a vital part in achieving this goal and helping Singapore overcome the constraints of limited land and resources.

Vertical farming - One of the flagship projects in this area is Sky Greens, the world's first low carbon, hydraulic-driven vertical farm. Located in Lim Chu Kang, Sky Greens uses vertically stacked towers to grow leafy vegetables, maximizing space and reducing the carbon footprint. The farm is highly water-efficient, recycling water for plant growth, and has significantly contributed to increasing local vegetable production.[137, 138] Other notable projects in the domain of vertical farming such as Sustenir Agriculture are paving the way to establish the standards in this technology.[139]

Cultivated meat - In the realm of alternative proteins, Shiok Meats is pioneering cellular agriculture in Singapore. This startup focuses on producing lab-grown seafood, such as shrimp and lobster, through cellular cultivation. By producing seafood without relying on traditional fishing methods, Shiok Meats contributes to reducing the environmental impact associated with overfishing and provides a sustainable protein source for the local and global markets.[140, 141]

Regulatory approval - On the product acceptance side, Singapore has made significant strides in establishing a robust legal framework to support the production and commercialization of alternative proteins, becoming the first country in the world to approve the sale of cultivated meat.[142] In 2020, the Singapore Food Agency (SFA) granted regulatory approval to Eat Just, a U.S. based company, to sell lab-grown chicken in the country. This landmark decision set a global precedent and established Singapore as a leader in the alternative protein industry. The SFA has since developed stringent safety assessments and clear regulatory pathways for other alternative protein products, including plant-based and cell-cultured proteins.[143, 144] This proactive approach has attracted numerous startups to Singapore, fostering innovation and investment in sustainable food technologies. The government's ongoing support through regulatory clarity and financial incentives continues to drive the growth of the alternative protein sector in Singapore.

Singapore recognises the need for substantial blended investment to scale these technologies and make them commercially viable. Given Singapore's status as a high-income country with access to global finance, the development of RAFT can be effectively supported through a combination of public research grants, subsidies, venture capital, and government procurements.

Public Research Grants are vital for fostering innovation in RAFT technologies. Singapore's government has consistently invested in R&D to drive advancements in agriculture. Agencies such as the Singapore Food Agency (SFA) and the National Research Foundation (NRF) offer grants to support research in vertical farming, alternative proteins, and sustainable agriculture.[145, 146] These grants enable universities, research institutions, and startups to explore new technologies, improve existing systems, and address challenges unique to Singapore's environment.

Subsidies play a crucial role in reducing the financial burden on companies and startups involved in RAFT.[147, 148] By offering subsidies for capital expenditure, such as the construction of vertical farms or the development of alternative protein production facilities, the government is encouraging private sector participation in sustainable agriculture. These subsidies can help offset the high initial costs associated with RAFT technologies, making it easier for businesses to scale up their operations and contribute to Singapore’s "30 by 30" goal.

Venture Capital is another essential financial instrument for driving the growth of RAFT in Singapore.[149] The city-state is already a thriving hub for venture capital, with numerous funds dedicated to technology and innovation. Venture capital has provided the necessary funding for RAFT startups to develop, test, and commercialise their products. Singapore-based venture capital firms, such as Temasek Holdings and the Southeast Asia-focused Golden Gate Ventures, have shown increasing interest in agri-tech and food tech, recognising the potential for high returns in these emerging sectors.[150] By investing in RAFT, these firms can support the growth of companies that are pivotal to Singapore’s food security.

Government Procurement is another powerful tool for scaling RAFT technologies.[151] The development of RAFT in Singapore, while promising, requires substantial investment to scale these technologies and make them commercially viable. Singapore’s government can use its purchasing power to create stable demand for RAFT products, such as locally grown vegetables or lab-grown meat. By integrating these products into public institutions, such as schools, hospitals, and the military, the government can provide RAFT businesses with a reliable market, enabling them to achieve economies of scale. This, in turn, can lower production costs and make sustainable food products more accessible to the broader population.

Singapore has the financial resources at its disposal to become a leader in the RAFT industry.

