Framework Convention on Climate Change

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Technology Executive Committee

03 September 2024

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17–20 September 2024 (20 September TEC-CTCN Advisory Board Joint session)

Draft knowledge product "Climate Technologies for Agrifood Systems transformation"

Cover note

I. Background

1. As per activity C.1.1 of the rolling workplan, the TEC is collaborating with the Food and Agriculture Organization of the United Nations (FAO) to produce a knowledge product in 2024 and to organize an event at COP 29 to launch the knowledge product.

2. Pursuant to the guidance at TEC 28, the TEC activity group, in collaboration with FAO, revised the annotated outline, developed the final draft knowledge product, key messages and recommendations for COP 29 and CMA 6 and prepared a concept note for the event at COP 29.

3. The open-eneded activity group, met three times, to consider the guidance provided at TEC 28 and to develop the knowledge product in collaboration with FAO. Two iterations of the knowledge product were shared and comments were provided by the activity group members.

4. At TEC 29, a representative of FAO and the co-leads of the activity group will present a final draft knowledge product.

II. Scope of the note

5. The annex to this note contains the revised draft knowledge product "Climate Technologies for Agrifood Systems transformation"

III. Expected action by the Technology Executive

6. The TEC will be invited to provide guidance to the activity group on the draft knowledge product, with a view to finalizing after TEC 29.

Annex

Climate Technologies for Agrifood System Transformation

Placing food security, climate change and poverty reduction at the forefront

(Draft Title)

Draft, 2 September 2024

Contents

Tables, figures and boxes

Abbreviations

AI	artificial intelligence
AMPA	Asociación Amazónicos por la Amazonía
AR6	Sixth Assessment Report of the IPCC
CCC	Copenhagen Climate Centre
CPI	Climate Policy Initiative
COP	Conference of Parties
CPA	clean production agreement
CRFS	Climate Resilience Food Systems
CTCN	Climate Technology Centre and Network
DAC	Development Assistance Committee
DSSI	decision support system for irrigation
FAO	Food and Agriculture Organization of the United Nations
FFS	farmer field school
FLW	food loss and waste
GDP	gross domestic product
GHG	greenhouse gas
GSMA	Global System for Mobile Communications Association
ICT	information and communication technologies
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
LDC	least developed country
LIC	low-income country
LMIC	lower-middle-income country
LT-LEDS	long-term low-emission development strategies
MCA	multi-criteria analysis
MSME	micro, small and medium-sized enterprise
NAP	national adaptation plan
NDC	nationally determined contribution
NENA	Near East and North Africa
OECD	Organisation for Economic Co-operation and Development
PLACA	Platform of Latin America and the Caribbean for Climate Action on Agriculture
PPP	purchasing power parity
SACCO	savings and credit cooperative
SHI	Sustainable Harvest International
SSC	South-South Cooperation
SDG	Sustainable Development Goal
SME	Small and medium-sized enterprise
SPLEWS	seasonal prediction and livestock early warning system
TAP	technology action plan
TEC	Technology Executive Committee
TNA	technology needs assessment
TW	treated wastewater
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children’s Fund
UNIDO	United Nations Industrial Development Organization
WEF	Water–Energy–Food
WHO	World Health Organization

Glossary

Agrifood systems	**The entire range of actors, and their interlinked value-adding activities, engaged in the primary production of food and non-food agricultural products, as well as in storage, aggregation, post-harvest handling, transportation, processing, distribution, marketing, disposal and consumption of all food products, including those of non-agricultural origin (FAO, 2021a).**
Agroecology	The science of applying ecological concepts and principles to manage interactions between plants, animals, humans and the environment for food security and nutrition. Throughout the world, farmers already apply this approach, which has a fundamental pillar in traditional and local knowledge (FAO, 2021a).
Aquaculture	The farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated (FAO, 2024a).
Biodiversity	The variety of life at the genetic, species and ecosystem levels. Biodiversity for food and agriculture is, in turn, the subset of biodiversity that contributes in one way or another to agriculture and food production (FAO, 2021a).
Climate	In a narrow sense, defined as the average weather; more rigorously, defined as the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands or millions of years (IPCC, 2021).
Climate change	A change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC, 2021).
Climate technology	See Box 1.
Climate adaptation technology	See Box 1
Climate mitigation technology	See Box 1
Conservation agriculture	A farming system that promotes minimum soil disturbance (i.e. little or no tillage), maintenance of permanent soil cover and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, contributing to increased water- and nutrient-use efficiency, and improved and sustained crop production (FAO, 2022a).
Fisheries	A fishery is an activity leading to the harvesting of fish, within the boundaries of a defined area. The fishery concept fundamentally gathers indication of human fishing activity, including from economic, management, biological/ environmental and technological viewpoints (FAO, 2024a).
Food loss and waste	Food loss is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers (FAO, 2019). Food waste refers to the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers (FAO, 2019).

Food security	The situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Four traditional dimensions can be identified (food availability, economic and physical access to food, and food utilization), as well as the two additional dimensions of agency and sustainability that are proposed by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security but are not formally agreed upon by FAO or other bodies, nor is there an agreed language on the definition (FAO, 2021a).
Livestock	Terrestrial, domesticated animals raised in an agricultural setting to provide traction or produce commodities such as meat, milk, eggs and hides. Livestock contributes to diverse agrifood systems globally, playing many roles for different groups of people (FAO, 2018a).
Nationally determined contributions (NDCs)	Commitments made by each country under the Paris Agreement, outlining the country's planned efforts to reduce national greenhouse gas emissions and adapt to the impacts of climate change. NDCs are submitted to the United Nations Framework Convention on Climate Change.
Precision agriculture	A management strategy that gathers, processes and analyses temporal, spatial and individual data and combines them with other information to accurately manage variations in the field. In so doing, it supports management decisions and utilizes precise machinery for improved resource-use efficiency, productivity, quality, profitability and sustainability of agricultural production (FAO, 2022a).
Resilience	The ability of individuals, households, communities, cities, institutions, systems and societies to prevent, anticipate, absorb, adapt and transform positively, efficiently and effectively when faced with a wide range of risks, while maintaining an acceptable level of functioning, without compromising long-term prospects for sustainable development, peace and security, human rights and well-being for all (FAO, 2021a).
Small-scale producers	Households running small-scale agricultural businesses of crops, livestock, fisheries, aquaculture, pastoralism or forestry, operating under greater constraints due to limited access to markets and resources such as land and water, information, technology, capital, assets and institutions (FAO, 2021a).
Sustainable agrifood systems	Systems that deliver food security and nutrition for all, while sustaining the livelihoods of agrifood systems' actors, without compromising the economic, social, and environmental bases for the food security and nutrition of future generations. Systems must be sustainable economically (i.e. profitable and equitable), socially (having broad-based benefits for society) and environmentally (with positive or neutral impact on the natural environment) (FAO, 2021a).
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, a community, assets or systems to the adverse impacts of shocks and stresses (FAO, 2021a).

Foreword

[to be added]

Executive summary

The global community has committed to responding to climate change while ensuring decent livelihoods and healthy food for everyone, keeping within planetary boundaries. Transforming agrifood systems is essential to meeting these challenges, with climate response being an intrinsic element.

The asks today on agrifood systems are many. The world is facing enormous and multiple challenges, including ensuring economic and social development, reducing poverty, meeting nutritional and food security needs, and protecting the environment. Transforming agrifood systems is needed to improve production, nutrition, natural resource management and livelihoods. All of these must be achieved while responding to the current and future threats of climate change.

In 2023, approximately 733 million people faced hunger, representing 1 in 11 people globally, and one in five in Africa. If current trends persist, around 582 million people could be chronically undernourished by 2030, with half of them in Africa (FAO *et al.*, 2024). Substantial improvements to agrifood systems at the global, regional and local levels are necessary not only to ensure decent employment and livelihoods but to uphold the right to adequate food for all individuals, particularly the most vulnerable populations (e.g. people with disabilities, older people, migrants, Indigenous Peoples).

Providing rapidly increasing populations with sufficient and nutritious food while remaining within sustainable environmental, economic and social boundaries is a pressing global concern. Climate change tightens the boundaries of potential solutions through its impacts and the need to adapt to them, as well as the mitigation measures required to keep global temperature increases within a 1.5 °C to 2 °C threshold. Climate change is a global crisis, but the effects on countries, people and communities are quite varied: the greatest exposure to hazards and lowest capacity to cope with them are found amongst people who have contributed the least to the problem. The need for more resilient systems that can sustain increasing demands in a setting of tightening constraints is evident. Resilience must be generated across environmental, social and economic domains, all the while maintaining the economic viability of agrifood systems to ensure that transition occurs in a just and fair manner. Business as usual is failing us; we need to change the way we do things to meet this challenge.

Climate technologies are an important enabler to meet the many demands on today’s agrifood systems. Their deployment must be designed to contribute to long-term development objectives and the just transition of agrifood systems.

Climate technologies encompass equipment and products, techniques, practices, practical knowledge and skills, in the context of the processes and institutional frameworks required for uptake. These technologies are for climate adaptation and/or climate mitigation.

The Paris Agreement emphasizes the transfer of technology and notes the crucial role of technologies in achieving ambitious adaptation and mitigation goals. Furthermore, acknowledging the importance of "existing technology deployment and dissemination efforts" the Parties encouraged cooperative action on the development and transfer of technology (Paragraph 2, Article 10, Paris Agreement).

Climate technologies embody the changes needed to depart from a business-as-usual trajectory to move towards resilient and sustainable agrifood systems. These technologies represent an essential means of accelerating needed progress on adaptation, whereby structural resilience for agrifood systems is built in. They are also fundamental to achieving low-emissions development. Effective implementation of climate technologies must be embedded within the broader objectives of agrifood system transformation, including improvements to livelihoods, diets and natural resource management. There are often synergies amongst these objectives, but trade-offs can also exist and need to be explicitly addressed.

In many low-income countries (LICs) and lower-middle-income countries (LMICs), agrifood systems represent a major share of the economy and employment. In this context, agrifood systems support the livelihoods of a large share of the world's poor people. Improving those livelihoods must be a priority in the process of transforming food systems to meet the challenges of climate change. The way in which climate technologies are identified, selected and deployed greatly influences the impacts on livelihoods.

Agrifood systems are made up of agrifood value chains, in which all steps – from producers to consumers – are linked; climate change technologies must be considered along the entire chain.

Agrifood systems are intricate networks made up of various actors and activities responsible for producing, processing, distributing and consuming food and agricultural products. They are defined as encompassing all products that originate from the production of crops, livestock, forestry, fisheries and aquaculture, and comprise pathways and supply chains not only from food producers to consumers, but from input suppliers to producers (the report contains the full definition).

Agrifood value chains are embedded in the broader concept of agrifood systems, and consist of several steps (which influence, and are influenced by, others) that transform raw materials into final products for consumers. Effective coordination and collaboration among stakeholders along the value chain are essential for optimizing the efficiency, quality, sustainability and resilience of the agrifood system. Additionally, advancements in technology, infrastructure, logistics and market access play crucial roles in shaping the dynamics of the agrifood value chain.

Technology needs assessments (TNAs) are used to identify the climate technologies for sectors in a specific country or context. The TNA process needs to be strengthened to reflect agrifood system heterogeneity and specific climate needs. Detailed country- and context-specific assessments are needed to define which climate technologies can be used, for which specific climate objective and at which specific stage of the value chain. Given the significant differences across agrifood systems, accurate and context-specific assessments of the local agrifood systems are needed to define and underpin the climate technology options to be used, deployed, taken up and expanded. Assessments need to identify technologies that are sustainable (economically, socially and environmentally) with due consideration for natural resources, water, and social inclusion.

It is important to consider the entire agrifood value chain, including processing, distribution and consumption in climate TNAs. Until now, much of the focus has been on production, yet there are many opportunities for effective climate technology deployment and for livelihood enhancement in other segments of the value chain, as illustrated in the report.

The assessment blocks need to be tied to a clear capacity needs and capacity-building strategy and effort: climate technologies cannot be deployed or taken up if the suitable and correct skill sets are not in place. This is also needed to ensure that institutions in the countries can access the needed financing sources and opportunities. Due attention needs to be paid to the informal sector; the report shows how access to climate technologies for smallholders and more vulnerable segments of the population often involves interacting with the informal sector.

There are considerable differences in capacity needs and institutional requirements between countries of different income levels. Concerted effort to ensure access for low income and smallholder actors along the entire agrifood value chain and of vulnerable populations is needed.

Three important factors that drive capacity needs for climate technologies are as follows: (i) the need for compatibility with the functions and non-climate-related objectives of agrifood system transformation; (ii) the existing capacity in place; and (iii) the nature of prevalent climate risks and associated vulnerabilities. There is considerable variation in all three of these factors in the agrifood systems across and within countries. Thus, context-specific approaches to meeting capacity needs are required.

Compared with higher-income countries, LICs and LMICs present significant differences in existing capacities, as well as in the priorities and constraints they face when managing agrifood systems. Ensuring complementarity between uptake of climate technologies and the effort to improve livelihoods dependent on agrifood systems has implications for the capacity needed. Effective deployment of climate technologies in developing countries requires concentrated efforts to improve mechanisms of access, especially for vulnerable people with low skill sets and low uptake potential. This can require improvements in human skills (basic and/or digital literacy) or overcoming institutional failures such as weak regulatory systems or lack of accessible financing options.

Interacting with the informal sector in agrifood systems for climate technology deployment is important in reaching vulnerable populations, particularly in LICs and LMICs. Improving the delivery of financial services and information are key enablers of capacity for climate technology uptake. Overcoming technology lock-ins and path dependencies is an issue in higher-income countries that requires a broad and coordinated effort across different interest and policy groups to achieve change.

Climate technologies in agrifood systems are significantly underfinanced.

Climate technologies in agrifood systems are receiving a minuscule share of total climate finance. Given the importance of the agrifood sector in countries' nationally determined contributions (NDCs), financing is inadequate to support the investments needed for effective climate response in agrifood systems.

According to the Climate Policy Initiative (CPI) (2023), in 2019/2020 only 4.3 percent of the global climate finance tracked at the project level (or 28.5 USD billion) went to agrifood systems, with this share dropping to around 1 percent when referring only to adaptation finance. In the same period, only 20 percent of the tracked venture capital investments in agrifood technology went to companies focusing on climate change, amounting to an annual average of USD 4.8 billion (Climate Focus, 2023; CPI, 2023).

Analysing climate-related development finance for agrifood systems for technology-related projects, shows that adaptation is the most targeted climate objective, attracting 51 percent of flows, compared with 23 percent for mitigation and 26 percent for cross-cutting. There are substantial differences between sectors, with 80 percent of flows for food security projects being dedicated to adaptation, compared with only 9 percent allocated to mitigation. This is followed by agriculture and fisheries, with 71 percent and 68 percent of flows going to adaptation, respectively. Projects related to energy and forestry have the highest share of mitigation focus, while projects related to environment and biodiversity attract mainly cross-cutting flows.

Finance flows provided under terms suitable to the nature of the technology investment (returns over the long term and often in the form of public goods) and capacity of countries (indebtedness and need for conditionality) need to be increased and further targeted, building in particular on the technology assessment blocks and on the capacity needs of the country.

Enhancing coordination between climate change and agrifood system policies is needed to ensure effective deployment of climate technologies. Lessons learned from the TNA process should inform the way forward.

The need to consolidate climate action and the planning, implementation and financing of agrifood system development is urgent. This is more so evident at a time when the high costs of climate-related damage to the agrifood sector are already being recorded (FAO, 2023a), where the need for adaptation is growing but consistently underfinanced (UNFCCC, 2023a), and where agrifood sector development is recognized as essential in reaching global food security and poverty eradication goals (FAO, 2017). Climate technologies in the agrifood sector are an essential means of accelerating needed progress on adaptation.

At the policy level, coordination between agrifood systems and climate change policy, programming and investments is essential to ensuring success. Although such a notion has been reiterated over time, it still appears to be one key bottleneck for implementation and full uptake.

Lessons from the experience of developing TNAs provide insights into how they can contribute to a better integration of climate change and agrifood sector policy in the NDCs. The TNA process calls for a first phase of identifying the decision context of technologies (Haselip *et al.*, 2019). This entails an understanding of how climate technologies and the TNA process relate to other national processes, including long-term development priorities. If the TNA is well run, this is the point at which policy priorities related to agrifood system transformation are identified. The TNA process involves the establishment of technical working groups that are often sectoral based and chaired by the national institution with a political mandate over that sector (Haselip *et al.*, 2019). Focusing on barriers to adoption in the TNA/TAP process brings more attention to the issue of access to technologies; something that is critical for developing countries. Aligning the results of the TNAs and TAPs with the investment criteria of international public climate finance is an effective way to increase the likelihood of obtaining financing.

It is true that the asks are many but building a system that supports cross linkages between sectors and demands, builds evidence into the process and builds local capacity is both readily feasible and responsive to the magnitude of the challenge. This is particularly important due to the context specificity of technology impact and the potential trade-offs that can arise.

Climate technologies in agrifood systems are a priority for developing countries and need to underpin NDCs 3.0.

Out of the latest NDCs submitted (as at 31 December 2023), 94 percent include adaptation and 86 percent include mitigation efforts in agrifood systems. Out of the 6,437 agrifood system-related climate technologies included in the NDCs, only 14 percent have an estimated cost. When specified, almost half (45 percent) said that technologies are fully dependent on the provision of external support (e.g. finance, technology transfer). In lower-income countries, around 80 percent of climate technologies for agrifood systems are either partially or fully conditional on the provision of external support.

In TNAs, the agriculture sector is consistently prioritized by developing Parties. Notably, 87 percent of Parties identify the agriculture, forestry and other land-use sectors as a priority for adaptation activities, while 35 percent consider the agriculture sector for mitigation activities. This is followed by the water resources sector (mentioned by 79 percent of Parties in their TNAs), and infrastructure and settlements, including coastal zones (prioritized by 39 percent) (UNFCCC, 2020).

Acknowledgements

[to be added]

1. Introduction

The importance of agrifood systems in climate action has garnered increasing attention from the global community, as evidenced most recently by the Conference of Parties (COP) 28 UAE Declaration on Sustainable Agriculture, Resilient Food Systems and Climate Action (hereafter, the "COP28 Declaration"). However, despite the urgency of the issue, solid analysis of where and how climate technologies can be most effective in agrifood systems is lacking. This report aims to address such a gap.

By their very nature, climate technologies must be compatible with the functions of agrifood systems, which are currently under significant pressure to address the food security and nutrition of a growing population. By 2050, feeding a global population of almost 10 billion people in a sustainable and nutritious way means a radical transformation in how food is produced, processed, traded and consumed. In 2023, approximately 733 million people faced hunger, representing 1 in 11 globally and one in five in Africa. If current trends persist, around 582 million people could be chronically undernourished by 2030, with half of them in Africa (FAO *et al.,* 2024). Substantial improvements to agrifood systems at the global, regional and local levels are necessary not only to ensure decent employment and livelihoods but also to uphold the right to adequate food for all individuals, particularly the most vulnerable populations (e.g. people with disabilities, older people, migrants, Indigenous Peoples). This transformation must provide nutritious products for consumers, without damaging natural resources and contributing to climate change.

The concept of climate change technologies (hereafter referred to as "climate technologies") is defined as a piece of equipment, technique, practical knowledge or skills with which to perform a particular activity in relation to climate change mitigation or adaptation. In this context, climate adaptation technologies aim to increase the capacity of people and systems to adapt to climate variability and change, while climate mitigation technologies seek to reduce greenhouse gas (GHG) emissions or increase the capacity of carbon sinks to absorb GHG from the atmosphere. These definitions (described in more detail in Box 1) are multidimensional and include the elements of equipment, know-how/skills, and institutional set-up.

Box 1. Definitions of climate technology, climate adaptation technology and climate mitigation technology

According to the Food and Agriculture Organization of the United Nations (FAO, 2022b), technology for sustainable agrifood systems can be defined as the application of science and knowledge to develop techniques to deliver a product and/or service that enhances the sustainability of agrifood systems.

The Technology Needs Assessment Guidebook (Haselip *et al*., 2019) approaches climate technology by building on the definition of technology provided by the Intergovernmental Panel on Climate Change (IPCC): a piece of equipment, technique, practical knowledge or skills for performing a particular activity. Here, it is common to distinguish between three different components of technology:

- The tangible component such as equipment and products, i.e. hardware.
- The processes associated with the production and use of the hardware. This component is essentially built from know-how (e.g. agricultural management, cooking and behavioural practices), i.e. software.
- The institutional framework, or organization, involved in the adoption and diffusion process of a technology, i.e. orgware.

These three components are all part of a specific technology, but the relative importance of each component may vary from one technology to another (Haselip *et al*., 2019; Metz and Davidson, 2000).