By investing in RAFT through public research grants, subsidies, venture capital, and government procurements, Singapore can drive innovation in sustainable agriculture, create high-tech jobs, and develop new industries focused on agri-tech and food tech. As Singapore continues to support the growth of RAFT, it is setting an example for other urban centres around the world, showcasing how a city-state with limited natural resources can achieve food security through innovation and strategic financial planning. The integration of advanced agricultural technologies into Singapore’s urban landscape will not only help secure its food future but also reinforce its position as a global leader in sustainable development and technological innovation. By leveraging these financial instruments, Singapore can ensure that RAFT becomes a cornerstone of its food security strategy, driving economic growth and contributing to global sustainability efforts.

Case Study B
Brazil financing innovations to complement agriculture sector

Brazil is an agricultural powerhouse and the largest net exporter of agricultural products.

The agricultural sector is crucial to Brazil's economy, accounting for a substantial portion of the GDP and providing livelihoods for millions of people, including smallholder and subsistence farmers. Brazil's diverse geography and rich biodiversity, particularly in the Amazon, Atlantic Forest, and Cerrado biomes, offer a variety of agricultural opportunities. However, this diversity also presents challenges, as different regions face varying environmental threats.

Climate change poses a significant risk to Brazil's agricultural sector, which is highly reliant on rainfed crops. Approximately 90% of Brazil's croplands depend on rain, making them vulnerable to extreme weather events like droughts, floods, and heatwaves.[152] Studies predict that by 2030, 51% of Brazil's agricultural lands could be pushed out of their optimal climate zones, with the figure rising to 74% by 2060.[153] This would severely impact the production of key staple crops like soybeans, corn, and sugarcane, which currently dominate Brazil's agricultural landscape.

To maintain a balance between economic growth and environmental conservation, Brazil needs to simultaneously handle the planning and adaptation of the agricultural systems to new threats imposed by climate change, and compliance with commitments to conserve the environment and biodiversity.[154]

Mindful of these imperatives, Brazil has already begun exploring RAFT practices.

Vertical farming – Recent advances in greenhouse technologies, including hydroponics and aquaponics, have provided promising momentum for vertical agriculture.[155] Between 35 to 40% of leafy vegetables sold in Brazil are now being hydroponically grown, and the country is home to Latin America's largest urban vertical farm, located in São Paulo. This facility uses advanced greenhouse technologies, including hydroponics and aquaponics, to produce fresh produce in a controlled environment, minimizing water usage and eliminating the need for pesticides.[156]

Cultivated meat – In the realm of alternative proteins, Brazil is making significant strides. More than a hundred companies in Brazil are involved in producing plant-based foods, exporting their products to over 30 countries.[157] Major food companies, such as JBS, have also entered the alternative protein market. JBS is building Brazil's first cultivated protein centre in Santa Catarina, set to open in late 2024 with an investment of approximately $62 million.[158] This facility will focus on producing lab-grown meats, contributing to the diversification of Brazil's protein sources and reducing reliance on traditional livestock farming, which is a significant driver of deforestation in the Amazon.

Addressing financing challenges requires a multidimensional approach.

Brazil's position as a middle-income country and agriculture industry leader, with access to both domestic and international finance, means multiple financing options are available. It is essential to foster collaborations between industry, universities, and research institutes. Enhancing knowledge dissemination through events can improve understanding and adoption among producers and experts. For this, policies supporting training courses and technical assistance services will be necessary to build capacity and support farmers in adopting and maintaining RAFT. With the rising interest in RAFT in Brazil, it is important that investors, farmers, entrepreneurs, and the government join forces to create a supportive environment for their development and cultural acceptance.

Public research grants and subsidies are essential for fostering innovation and supporting the development of RAFT technologies in Brazil. The Brazilian government has already implemented several agricultural incentive programs that could be adapted to support RAFT. For example, the Safra Plan offers subsidised credit lines for producers of different sizes, while the Low-Carbon Agriculture Plan (Plano ABC+), now in its second phase, provides funding for low-carbon agricultural activities. Although RAFT technologies are not explicitly included in these programs, integrating them could significantly boost investment in sustainable agriculture.