Traerup and Bakkegaard (2015) also build on the IPCC definition of technology to define climate adaptation technology. They incorporate definitions from United Nations Development Programme (UNDP) (2010) and UNFCCC (2010), describing it as "all technologies that can be applied in the process of adapting to climatic variability and climate change" and "the application of technology in order to reduce the vulnerability, or enhance the resilience, of a natural or human system to the impacts of climate change."

Dhar, Desgain and Narkeviciute (2015) define climate mitigation technology as encompassing technologies and practices that can lead to a reduction in GHG emissions or an increased capacity of carbon sinks to absorb GHG from the atmosphere. It is worth noting that the definition of this technology varies across sectors.

To summarize, in the report, climate technologies will be defined as encompassing equipment and products, techniques, practices, practical knowledge and skills, in the context of the processes and institutional frameworks outlined in the above definitions.

Agrifood systems play a central role in global efforts to reduce poverty and hunger, improve people's nutrition and health, and respond to climate change. Most of the world's poor people live in rural areas and depend on agrifood systems for some part of their livelihood (FAO, 2024). Today, 3 billion people are unable to afford a well-balanced, healthy diet that includes whole grains, fruits, vegetables and animal-sourced foods (Ambikapathi and Mason-Cruz, 2024); a situation further hampered by food loss and waste in agrifood systems (FAO, 2019). Transforming agrifood systems to diversify and enhance the nutritional quality of food products, making them affordable and accessible to all, is crucial for achieving nutritional security and upholding the right to adequate food for everyone. At the same time, it is vital that those whose livelihoods depend on agrifood systems have access to food (FAO, 2023).

Water is essential for agrifood systems, and access to fresh hygienic water is vital for human life. However, population growth is leading to increased demands on land, water and energy, thus exacerbating water scarcity issues for food production, especially in drought regions (UNESCO World Water Assessment Programme, 2012; Khan and Hanjra, 2009; Cook *et al*., 2018). The global population is expected to increase to 8.5 billion and 9.8 billion by 2030 and 2050, respectively, amplifying pressures on agriculture for food production, with this latter being anticipated to increase by 35 to 56 percent in 2050 (United Nations, 2022; UNESCO World Water Assessment Programme, 2012; van Dijk *et al.,* 2021). Moreover, accounting for 70 percent of global freshwater withdrawals, irrigation puts a strain on water resources, especially in arid regions where water usage surpasses recharge rates (UNESCO World Water Assessment Programme, 2012; Khan and Hanjra, 2009). Population growth, urbanization and climate change further intensify competition for water resources (FAO, 2014), with the 2022 IPCC report highlighting the severe repercussions of intensified global warming and extreme weather events on food and water security, as well as agricultural productivity (IPCC, 2022a).

Strong links exist between climate change response, water management, livelihoods, nutrition, and food security. Climate change continues to burden all aspects of agrifood system functions. The increased frequency of extreme weather events has resulted in reductions in incomes – particularly for those dependent on agrifood systems – and rising food prices, thus leading to higher incidences of malnutrition in all forms, including micronutrient deficiencies, undernutrition and, more recently, overweight and obesity (Ambikapathi and Mason-D'Croz, 2024). Growth in agricultural income has been a key trigger for significant reduction in poverty and is still needed in many low-income countries (LICs) and lower-middle-income countries (LMICs).[1] Inadequate adaptation and inappropriate mitigation can stymie needed growth; in contrast, inclusive adaptation and mitigation strategies for agrifood systems that ensure

[1] For the current 2024 fiscal year, low-income economies are defined as those with a GNI per capita, calculated using the World Bank Atlas method, of $1,135 or less in 2022; lower-middle-income economies are those with a GNI per capita between $1,136 and $4,465;

economic and social inclusion in transitioning towards climate-resilient development pathways can enhance the benefits to livelihoods and nutrition, especially for those in vulnerable situations.

As reported in the Sixth Assessment Report of the IPCC (AR6) (IPCC, 2022a), 3.3 billion people live in countries classified as very highly or highly vulnerable (Schipper *et al*., 2022). This assertion is corroborated by the United Nations Framework Convention on Climate Change (UNFCCC) in its synthesis report for the technical assessment component of the first global stocktake (UNFCCC, 2022): state of adaptation efforts, experiences and priorities. In both cases, emphasis was placed on the notion that adaptation efforts should be inclusive, both socially and territorially, and reduce existing inequalities (in particular, gender inequalities and those faced by marginalized groups). Aligning the development agenda with climate goals was identified as a potential enabler of inclusive growth.

The UNFCCC's synthesis report on the technical dialogue of the first global stocktake (UNFCCC, 2023b) calls for urgent increased adaptation actions to reduce and respond to increasing climate impacts, particularly for those who are least prepared for change and least able to recover from disasters. The COP28 Declaration recognizes the multiple objectives of agrifood system transformation and the urgency of increasing the resilience of said systems. The 160 countries that endorsed the declaration (as at 30 July 2024) expressed their intent to "pursue broad, transparent, and inclusive engagement, as appropriate within our national contexts, to integrate agriculture and food systems into National Adaptation Plans [NAPs], Nationally Determined Contributions [NDCs], Long-term Strategies, National Biodiversity Strategies and Action Plans, and other related strategies before the convening of COP30" (United Nations Climate Change, 2023). The declaration also calls for the scaling up of finance for climate action in agrifood systems and for the acceleration and scaling up of science- and evidence-based innovations, including those from local and Indigenous Peoples' sources.

Agrifood systems have an important role in both adapting to, and mitigating, climate change. It is a sector highly exposed to climate-induced hazards, and thus vulnerable to their effects, while simultaneously being responsible for GHG emissions. As in all systems, energy is needed to support agrifood systems' functioning. Currently, agrifood systems account for 30 percent of global energy use and 31 percent of human-induced GHG emissions. This is combined with one third of the food being lost or wasted post-harvest (FAO, 2019). Climate technologies are key in supporting the transition of these systems to ensure they are more resilient and efficient.

Climate technology plays a crucial role in the global effort to address climate change, as outlined in international agreements such as the Paris Agreement, with governments, businesses and research institutions actively investing in and developing climate technologies in the hope of guaranteeing a more sustainable and resilient future in the face of such challenges.

Technology refers to the application of scientific knowledge, skills, methods and tools to solve practical problems, achieve specific objectives or create products and services, often with the aim of improving efficiency, productivity or the overall human experience.

In a broader sense, technology encompasses both tangible inventions (physical devices and systems) and intangible advancements (software, algorithms and methodologies) that contribute to the progress of society. It plays a crucial role in shaping the way agrifood systems and the related people live, work, communicate and interact with their environment. Climate technologies are a specific enabler of climate actions in agrifood systems. If current trends of drivers affecting agrifood systems do not change, the sustainability and resilience of agrifood systems will be under threat and food crises are likely to increase in the future. In this setting, technologies function as triggers/accelerators and can enable sustainable outcomes for agrifood systems.

The important role that technologies play in adaptation for agrifood systems is often recognized by countries in their communications. UNFCCC's synthesis report for the technical assessment component of the first global stocktake noted that for adaptation, the most commonly prioritized sectors for technology development and transfer were agriculture (87 percent of the Parties), water resources (79 percent) and infrastructure and settlements, including coastal zones (33 percent) (UNFCCC, 2022).

In the context of agrifood systems in developing countries, the lack of access to technology poses a significant barrier to progress. While cutting-edge technology solutions are transforming agrifood systems and agriculture practices in many parts of the world, a substantial portion of farmers, fishers or small-scale producers along the agrifood value chain in developing countries still rely on traditional methods. This divide hampers the ability of those in developing countries to improve productivity, enhance sustainability and adapt to the challenges of a changing climate. Access to modern technology in agrifood systems is often constrained by factors such as economic constraints, inadequate infrastructure, inappropriate policy and regulations, and limited education.

While the focus is typically on adopting cutting-edge technology, it is crucial to recognize the inherent value of traditional knowledge and local wisdom in agrifood systems. Farmers in developing regions often have cultivated practices (passed down through generations) that are well suited and adapted to their specific ecosystems. These traditional methods often embody a deep understanding of local conditions, resource management and sustainable agriculture. Such knowledge can be usefully transferred beyond their place of origin, thus augmenting their potential contribution to successful climate action.

With one of its objectives relating directly to agriculture (Article 2), the Paris Agreement aims to enhance adaptability to changing environmental conditions and to mitigate their negative impacts by promoting a climate-resilient approach in which GHG emissions are lowered and food security is ensured. The agreement recognizes that each participating Party has varying capabilities in terms of implementing these approaches to achieve the specified goals. Therefore, each Party is tasked with establishing its own NDC: ambitious targets aimed at responding to climate change within the agreement's scope, and with the support of developed country Parties, to ensure effective implementation.

Due to the complexity of the issues at hand, the Parties to the agreement have also recognized the need for "integrated, holistic and balanced non-market approaches" (United Nations, 2015) that aim to eliminate poverty and promote sustainable development. Among these approaches, the agreement emphasizes the importance of technology transfer and notes the crucial role of technologies in achieving ambitious adaptation and mitigation goals. Furthermore, acknowledging the importance of "existing technology deployment and dissemination efforts" (United Nations, 2015, Article 10, Paragraph 2), the Parties encourage cooperative action on technology development and transfer. As the process of NDCs continues to evolve and update, the identification of viable climate technologies to support implementation of NDCs at the country level will be crucial.

1.1 Overview of the report

This report focuses on climate technologies that support agrifood transformation across different sectors (crops, livestock, fisheries, forestry, aquaculture) towards enhancing resilience (adaptation), inclusiveness (small-scale producers, Indigenous Peoples, vulnerable communities) and reducing GHG emissions (mitigation). It will also include cross-over technologies (e.g. those that address both adaptation and mitigation).

The report builds upon the 2023 Technology Executive Committee (TEC)–FAO thematic dialogue, as well as previous work of both TEC and FAO on agrifood systems and climate technologies. It aims to present an overview of the agrifood systems, as well as the climate and technology interlinkages across different components of these systems. It identifies the promising areas in which climate technologies can support agrifood system transformation, including both adaptation needs and mitigation potential.

In the report, the Water–Energy–Food (WEF) Nexus is integrated into and within the broader debate on sustainable development and as part of the overall vision for sustainable food and agriculture, integrating social, economic and environmental requirements. In this context, the overarching aims are eradicating hunger, reducing poverty, and sustainably managing and using natural resources and ecosystems (see Box 2 for an overview of the WEF Nexus). Agrifood systems and food security are the main points of departure in the report, but linkages to water and energy are woven in throughout. In this way, a functional approach to WEF is included. The integrated approach also aims to build in solutions for small-scale producers and vulnerable populations, including gender considerations, at the centre of the discourse. This will be achieved by identifying sustainable solutions that address, and can cater for, their needs and are embedded within their rights. Indigenous Peoples and technologies are included as specific cases in the relevant subsections of the report.

Box 2. Water-Energy-Food Nexus and climate technologies

The WEF Nexus serves as a conceptual framework that highlights the interlinkages between water, energy and food systems (Taguta *et al*., 2022). It emphasizes how actions in one sector can influence others at various levels, and reinforces the necessity for integrated approaches to challenges related to resource scarcity, environmental degradation and climate change (Allouche, Middleton and Gyawali, 2015). Having initially generated interest following the Bonn 2011 Nexus Conference, this concept has been subject to diverse interpretations, with different terminologies emerging such as “food-energy-water” and “water-energy-land-food” (Hejnowicz *et al*., 2022).

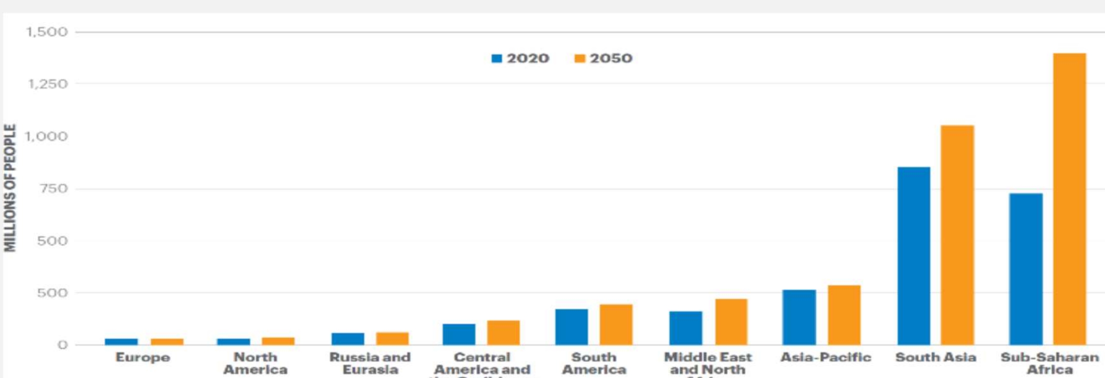
WEF Nexus objectives

The WEF Nexus aims to promote the coordinated management of water, energy and food resources, emphasizing the interdependencies among these elements for ensuring sustainable development and food security in a changing climate (FAO, 2014a; Proctor, Tabatabaie and Murthy, 2021). This approach also focuses on enhancing resilience and mitigation (Hoff, 2011; FAO, 2014a).

Achieving WEF development in a dynamic world

Currently, the growing demand for water, energy and food is not being adequately met, with 2 billion individuals lacking access to drinking water, 0.8 billion lacking electricity, and 2.4 billion facing food insecurity (Figure 1).

Figure 1. Food-insecure people by region, 2020 and 2050 projections



Source: **Institute for Economics and Peace.** 2021. Ecological Threat Report 2021: Understanding ecological threats, resilience, and peace. Quantifying Peace and its Benefits. https://www.economicsandpeace.org/wp-content/uploads/2021/10/ETR-2021-web.pdf

Global forecasts suggest a future rise in the need for freshwater, energy and food due to several factors including population growth, economic development, urbanization and climate change (Hoff, 2011; FAO, 2014a). For instance, with a 35 to 56 percent increase in food demand and a 16 to 57 percent increase in energy consumption by 2050, the stress on these resources will intensify further (van Dijk *et al.*, 2021; United States Energy Information Administration, 2023).

Addressing these challenges necessitates adopting a WEF Nexus approach to enhance water, energy and food security while carefully managing resources within a context of climate change and transitioning towards a circular economy (FAO, 2014a).

WEF interlinkage with climate technologies

According to Li *et al*. (2023), the presence of interlinkage between the WEF Nexus and climate change underlines the importance of addressing climate-related challenges within this framework.

Correa-Porcel, Piedra-Muñoz and Galdeano-Gómez (2021) identified several key innovations associated with the WEF Nexus, which contribute to the building of resilience against climate-related pressures. Examples include mulching and crop rotation techniques, which are found to enhance soil water storage during the drought period, and crop diversification, which improved tolerance to local environmental conditions and increased crop yields. Additionally, gene editing emerged as a promising method for breeding crop varieties with desirable traits (i.e. resilient to drought), and for helping to reduce fertilizer use and enhance soil fertility. Certain irrigation technologies, such as drip irrigation systems, were highlighted as enhancing water use efficiency by delivering water directly to the root zone of plants, thus minimizing wastage through evaporation or runoff. Furthermore, renewable energy sources such as biofuels, biogas and photovoltaic panels were recognized as promoting sustainable energy practices and environmental sustainability. Integrated rooftop greenhouses in urban settings were seen as innovative solutions to integrate food production into urban environments. Finally, in some cases, agroforestry can also have water, energy and food benefits when trees are integrated with crops and/or livestock to offer multifaceted solutions. Such an approach can result in water conservation, reduce conservation, soil erosion, provide renewable energy sources (wood for fuel, specific trees for biofuel production, etc.) and enhance food security through diversified production (Correa-Porcel, Piedra-Muñoz and Galdeano-Gómez, 2021).

Other technologies were identified through several different studies, demonstrating the potential to create interlinkages across sectors in the WEF Nexus. One notable example is precision farming technologies, which include a range of agricultural tools and techniques (e.g. remote sensing, global positioning systems, geographic information systems, yield monitoring, variable rate technology, sensors) that enable farmers to optimize the efficiency and effectiveness of their agricultural practices through precise management of inputs such as water, fertilizers and pesticides (Tayefeh *et al*., 2023). Other innovative techniques include the use of biochar as a soil improver, and mulching to improve soil fertility and crop productivity (Belmonte, Benjamin and Tan, 2017; Scardigno, 2020).

Challenges

As previously mentioned, the WEF Nexus emphasizes the interlinkages between water, energy and food systems, and offers integrated solutions to address the challenges of resource scarcity and climate change. As global demand for these resources rises, innovative technologies such as precision farming and renewable energy sources have the potential to enhance sustainability and resilience. However, implementation challenges have emerged, including economic barriers such as high investment and maintenance costs (e.g. solar-powered systems) alongside political/governmental challenges including the absence of clear guidelines for these technologies. This can be especially cumbersome for marginalized groups and peoples in vulnerable situations, including small-scale producers and Indigenous Peoples. This highlights the need for supportive policies and financial aid to maximize the advantages of WEF Nexus strategies.

The focus of this report and much of the analysis is on developing countries, since that is where adaptation in agrifood systems is most urgent. It is also where use of climate technologies for adaptation is lagging and where information about appropriate and accessible technologies for the agrifood systems is lacking. However, examples and analyses of higher-income countries are also provided throughout the report.

The report is organized into six sections. The introduction outlines the context of climate action in agrifood systems and the role of climate technologies therein.

The second section describes adaptation technologies across crop, livestock, fisheries, aquaculture and forestry sectors. Technologies at varying stages of the value chain are considered: from pre-production through production, processing and distribution.

The third section focuses on capacity needs for technology uptake, implementation and maintenance, as well as the institutional needs for technology uptake both at the upper stream and lower stream levels. Dimensions of gender, diversity, social inclusion and traditional and Indigenous technologies will be covered.

The fourth section investigates the amount (and sources) of finance being channelled into climate action in the agrifood sector and highlights the resultant implications for technology financing.

The fifth section provides a global overview of climate technologies and their potential in agrifood systems from the perspective of various countries, agricultural sectors and agrifood value chains. These case studies document a range of experiences, focusing in particular on: (i) regional representation from across the globe; (ii) differences in the stages of agrifood value chains (production, processing, consumption); (iii) the range of different subsectors (crops, livestock, fisheries, aquaculture, forestry); and (iv) the various areas of focus (gender, social inclusion, technology, nutrition, livelihoods).

The sixth section outlines the policy gaps and opportunities, with a focus on how the NDC 3.0[2] process could be improved by technology needs assessments / technology action plans that are able to promote robust coordination between agrifood and climate change policies, and identify bankable projects.

The seventh and final section summarizes the conclusions from the analysis undertaken.

[2] The NDCs 3.0, set to be submitted in 2025, should be informed by the outcomes of the first global stocktake. These new NDCs must be both progressive and more ambitious than the current commitments. https://unfccc.int/ndc-3.0

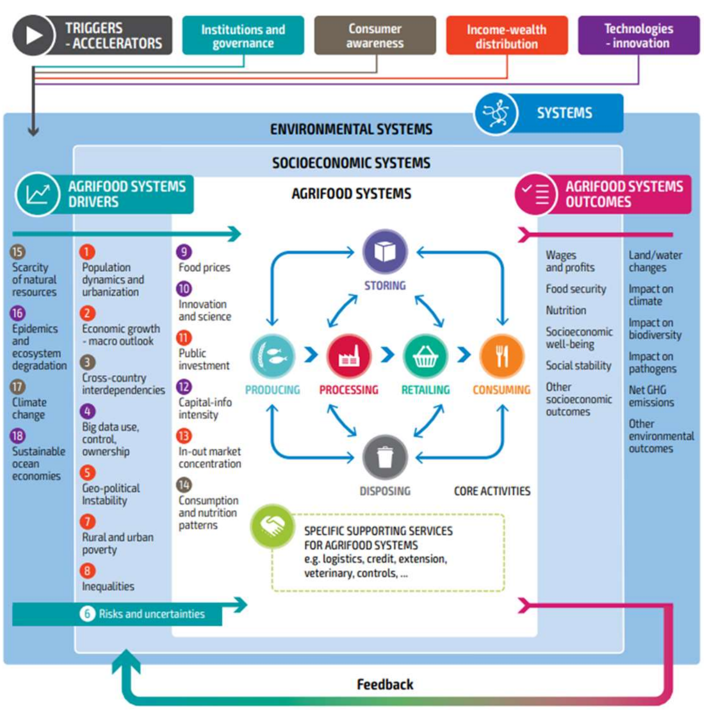
2. Climate technologies for sustainable agrifood system transformation

Playing a key role in the transition of agrifood systems, technology enables these systems to produce more efficiently with fewer resources and at a lower cost. Ranging from simple tools and techniques, such as changing planting dates, and crop varieties, irrigation and fertilizers, to complex systems and innovations, technology can be integral to improving the livelihoods of rural people and smallholder producers. The level of technology used in agriculture varies widely between, and also within, developing and developed countries, and it affects each step of the value chain, from production to consumption. Climate technology represents an additional layer that can support agrifood system transformation in enhancing adaptation and mitigation (Marshall *et al*., 2021; FAO, 2021b; FAO, 2024).