The Brazilian government has also made significant strides in promoting incentives for agricultural production which could be adapted to encompass RAFT. Of these, the best known and most used is probably the *Safra Plan*, which encompasses subsidised lines of credit catered to producers of different sizes and capabilities. Similar initiatives exist supporting renewable energies.[159] Also, since 2010 and currently in its second phase, the low-carbon agriculture plan (Plano ABC+) has provided credit to finance low-carbon agricultural activities to provide incentives for the uptake of a predetermined set of activities. While RAFT technologies are not explicitly barred from subsidised credit through the Plano ABC+, so far there is no real indication of participation in the program.[160]

Attracting sustainable investment - International cooperation could be used by Brazil to scale RAFT practices, aligning them with global sustainability goals. A novel form of financial regulation emerging worldwide is the green taxonomy to guide sustainable investments and a Brazilian green taxonomy is currently under development.[161] Including RAFT in green taxonomies could provide further incentives for investors hoping to “green” their portfolios and fund managers to provide innovative products.

Green bonds and blended finance - are emerging financial tools in Brazil that could support RAFT technologies. While green bonds in Brazil have primarily funded renewable energy and industry, they could be expanded to include RAFT, aligning with the country's sustainability goals. The Sovereign Sustainability Bond Framework, launched in 2023, raised about $4 billion for various sectors, but agriculture remains underfunded. Blended finance, which combines public, private, and philanthropic capital, can also attract investment by reducing risks. Initiatives like Eco Investing Brazil aim to mobilise private capital for sustainable practices, potentially benefiting RAFT projects.

Carbon/nature credits - Two-thirds of the Amazon rainforest exists inside Brazil's borders. Therefore, Brazil is well-positioned to capitalise on the growing market for carbon credits and become a potential leader in this market. Carbon taxes and cap-and-trade systems can be an opportunity to offset the environmental impacts of high-income countries while funding RAFT technology investments in the country. In Latin America, an existing carbon market created by the Mexican government includes both a cap-and-trade system and a carbon taxation. It is one example of how these markets could be used to finance sustainable development such as RAFT. In Brazil, a legislative bill is currently under consideration aimed at regulating the carbon market and establishing the Brazilian Greenhouse Gas Emissions Trading System (SBCE).[162] In the initial regulations, agricultural production will not be subject to the same carbon pricing mechanisms as other industries. According to the bill, the implementation of Brazil's carbon market is expected to be gradual, with full operationalization not anticipated until 2027, so there is time to adjust and include a broader set of options.

Development of RAFT in Brazil represents a significant opportunity for sustainable economic growth.

By adopting RAFT technologies, Brazil can mitigate the impacts of climate change, reduce deforestation, and preserve its rich biodiversity while ensuring a stable food supply for its population.

The sector is currently poorly regulated and lacks representation within the wider agriculture industry, which poses significant challenges when it comes to mobilizing finance and incentives fostering market development. This sector also lacks cohesive strategies for collective mobilization, preventing it from advocating for tax incentives or specialised credit lines from governmental bodies.[163] Stakeholders in the various disruptive agriculture technologies could consider joining forces under a single RAFT umbrella to increase their visibility and influence.

To achieve these goals, Brazil must leverage a combination of public research grants, subsidies, venture capital, public-private partnerships, green bonds, blended finance, and carbon credits. These financial instruments can provide the necessary support for innovation and help to scale-up RAFT technologies, establishing Brazil as a leader in resilient agriculture.

Case Study C
Rwanda: Embracing RAFT and international support needed

Agriculture is vital to Rwanda’s economy – Often celebrated for its rolling hills and scenic landscapes, Rwanda is a nation where agriculture plays a central role in both livelihoods and the economy. With nearly 70% of the population engaged in farming, agriculture contributes almost 30% to the country’s GDP.[164, 165] However, the sector faces mounting challenges due to limited arable land, soil and ecosystem degradation, and the escalating effects of climate change. These pressures underscore the urgent need for innovative approaches that can sustain agricultural productivity while minimising environmental impacts. To address these challenges, Rwanda must invest in its current food production systems. Modernising agriculture is necessary but might not be sufficient as resources become scarcer.[166] Complementing and conserving conventional agriculture with RAFT technologies such as hydroponics and insect production has also been recognised to be of critical importance. The Rwandan government, in partnership with international organizations, has made significant strides in promoting these practices, aiming to increase agricultural yields, enhance farmers’ incomes, and open up new export opportunities.[167, 168, 169]