2.1 Agrifood systems

Agrifood systems are intricate networks made up of various actors and activities responsible for producing, processing, distributing and consuming food and agricultural products. Embedded in both socioeconomic and environmental systems, the feedback loops found in agrifood systems are shown in Figure 2. agrifood systems are defined as encompassing all products that originate from the production of crops, livestock, forestry, fisheries and aquaculture, and comprise pathways and supply chains not only from food producers to consumers, but from input suppliers to producers.[3]

Figure 2. Agrifood systems



[3] While non-agricultural food products, such as synthetic meat, are currently negligible, they are likely to grow and could have a major impact on the resilience of agrifood systems. While such products may reduce risks linked to climatic events and pests, the potentially negative impacts should not be ignored, especially in terms of loss of jobs and livelihoods for people working in agricultural food production (FAO, 2021).

Source: **FAO.** 2022c. *The future of food and agriculture: Drivers and triggers for transformation – Summary version.* Rome. https://doi.org/10.4060/cc1024en

Within agrifood systems, a number of pathways exist that link producers to consumers. These encompass small-scale subsistence producers that manufacture for their own consumption with very little use of external inputs, to input-intensive production systems that manufacture for commercial markets locally and internationally. Such pathways may include small-scale food processors working in the informal unregulated sector, or high-tech processing operations managed by global agrifood businesses. In this context, the production of non-food commodities (e.g. maize for biofuel production or cotton for textiles) is included. Being heavily dependent on climatic, biological, physical and chemical processes, agrifood systems face multiple potential shocks and stresses, including climate change, extreme weather events, pest and disease upsurges, and water scarcity and degradation (FAO, 2021a).

2.1.1 Climate change and agrifood system interlinkages

Climate change and agrifood systems are tied by a dual link: on the one hand, agrifood systems are severely affected by climate change; on the other hand, agrifood systems are a source of GHGs. Carefully assessing which climate technologies are viable and feasible along all stages of the value chain can support both adaptation to climate change and mitigation strategies through the agrifood system. Climate technologies can augment and accelerate the capacity to manage the physical, biological and social limitations that climate change imposes on agrifood systems (though they are not a panacea for overcoming all of these).

Figure 3. Summary of climate change impact on the agriculture sector

- Increased frequency and intensity of extreme climate events such as heat waves, droughts and floods, leading to loss of agricultural infrastructure and livelihoods
- Decrease in fresh water resources, leading to water scarcity in arable areas
- Sea-level rise and coastal flooding, leading to salinization of land and water, and risks to fisheries and aquaculture
- Water and food hygiene and sanitation problems
- Changes in water flows impacting inland fisheries and aquaculture
- Temperature increase and water scarcity affecting plant and animal physiology and productivity
- Beneficial effects on crop production through carbon dioxide "fertilization"
- Detrimental effects of elevated tropospheric ozone on crop yields
- Changes in plant, livestock and fish diseases and in pest species
- Damage to forestry, livestock, fisheries and aquaculture
- Acidification of the oceans, with extinction of fish species

Source: **FAO.** 2016. *The State of Food and Agriculture 2016. Climate change, agriculture and food security.* Rome. https://openknowledge.fao.org/items/5dc75cb7-bb13-4d4c-ab33-0c03b3a5da38

Climate change significantly impacts agriculture in various ways. Changes in temperature, precipitation patterns, and the frequency of extreme weather events can drastically affect crop yields. Heat stress, drought and flooding can reduce crop productivity (though some regions might benefit from longer growing seasons). Furthermore, warmer temperatures and altered rainfall patterns can increase the prevalence of pests and diseases, leading to higher crop losses and greater pesticide use, which can have additional environmental and health impacts.

Water resources are also affected by climate change. For example, changes in rainfall and glacier melting can cause water scarcity or flooding, thus disrupting agricultural production. Irrigation systems may become less reliable, and competition for water between agriculture, industry and households can intensify. Soil health is another critical concern, with increased temperatures and altered precipitation potentially leading to soil erosion and degradation, and loss of fertility. Extreme weather events can disrupt soil structure, reducing its capacity to retain the water and nutrients essential for crops.

Elevated temperatures can affect livestock health, productivity and reproduction. Changes in crop production can impact feed availability and quality, while water scarcity can further stress livestock. Aquatic ecosystems and fish populations are also vulnerable, with changes in water temperature, acidity, and oxygen levels potentially affecting fish populations, and thus disrupting both wild fisheries and aquaculture.

Food supply chains face disruptions from extreme weather events such as hurricanes, floods and droughts, which can damage infrastructure, delay transportation and cause post-harvest losses. These disruptions can lead to increased food prices and reduced availability. The nutritional quality of food is also at risk. Elevated carbon dioxide (CO_2) levels can lead to a reduction in essential nutrients in crops (such as protein, iron and zinc), which can negatively impact human health, especially in regions with already nutrient-deficient diets.

Changes in agricultural productivity and supply chain disruptions can exacerbate food insecurity and malnutrition by increasing food prices and reducing food access, availability and adequacy, especially for vulnerable populations. Rural communities, which often rely on agriculture for their livelihoods, are particularly affected by these impacts, leading to increased poverty, migration and social instability. These disruptions can also contribute to increased inequality, including specific gendered impacts (FAO, 2024a).

Between 2007 and 2022, analysis from 60 countries showed that agricultural losses made up an average of 23 percent of the total impact of disasters across all sectors. Although not solely attributed to climate change, the increased frequency and severity of climate hazards is clearly a key driver (FAO, 2023a). For small-scale producers and other actors in agrifood systems in those countries, stresses can be particularly pervasive and chronic, and often amplify the effects of existing infrastructure deficiencies, including those relating to roads, power, irrigation, clean water, processing, storage and distribution. Said deficiencies affect millions of farmers and other rural people by contributing to their geographic and economic isolation; a situation that limits opportunities to develop businesses, restricts access to services and increases dependence on local weather conditions. Inclusive access to technology aimed at building resilience is a fundamental path to ensuring that smallholders can withstand some of the increasing environmental stressors (FAO, 2023).

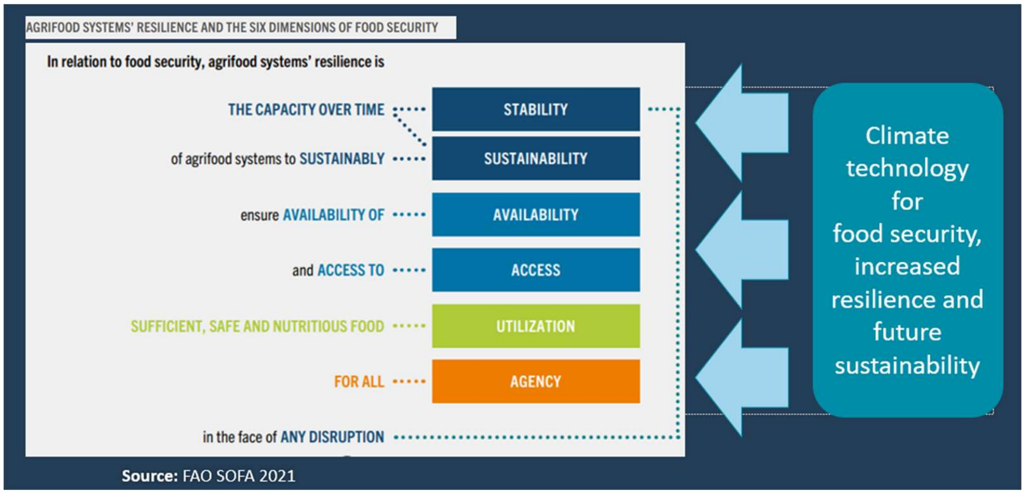
Agrifood systems contribute to climate change through various activities across the entire supply chain, from production to consumption. Greenhouse gas emissions originate from various sources, including current agricultural practices, land use (and related changes), energy use in agriculture, food processing, packaging, distribution, food loss and waste, and dietary choices. Specifically, GHG emissions are linked to certain agricultural practices within subsectors, fertilizer use, soil carbon loss, deforestation and land clearing, and energy consumption in agrifood systems. Food loss and waste also contribute to these emissions, accounting for 8 to 10 percent of global GHG emissions (IPCC, 2022a).

Total emissions from the agriculture, forestry and other land use sector amount to 11.9 ± 4.4 GtCO2eq per year. This sector also accounts for 21 percent of total net anthropogenic emissions (IPCC, 2022a). Moreover, after considering emissions across food supply chains and food waste in landfills, total food system emissions account for about 31 percent of global GHG emissions (Tubiello *et al.*, 2022).

2.1.2 Agrifood system resilience underpinning agrifood system transformation and linkages to climate technologies

Climate change increases the exposure and vulnerability of agrifood systems to shocks and stresses. Due to this, adaptive capacity (i.e. the capacity of actors to prevent, anticipate, absorb, adapt and transform) is undermined. Ensuring that agrifood systems are resilient to stresses such as climatic shocks is essential; however, this becomes more difficult under the already felt effects of climate change (FAO, 2021a; FAO, 2016). Once resilience capacities are compromised, the likelihood of acute and chronic food insecurity and malnutrition increases. Ultimately, the resilience of an agrifood system derives from its capacity over time to sustainably ensure the availability of, and access to, sufficient, safe and nutritious food for all in the face of any disruption (see Figure 4) (FAO, 2021a; FAO, 2016). These capacities can be strengthened through inclusive policies that prioritize the needs of the most vulnerable populations. The ability of agrifood systems to ensure food security and nutrition, and the realization of the right to adequate food for all, depends not only on their own capacities, but on States' obligations and other interconnected socioeconomic and environmental systems such as transport, education, health, water, soil and energy, as well as social protection mechanisms (FAO, 2021a).

Figure 4. Food security, food security dimensions and linkages to technology



Source: Based on. **FAO.** 2021a. *The State of Food and Agriculture 2021. Making agrifood systems more resilient to shocks and stresses*. Rome. https://doi.org/10.4060/cb4476enhttps://doi.org/10.4060/cb4476en

2.1.3 Agrifood system transformation and climate technologies

In this context, climate technology is key to supporting this transition whereby agrifood systems are more resilient to shocks. As mentioned previously, resilience means reacting to climate change (adaptation) and ensuring future viability of agrifood systems (mitigation). For the former, adaptation technologies aim to ensure that agrifood systems can recover from, or increase their resilience to, the impacts of climate change. For the latter, mitigation technologies support the overall mitigation strategies of countries in terms of the agrifood sector (FAO, 2021; FAO, 2021; IPCC, 2022a).