Economic Policy Incentives

As evidence for these efforts, the government has pledged to invest RWF 8.2 billion (around USD 6.5 million) in research infrastructure by upgrading and constructing greenhouses and hydroponic facilities.[170] On the insect production side, Rwanda has marked two major milestones: the launch of national standards to guide the emergence of the edible insects sector; and the establishment of the country’s first commercial insect-based animal feed plant.[171]

Rwanda's agricultural transformation requires strategic investments in research and development (R&D), infrastructure, and capacity building. R&D is essential for adapting RAFT to small holder farmers, while infrastructure development and improved access to electricity and internet are crucial for scaling these innovations.[172, 173] Capacity building through training and education will equip farmers to adopt RAFT technologies, enhancing agricultural resilience.

The country’s limited financial resources present a significant challenge to fully realizing this vision, making it difficult to implement at large scale. However, Rwanda can leverage international support to overcome these financial barriers and develop RAFT into a viable and sustainable agricultural model.

Green bonds - One promising avenue is the issuance of green bonds. These bonds, specifically targeted at financing environmentally sustainable projects, could attract investment from international development agencies, impact investors, and private sector entities. The USD 500 million "African Development Bank (AfDB) Green Bond" issued in 2015 is a good example. By channelling funds raised through green bonds into RAFT projects, such as the construction of hydroponic farms or the insect protein facilities, Rwanda can secure the capital needed to scale these initiatives.

Blended finance - Blended finance presents another opportunity. By combining public and private resources, blended finance can help de-risk investments in RAFT technologies. For instance, Rwanda could partner with international donors and private investors to create a blended finance facility that offers concessional loans or guarantees for RAFT projects. For example, the Agriculture Fast Track Fund provides concessional loans and guarantees to lower the financial risks for private investors, making it easier to attract commercial funding for agricultural projects. This approach would lower the perceived risk associated with investing in innovative agricultural technologies, making it more attractive to investors.[174]

Impact investments – Additionally, impact investment funds focused on RAFT could play a crucial role in attracting capital to the sector. These funds, designed to generate both financial returns and positive environmental impacts, could provide the necessary financing to help RAFT startups and projects scale to achieve commercial viability. Rwanda could also explore development grants from international organizations such as the World Bank or the African Development Bank.[175, 176] These grants could be used to finance early-stage RAFT projects, including R&D, capacity building, and pilot projects, demonstrating the potential of RAFT technologies and attracting further investment.

Long term off-take agreements – International long term off-take agreements might also play a role in the development of RAFT and the local economy in general. Such North-South (e.g., Cotton Purchase Agreements between Burkina Faso and Switzerland) or South-South (e.g., Rice Offtake Agreements between Vietnam and the Philippines) agreements already exist for traditional agriculture.[177, 178, 179] Leveraging low operating and labour costs and access to renewable energy available in Rwanda to develop similar agreements around RAFT could secure the inflow of private money into the sector, and encourage the government to invest into the necessary infrastructures necessary to scale production. Long-term offtake agreements can be a vital tool for ensuring stable markets and incomes for agricultural producers in low-income countries, while simultaneously providing high-income countries with reliable access to essential agricultural commodities.[180, 181]

Carbon/nature credits - Finally, Rwanda's natural resources and biodiversity present opportunities for generating revenue through carbon and nature credits. A proposed nature-type credit market, similar to carbon trading but including biodiversity credits, could enable financial flows from wealthier to less affluent nations.[182] This market would compensate for environmental impacts that high-income countries cannot mitigate, while also funding investments in RAFT in the Global South. Such investments could enhance resilient food production systems and create secondary revenue from carbon or biodiversity credits. An example transferable to the case of RAFT in Rwanda is Kenya's Kasigau Corridor REDD+ Project, where collaboration between Wildlife Works and international partners generates revenue through carbon credits. This project highlights successful international cooperation for climate change mitigation and nature restoration, demonstrating how North-South financial flows can support both global environmental goals and local economic development, while fostering sustainable food.[183]

The successful implementation of RAFT in Rwanda holds the potential to not only transform the country's agricultural sector but also to achieve long-term food security and economic sovereignty. RAFT comes as a critical complement to local traditional agriculture. It offers a sustainable solution to the challenges posed by limited land, climate change, and soil degradation, ensuring that Rwanda can produce sufficient food to meet its needs without compromising the environment.