In the context of agrifood systems, the three dimensions of technologies, covering knowledge, equipment and institutions, are interlinked. More specifically, equipment (i.e. the tools used to enhance the efficiency, quality, safety and sustainability of agrifood systems) and practice (i.e. the behaviours, methods, norms, values and institutions shaping the ways in which actors interact with each other and technology) are ultimately interrelated in the way they influence the performance and resilience of agrifood systems. Functioning as an umbrella term comprising several technologies, agriculture practice can be used to improve the function and impact of agrifood systems. When considering the uptake and use of technologies within agrifood systems, due attention needs to be given to all dimensions of technologies (Haselip *et al*., 2019; FAO, 2016; FAO, 2017).

Innovation also plays a vital role in functioning as a technology accelerator. Innovation in agrifood systems is the process of creating, adapting and adopting new or improved technologies, practices, knowledge, policies or institutions that can enhance the performance and outcomes of the agrifood system in question. Its role is to address the multiple challenges and opportunities that affect food security, nutrition, environmental sustainability and economic prosperity for all. Innovation can (i) improve the productivity, quality, diversity and safety of food and agricultural products, (ii) reduce the environmental footprint and resource use of agrifood systems, (iii) increase the resilience and adaptability of agrifood systems to shocks and stresses, and (iv) empower the actors and stakeholders of agrifood systems to participate in decision-making and benefit-sharing.

Overall, it is important to understand how technology applications affect agrifood systems, including through current practices, economic performance, social inclusion and environmental factors. Such knowledge is also needed to foster responsible technology uptake, and to develop technological innovations that consider the needs and values of different actors (IPCC, 2022a; FAO, 2024a).

Box 3. Emerging technologies and innovations for agrifood systems

Emerging technologies and innovations present potential ways to accelerate the transformation towards resilient, sustainable and inclusive agrifood systems. This is particularly the case in an era marked by a number of unprecedented crises due to ongoing issues such as climate change, species extinction, rises in conflict, persistent inequalities and vulnerabilities in global health, all of which negatively affect agrifood systems. If the livelihoods of people and the environment are to improve, and if climate adaptation and mitigation are to be achieved, there is an increased need to close the gap between the creation of a technology or innovation and its adoption.

New emerging methodologies, such as horizon scanning, scenario building and strategic foresight, may in the future play a key role in addressing the knowledge gap surrounding emerging agrifood technologies and innovations. These technologies can inform long-term policymaking and investments, particularly when looking at the period of 2030 to 2050.

Alexandrova-Stefanova *et al.* (2023) identify 167 emerging agrifood technologies and innovations as potential options for future innovation. The technologies are categorized by typologies based on their impact, timeline and application areas. Among these, 32 of the most promising technologies were further analysed to determine their potential in addressing multiple agrifood challenges and out of these, decision makers and a broader multi-stakeholder community singled out a subset of 20 technologies based on their perceived impact and time needed to mature. The most promising technologies and innovations included: **policy innovations,** through governance and regulatory frameworks; **nature-based solutions,** using natural resources and ecosystem services; **data-driven technologies**, utilizing big data, artificial intelligence (AI), and internet of things to enhance agricultural productivity.

2.2 Agrifood value chains and technology needs assessments

Agrifood value chains are embedded in the broader concept of agrifood systems, and consist of several steps (which influence, and are influenced by, others) that transform raw materials into final products for consumers. Effective rules, roles and coordination and collaboration among stakeholders along the value chain, coupled with adequate resource availability, are essential for optimizing the efficiency, quality, sustainability and resilience of the agrifood system. Additionally, advancements in technology, infrastructure, logistics and market access play crucial roles in shaping the dynamics of the agrifood value chain.

Agrifood value chains do not function in isolation: producers typically handle multiple agricultural, livestock or fisheries products and have to make interrelated decisions regarding these (i.e. farming systems); and business services, infrastructure (e.g. transportation, storage, processing) and policies are often not specific to a single commodity (e.g. finance, markets and land policy) (FAO, 2014b).

Carefully assessing which climate technologies are viable and feasible along all stages of the value chain can support both adaptation to climate change and mitigation strategies through the agrifood system.

Technology needs assessments (TNAs) are used to identify the climate technologies for sectors in a specific country or context. The TNA process is defined as a series of participatory activities that aim to identify, select and implement climate technologies, with the overarching goal of helping the sectors in question adapt to, or increase their mitigation efforts in relation to, climate change (Haselip *et al*., 2019).

In their TNAs, the agriculture sector is consistently prioritized by developing Parties, which recognize its crucial role in the implementation of both mitigation and adaptation technologies to achieve NDC goals. Notably, 87 percent of Parties identify the agriculture, forestry and other land-use sectors as a priority for adaptation activities, while 35 percent consider the agriculture sector for mitigation activities. This is followed by the water resources sector (mentioned by 79 percent of Parties in their TNAs), and infrastructure and settlements, including coastal zones (prioritized by 39 percent) (UNFCCC, 2020).

For adaptation in the agriculture sector, the most five prioritized technologies are sprinkler and drip irrigation (mentioned by 37 percent of Parties), crop diversification and new varieties (27 percent), drought-resistant crop varieties (21 percent), conservation agriculture and land-use planning (21 percent) and agroforestry (18 percent).

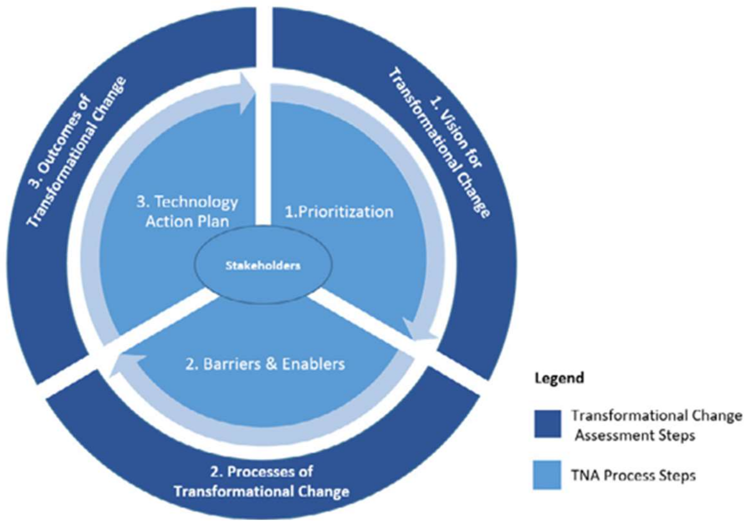
The water resources sector is highly prioritized by Parties and is recognized as playing a crucial role in agrifood systems. For adaptation in this sector, the top three prioritized technologies are rainwater harvesting (mentioned by 54 percent of Parties), subsurface storage and use (19 percent) and small reservoirs and dams (15 percent) (UNFCCC, 2020).

In the energy sector, most of the technologies are related to electricity generation, including solar photovoltaic, hydroelectricity, and biomass/biogas (UNFCCC, 2020).

The TNA process has three main steps and related objectives (Figure 5):

1. To identify and prioritize mitigation/adaptation technologies for selected sectors/subsectors;
2. To identify, analyse and address the barriers hindering the deployment and diffusion of the prioritized technologies, including enabling the framework for the said technologies;
3. Based on the inputs obtained from the two previous steps, to draw up a technology action plan (TAP) for the uptake and diffusion of prioritized technologies. TAPs also contain project ideas, which are concrete actions for the implementation of a prioritized technology.

Figure 5. Transformational change in the context of technology needs assessments



Source: Reproduced as shown in **). UNEP.** 2022b. *Transformational Change: Guidance for Technology Needs Assessment*. https://tech-action.unepccc.org/wp-content/uploads/sites/2/2023/01/transformational-change-guidance-for-tna.pdfhttps://tech-action.unepccc.org/wp-content/uploads/sites/2/2023/01/transformational-change-guidance-for-tna.pdf

The multi-criteria analysis (MCA) methodology is employed alongside the TNA to identify and prioritize technologies. The aggregated steps for undertaking an MCA follow the approach set out in Dodgson *et al*. (2009), Traerup and Bakkegaard (2015) and Dhar, Desgain and Narkeviciute (2015), as follows:

1. Establish the decision context (scope of the analysis, key stakeholders, etc.);
2. Identify the options and identify criteria;
3. Describe the expected performance of each option against the criteria;
4. Weighting: assign weights for each of the criteria to reflect their relative importance in the decision-making process;
5. Value: combining weighting and scoring to derive an overall value for each technology option and review results;
6. Conduct a sensitivity analysis of the results to changes in weights, scores and key variables.

The selection of criteria within the MCA is contingent upon the national context and priorities, which vary based on the objective of the climate technology, whether it be for mitigation or adaptation. Once sectors and technologies are prioritized, countries proceed to complete a TAP. This identifies specific policy, institutional and other related actions, along with strategies for the implementation of prioritized technologies, and serves as a strategic approach towards achieving the country's NDCs.[4]

2.2.1 Climate technologies in agrifood systems: Adaptation and mitigation technologies

Climate adaptation and mitigation technologies are essential in addressing global climate change. In the agrifood sector, the interconnection between water, energy and food resources is of particular importance. These technologies are also used to promote sustainable resource management, making them vital for the sector's resilience and sustainability. Furthermore, when looking at the specific

[4] A full list of possible criteria is contained in Traerup and Bakkegaard (2015), and Dhar, Desgain and Narkeviciute (2015).

groupings of adaptation and mitigation technologies, it is apparent that a number of technologies have both adaptation and mitigation co-benefits.

Chapters 5 and 4 of IPCC (2022a) review potential adaptation options relevant to the agrifood sector, offering a comprehensive overview of available options and technologies. The options are organized into the adaptation categories seen in Table 1.