Beyond food security, RAFT also represents a significant business opportunity for Rwanda. By positioning itself as a leader in sustainable agriculture, Rwanda can attract foreign investment, create new industries, and open up export markets for its agricultural products. This could lead to the development of a comprehensive agricultural value chain within the country, generating jobs, boosting the economy, and enhancing Rwanda's standing on the global stage. As Rwanda continues to embrace RAFT, it is not only securing its own food future but also setting an example for other nations in the region, demonstrating that sustainable agriculture is both an economic imperative and a moral responsibility.

CHAPTER V

Conclusions and Recommendations

NATURE FINANCE

Food security in a severely climate disrupted world beyond 1.5°C is feasible if early action is undertaken underpinned by smart financing, national and regional strategies, and international collaboration.

Tomorrow's food systems must deliver in a climate future far more severe than implied by the Paris Agreement 1.5°C goal.

Current forms of agriculture, from small holdings to large-scale commercial systems, are already facing climate disruption. Regenerative agriculture and other advanced soil-based practices play an important role today in increasing resilience, improving soil conditions, nutritional outcomes, and in reducing emissions. Over time, however, climate impacts and ecosystem decline will make these practices increasingly unviable in many places. Given the time needed to scale food production systems that are resilient to a far higher level of climate change and nature degradation, such systems need to be invested in now, especially in those countries that are most vulnerable to climate impacts, both because of their locations and limited resilience capabilities.

Capital intensive food production systems, including those not reliant on soil integrity and open weather conditions, will have to be part of the solution. There will be many pathways to ensuring food security, the main one always remaining traditional soil-based agriculture, preferably in its regenerative form (see Box 5). Local production, however, will increasingly be embraced as a pillar of food security in a world of growing dislocation and uncertainties, including reduced certainties about the functioning of global food supply chains and sufficient humanitarian food support. Wealthier countries facing growing climate disruptions with limited useable land will embrace capital intensive, climate resilient approaches both to ensure food security and to drive their technology competitiveness.

Box 5. On the limitations of RAFT, and importance of agriculture beyond food security

While Resilient and Adaptive Food Techniques (RAFT) offers promising advancements in sustainable food production, it alone cannot replace traditional agriculture. There are compelling technical, economic, social, and environmental reasons why agriculture will remain essential, especially if it adopts regenerative practices.

1

Technical Limitations of RAFT. From a technological perspective, RAFT currently lacks the capability to produce staple crops like maize, wheat, and soybeans at a cost that competes with conventional or regenerative agriculture, and this is unlikely to change in the medium term. These three crops alone account for approximately 60% of the caloric and protein intake humans derive from plants. Thus, given these limitations, traditional agriculture remains a cornerstone for global food security.

2

Social and Economic Role of Agriculture. Agriculture is a fundamental social and economic pillar worldwide. While it contributes about 4% of global GDP, this figure can exceed 50% in certain countries, providing economic stability and opportunities for equity. In regions such as Sub-Saharan Africa, for example, agricultural growth has averaged approximately 4.3% annually since 2000, contributing significantly to economic progress, as noted by the United States Agency for International Development (USAID). Today, around 27% of the global workforce is employed in agriculture, which is also crucial in preserving local cultural heritage, particularly in an increasingly liberalised global food market.

3

Environmental Contributions of Agriculture. Agriculture also plays an often underappreciated role in environmental conservation, biodiversity enhancement, and climate action. Regenerative agriculture exemplifies this potential, with the ability to transform farming from a net carbon emitter to a carbon sink. It offers additional benefits for biodiversity, such as increased pollinator populations, improved soil and wildlife diversity, and enhanced resilience to natural disasters like droughts and floods.

Low and middle-income countries will struggle to afford such capital-intensive systems.