Table 1. Adaptation categories and options relevant to the agrifood sector[(a)]

Adaptation category	**Adaptation option**
Agricultural diversification	Agricultural diversification: on-farm biodiversity (i.e. intercropping)
	Agricultural diversification: landscape
	Mixed systems: crops, trees, silvopastoral, fisheries, aquaculture, agroforestry
	Agroecological approaches at multiple scales
Agronomic management (farm level)	Organic management
	No till, reduced tillage or conservation agriculture
	Integrated pest and weed management
Livestock management	Seasonal feed supplementation
	Improved animal health and parasites control
	Thermal stress control
Shift in production timing/location/species/density	Substitution/change plant or animal type
	Adjustment of planting dates/counter-season crop production
	Shifting location of crop production, grazing; relocation of aquatic species
Reduced land degradation; soil conservation and improvement; carbon capture	Reduced deforestation and forest degradation
	Reforestation and forest restoration
	Afforestation and land rehabilitation
	Improved soil management (reduced soil erosion, salinization, compaction)
Water management (farm level)	Improved irrigation efficiency and use
	Drip irrigation
	Integrated water management/water conservation and efficiency
	Climate-smart facilities (e.g. deeper ponds, water storage)
Genetic improvement	Conventional breeding (cultivar or species improvement, assisted evolution in fisheries)
	Biotech and bioengineering
	Community forest management
	Community seed/feed/fodder banks
	Collective water storage and management schemes
	Farmer-to-farmer training, farmer field schools
	Social support networks
Climate services	Improving weather forecasting and early-warning systems
Infrastructure	Food storage infrastructure

	Improved food transport and distribution
	Improved efficiency and sustainability of food-processing, retail and agrifood industries
	Investment in protection infrastructure
Consumer-side behaviour change	Dietary changes
	Reduce food waste (retailer and consumer)
Food system transformations	Food sovereignty, agroecology, right-to-food approaches
	Integrated approaches at multiple scales
	Shortening supply chains, direct sales, circular economies
Policy and planning	Community-based adaptation (including disaster risk management)
	Local governance and conflict resolution schemes
	Regional and local food systems strengthening
	National and international adaptation planning, coordination, policy and governance
	Improving access to community services and social protection
Livelihood diversification	Diversification of livelihoods (economic diversification, either on-farm or employment in local community)

(a) The terminology as presented in the table follows the IPCC source documentation. Technical terms across institutions may vary; therefore, kindly consider these as IPCC reference terminology.

Source: Adapted from **IPCC.** 2022a. *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M. et al., eds. Cambridge, UK and New York, USA, Cambridge University Press. https://doi.org/10.1017/9781009325844

Many effective adaptation strategies involve ecosystem-based approaches, such as agroecology and some agroforestry practices, since these have the potential to enhance resilience to climate change. However, the co-benefits (e.g. improvements in soil health and biodiversity, and reduced dependency on external inputs) and trade-offs (e.g. initial investments in trees and labour, management complexity, and the need to learn new practices meaning delayed benefits) associated with these approaches vary depending on the socioecological context.

On the mitigation side, in IPCC (2022a), mitigation measures are represented as land-based climate technologies and management practices aimed at reducing GHG emissions and/or enhancing carbon sequestration within the land system (IPCC, 2022b). The analysis in the report looks at the scientific literature on mitigation technologies and measures their potential (in terms of technical, economic, sustainable and feasible aspects), co-benefits and the risks associated with their implementation. The analysis uses sectoral assessments and integrates assessment models to evaluate identified land-based mitigation measures (see Table 2).

Table 2. Mitigation measures [(b)]

Sector	Measure type	Mitigation measure
Forests and other ecosystems	Protect	Reduce deforestation and degradation
		Reduce conversion of coastal wetlands
		Reduce degradation and conversion of peatlands
		Reduce degradation and conversion of grasslands and savanna
	Manage	Improve forest management
		Fire management (forest and grassland/savanna fires)

	Restore	Afforestation, reforestation and forest ecosystem restoration
		Coastal wetland restoration
		Peatland restoration
Agriculture	Sequester carbon	Soil carbon management in croplands
		Soil carbon management in grasslands
		Agroforestry
		Biochar application
	Reduce emissions	Enteric fermentation
		Manure management
		Crop nutrient management
		Improve rice management
Bioenergy	-	Bioenergy and ioenergy with carbon capture and storage
Demand-side	-	Reduce food loss and waste
		Shift to sustainable healthy diets
		Improve use of wood products

(b) The terminology as presented in the table follows the IPCC source documentation. Technical terms across institutions may vary; therefore, kindly consider these as IPCC reference terminology.

Source: Adapted from **IPCC.** 2022b. *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

In addition, through efforts to accelerate development and deployment of clean technologies and sustainable solutions in the agriculture sector, seven breakthrough technological areas have been identified (Mukherji *et al.,* 2023). These are categorized as key intervention areas to drive significant advancement in the agriculture sector with the primary objective of making climate-resilient and sustainable agriculture the most attractive and widely adopted option for farmers globally by 2030. These breakthroughs are essential to reduce emissions, ensure food and nutrition security, protect natural resources, and enhance the climate resilience of smallholder producers (see Table 3).

Table 3. Agricultural breakthrough technological areas [(C)]

Breakthrough technological areas	
Reduced emissions from fertilizers	Precision fertilization technologies
	Integrated soil fertility management
	Nitrification inhibitors (chemical and biological)
	Low-emission fertilizers including slow release and controlled release fertilizers
	Biological nitrogen fixation through use of intercropping, biofertilizers and genetic engineering
	Organic fertilizers (compost manure and crop residues) and use biochar to improve soil fertility
Reduced methane emissions from livestock	Mitigation strategies for enteric methane emissions
	Manure management strategies and technologies for reducing methane emissions
Agroecological and enabling environment innovations for transitioning to	Improve resource use efficiency
	Increase inputs substitution
	Strengthen resilience and synergies
	Co-creation of knowledge
	Implement inclusive business models

sustainable food systems	Reform policies and institutions
Crop and livestock breeding	
Alternative proteins	Plant-based proteins
	Microbial fermentation-based proteins
	Cultivated meat proteins
	Insect-based proteins
Reduce food loss and waste and associated emissions	Improved agricultural practices
	Better post-harvest handling
	More efficient processing methods
	Better packaging and storage
	Better use of by-products
	Reduced food spoilage
	Improved inventory management
	Food donation programmes
	Reduced household food waste
	Composting food scraps and other organic materials
Digital services	Applications in agricultural research such as genetics
	Provision of index-based crop insurance, increasingly bundled with other services
	Provision of agricultural advice and market information
	Real-time weather forecasts
	Flood and drought monitoring and management tools

(c) The terminology as presented in the table follows the source documentation. Technical terms across institutions may vary therefore kindly consider the terms reported in the table as aligned with the reference terminology.

Source: Adapted from **Mukherji, A., Arndt, C., Arango, J., Flintan, F., Derera, J., Francesconi, W., Jones, S., et al.** 2023. *Achieving agricultural breakthrough: A deep dive into seven technological areas.* Montpellier, France, CGIAR System Organization. https://hdl.handle.net/10568/131852

These breakthrough technological areas were selected based on their potential to reduce GHG emissions and promote climate resilience. However, additional principles were considered: (i) sustainable increases in agricultural productivity and incomes; (ii) reduced GHG emissions from the agrifood sector; (iii) improved soil, water resources and natural ecosystems across all geographies; and (iv) enhanced adaptation and resilience to climate change for smallholder producers.

Although a possible spectrum of technologies in terms of adaptation or mitigation (or both) exists, all technology viability is extremely context and case specific. Robust assessments of the technical viability of the technologies being considered should support the implementation steps, with clear indications of the climate objectives to be achieved.

On the adaptation side, a number of technologies are accepted as being available to reduce climate impacts in agrifood systems. Examples include cultivar improvements, community-based adaptation, agricultural diversification, climate services, infrastructural redesign to manage environmental impacts and adaptive management in fisheries and aquaculture. However, the evidence regarding their capacity to mitigate risks and their effectiveness under different warming scenarios is still weak, and some lack adequate economic or institutional feasibility, or sufficient information about their feasibility and impacts. Robust evidence is also needed to support mitigation efforts; a number of the technologies might not achieve the GHG emission reduction anticipated or could see very high investment costs.

While effective adaptation and mitigation technologies exist, their success is highly context specific. Climate strategies must be tailored to local conditions, farming systems, and the socioeconomic situations of producers, whereby factors such as gender, inequality and the need for social inclusion, including of vulnerable populations groups, must be taken into account. They should also include farmers, fishers and their communities, including Indigenous Peoples, in the design, planning and implementation and take into account local and traditional knowledge. This context dependency is particularly evident in cases of maladaptation, where commonly used adaptation options can become counterproductive if applied inappropriately or in unsuitable contexts. In IPCC (2022a), maladaptation emerged as a major theme across all sectors in general, with agricultural, forestry and fisheries practices being particularly affected. For instance, while efficient irrigation technologies such as drip and sprinkler systems can reduce water usage per unit of output, their widespread adoption may lead to increased overall water extraction by expanding irrigated land.

Furthermore, studies (Berrang-Ford *et al.,* 2021; Vermeulen *et al.,* 2018) emphasize that efficient adaptation requires moving away from small, fragmented, sector-specific actions. To ensure alignment with the engagement of small-scale producers, successful local adaptations should be identified and scaled up through co-creation, knowledge-sharing and capacity-building initiatives. Developing participatory national adaptation plans that involve small-scale producers fosters ownership and increases the likelihood of successful implementation. Strengthening local institutions by empowering farmer cooperatives, NGOs and extension services is also important, as these groups can disseminate information, facilitate resource access and provide technical assistance. Finally, ensuring that adaptation solutions are context specific, gender responsive, inclusive of vulnerable population groups and consider the socioecological context of small-scale producers helps minimize negative impacts (e.g. short-term costs, unintended consequences) and maximize benefits (e.g. increased resilience, enhanced food security).