With adoption by wealthier countries and continued technology development, the delivered cost of nutrition will over time fall, as it has with renewables and electric vehicles. Now and for some time, however, these technologies will not be affordable by low to middle income countries given their costs, the cost of capital to those countries, and their lower incomes and ability to pay for higher cost nutrition. Left to itself, this process will deliver affordable technology too late to support improved food security in low and middle-income countries, or not at all.

Climate resilient, capital intensive food production systems must be made more affordable through both self-interested and solidarity-based action of wealthier countries. Bringing down the cost of nutrition delivered by such systems requires intensive R&D and policy incentives that allows for the benefits of rapid scale. Our estimates indicate that whilst significant investments are needed to bring down the cost of nutrition delivered by these technologies to parity with the equivalent from conventional food production, in the wider context this level of investment could be considered modest.

Much like Germany's actions with promoting renewables and China with their policies on electric vehicles, wealthier countries will also need to act in a similarly ambitious way with regards to localising food production and sharing the gains from developing the next generation of globally relevant food technologies. Some countries are already moving along this pathway, but the competitive landscape still remains open.

Accelerated adoption by low and middle-income countries requires international cooperation.

The lag between wealthier and low and middle-income countries' adoption of renewables was 10-15 years. To ensure food security given the pace of climate change and nature loss, the equivalent lag for climate resilient, capital-intensive food systems will have to be dramatically shortened. Waiting for the technology to become cheap enough is not a serious option.

International cooperation is critical to enable the ramping up of investment in such systems to happen earlier in the technology-learning-scaling cycle that should eventually bring down costs to affordable levels. Wealthier countries may engage for many reasons, from their industrial and geopolitical strategies, to securing continued access to critical resources, and from actions to reduce forced migration, to enacting regulated, trade related, or reputation-linked ways to offset their climate and broader nature footprints.

Financial innovations can enable early adoption to be scaled in low and middle-income countries.

There is no one-size-fits-all equivalent to the Feed in Tariff deployed so effectively in scaling early adoption of renewables. But there is a cluster of financial innovations that can be packaged and standardised into a series of off-the-shelf instruments to be used across different technologies and low and middle-income country contexts.

Key components would include KPI-linked debt and broader financing instruments, whether at the sovereign or corporate level that could be blended with public finance, or entirely commercial funding betting on higher food prices in a climate impacted future. This could be augmented by the use of climate and nature financial derivatives such as carbon and biodiversity credits, which could provide the equivalent of a performance based guaranteed offtake revenue stream, also then helping to further de-risk the investments. Other options include the often called for redeployment of perverse environmental subsidies.

Risks associated with such a strategy need to be understood and mitigated.

Incentivising the adoption of capital-intensive food production systems, whilst hopefully reducing climate risks and increasing food security, might create new external dependencies and costs linked in particular to intellectual property rights. At this early stage, there is a real opportunity to build on the lessons of creating open source or at least IP-limited technologies in the field of critical medical solutions through public interest co-investment with commercial actors. Other risks might include unintended impacts on existing food production systems and farmers, and the risk of de-natured production resulting in less attention paid to nature restoration and conservation despite the opportunity provided by reduced land pressure to invest in conservation and restoration.

Affordable, accessible nutrition for all in a severely climate disrupted world is one of, if not the single most important global challenge to address. Stopping and reversing climate change and nature loss is of course the first best solution and requires the continued intensification of collective efforts. Yet this should not prevent us embracing the coming need to deliver food security in a world that in many parts will be unable to deliver affordable, accessible food through open weather, soil-based solutions. Important is to avoid inertia in pivoting to ambitious action because of a toxic combination of hope, denial and vested interests, or even solidarity with existing but unsustainable farming communities.

It is time, indeed past time, to consider radical alternatives to ensuring food security in a severely climate disrupted future.

There is no intention here to promote a particular technology or food production system, or to advocate for specific ways to finance their early adoption. What is intended is to remind us of all that business-as-usual will simply not deliver, and it is critically important for us all to consider what for many may be unthinkable ways forward. This is true for food security, and it is true for many if not all other aspects of the future lives that we and our decedents will have.

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