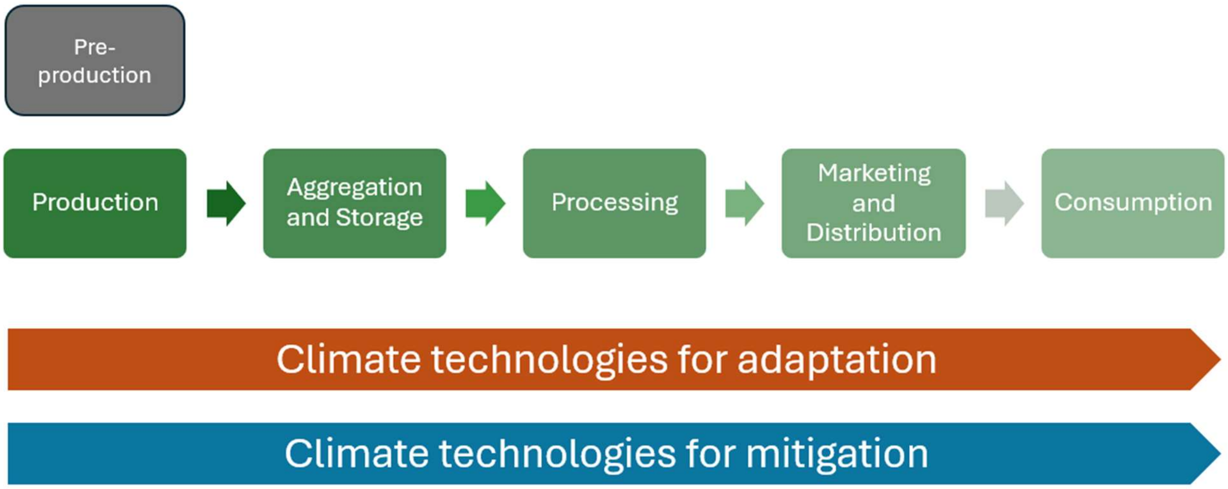
The impacts of climate change, combined with non-climatic drivers, can create poverty traps that increase the likelihood of chronic poverty. Many adaptation efforts aim to reduce exposure to climate-related hazards or to help households cope with climate change, rather than addressing the root causes of structural vulnerability. Addressing structural vulnerability requires a response to climate change in which a higher level of coordination (from community to national levels), as well as enhanced coordination and integration across sectors with a focus on social protection, is a necessity (also see Box 7).

2.3 Climate technologies and agrifood system value chains

When specifically assessing climate technology interventions to support agrifood system transformation, a value chain approach is needed to understand how technologies can specifically support adaptation and mitigation needs in agrifood systems. Specific to the country or context, value chains are core elements of agrifood systems, and function as the pathway of processes that a product follows as it moves from the primary producer to the final consumer, with value being added at each stage of the process (FAO, 2014; FAO and UNIDO, 2024).

A typical agrifood value chain contains five steps: production, storage, processing, transport and distribution, and consumption. A pre-production stage also exists; this includes all activities at the planning stage, including potential inputs for production, land preparation and feed selection. These stages are important when considering the interlinkages with climate technologies (see Figure 6).

Figure 6. A typical agrifood value chain

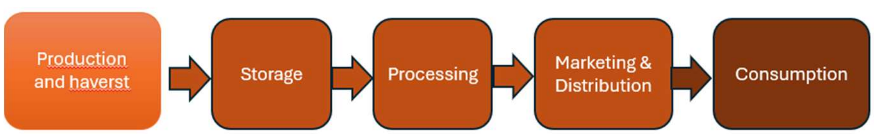


Source: Generated by FAO and TEC authors of present report.

2.3.1 Climate technologies and crops

Crops are cultivated for various purposes, including food, fibre and fuel. The complexity and technological aspects of the crop value chain ultimately depend on the specific crop and context. Each stage, from pre-production to production and ultimately to consumption, includes activities that have technology and climate change linkages (Figure 7).

Figure 7. Stages of the crop value chain



Source: Generated by FAO and TEC authors of present report.

In the pre-production stage, farmers select seeds, fertilizers and pesticides, and plan farm activities such as crop rotation, irrigation and land preparation (integrated pest management approaches can be used for this). During production, tasks include planting, pest management, soil and water management, and harvesting. Post-harvest processes, including storage and processing, ensure longer shelf life and better market access. Storage methods (e.g. cooling and hermetic storage) help to preserve the quality of the produce. Processing is undertaken to conserve and handle agricultural products, making them suitable for use. These processes add value to the products, and help to reduce losses and maintain food safety. Finally, processed food goes through distribution, which involves various intermediaries who transport and store the food before it reaches consumers.

Different climate adaptation and mitigation technologies are important for each stage of the crop value chain. Climate adaptation technologies for crops aim to enhance the resilience of agricultural systems to the impacts of climate change, such as extreme temperatures, altered precipitation patterns, increased frequency of droughts, floods, and the spread of pests and diseases. These technologies help farmers adapt to changing environmental conditions, optimize crop productivity and ensure food security.

In the pre-production and production stages, the primary focus is on adaptation technologies such as genetic improvements (crop variety selection can increase crop tolerance to drought, floods, lodging, heat, salinity, water stress, pests or disease), agricultural diversification (e.g. use of mixed systems, agroecological approaches), improved agronomic practices (e.g. organic management, integrated pest and weed management, intercropping, integrated soil fertility management, use of soil amendments), adjustments in production timing, location or crop selection, and enhanced water management (e.g. solar-powered irrigation, drip irrigation). During the post-harvest stage, infrastructure (e.g. food storage, sustainable cooling and drying infrastructures, and improved efficiency and sustainability of food-processing and agrifood industries) are most relevant for food loss reduction. At the consumption stage, changes in consumer behaviour (e.g. dietary changes, reduction of food waste) are key climate change strategies. Ultimately, policy and, strategic planning, and systemic shifts within the food system can influence the entire value chain. Some measures include shortening supply chains to enhance efficiency, encouraging direct sales between farmers and consumers to strengthen local economies, and fostering circular economies that prioritize waste reduction and resource optimization.

Climate mitigation technologies for crops focus on reducing GHG emissions, enhancing carbon sequestration, and promoting sustainable agricultural practices to mitigate the impacts of climate change. For example, reduced-emission fertilizer practices, agroecological practices (including conservation agriculture, cover cropping and green manures, bio-based fertilizers, and crop rotation and intercropping), and crop breeding are most relevant during the production stage. In contrast, digital services (e.g. irrigation scheduling systems, real-time weather forecasts, energy management systems, distribution route optimization) offer benefits across the entire value chain. Additionally, the integration of renewable energy sources and application of energy-efficient technologies and practices into production systems can reduce dependence on fossil fuels and ensure access to energy for food production, thus contributing to mitigating climate change and improving the sector's productivity and resilience.

2.3.2 Climate technologies and livestock

The livestock value chain involves various actors, from farmers to corporations, with different roles based on the chain's complexity. In simpler chains, one household may handle all stages, while industrialized chains have specialized actors or vertical integration (Figure 8).

Figure 8. A generic livestock value chain

Source: Generated by FAO and TEC authors of present report.

Input suppliers provide essential resources such as feed, machinery and medicines. The production stage encompasses breeding, multiplying, finishing and production of animal products (e.g. milk and eggs), and is managed by individual farmers or specialized units. Breeding involves selecting animals with desirable traits, while multiplying produces offspring and finishing raises them to market weight.

Processed animal products, such as milk and meat, require hygienic conditions and preservation methods due to their perishable nature. Processing generates significant waste, necessitating proper disposal methods to minimize environmental impact.

Wholesalers and retailers connect producers to consumers, using cold chains to minimize food losses. Small-scale producers can sell products directly to consumers. Transportation is a crucial part of the value chain, with efficient aggregation and cold chain systems ensuring that products reach markets in good condition.

Throughout the livestock value chain, climate change poses significant challenges. The sector is both a contributor to and impacted by climate change. It is responsible for a substantial portion of GHG emissions, primarily through methane from enteric fermentation and manure management. At the same time, the sector faces threats from climate change impacts such as reduced forage availability, water scarcity, extreme weather events and emerging diseases.

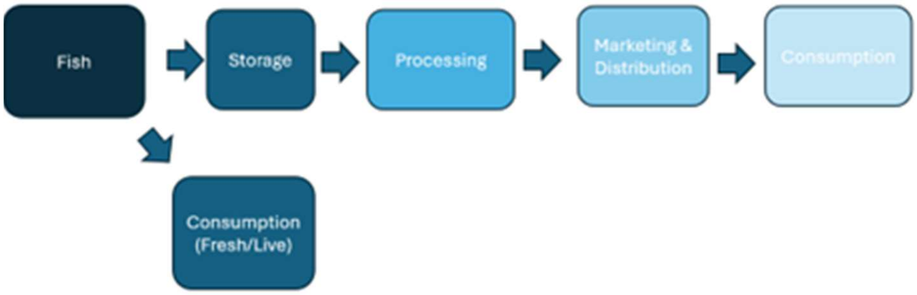
Climate adaptation technologies for the livestock sector aim to enhance the resilience of animal agriculture systems to the impacts of climate change. These technologies – such as livestock management (e.g. alternative feed sources), seasonal prediction systems, sustainable pasture management, genetic improvement (e.g. a shift to heat-, pest- and disease-tolerant breeds and species), agricultural diversification, and change in animal type – have the greatest impact on the production stage, though their benefits do also extend to other parts of the chain. Infrastructure technologies (e.g. food storage infrastructure, improved food transport and distribution, natural or artificial shade and shelter structures, climate-controlled housing systems) are important for the post-harvest stage. Consumer behaviour changes, such as reducing food waste, are crucial at the consumption stage, while policy and planning adaptations can impact the entire value chain. Climate mitigation technologies are essential for the livestock sector due to the significant role that this sector has in GHG emissions. These technologies also promote efficient resource use, reduce waste and minimize the environmental footprint. Key mitigation technologies for the production stage include livestock breeding and methods to reduce methane emissions, from enteric fermentation and manure management, improvements in animal health, and improvements in feed quality. Technologies such as alternative proteins (e.g. cultivated meat and insect-based proteins), consumer behaviour changes (reducing meat consumption), technologies that aim to reduce food loss and waste (e.g. efficient processing methods, improved packaging and storage, and reduced food spoilage), and the use of digital services are important across the entire value chain. Moreover, governments can promote research and development of more evidence-based and environmentally friendly livestock production methods.

Installing renewable energy systems, such as solar panels, biogas plants and heat pumps, to power livestock farms, processing facilities and cooling/heating systems reduces reliance on fossil fuels and lowers GHG emissions. Implementing biogas production systems to convert animal manure into renewable energy and biofertilizers reduces methane emissions, utilizes organic waste and generates additional revenue streams for livestock farmers. Given the perishable nature of animal products such as meat, eggs and milk, which require cooling and processing throughout the value chain, the use of energy-efficient technologies and effective energy management can support adaptation and mitigation efforts.

2.3.3 Climate technologies and fisheries

Fisheries value chains encompass multiple stages, from pre-production (acquisition of a fishing boat and equipment) and fish production to consumption (see Figure 9). At the production level, fisheries involve catching or harvesting various species from aquatic resources. After the catch, fish can be consumed immediately or processed through several stages before reaching the consumer. Post-production stages include storage, processing, marketing and distribution, and consumption. Extending the value chain to include storage and processing enhances the product’s shelf life and adds value at each stage.

Figure 9. A generic fisheries value chain



Source: Generated by FAO and TEC authors of present report.

Climate technologies are essential for helping fisheries adapt to climate change and for providing alternative mitigation solutions. Adaptation technologies for fisheries aim to enhance the resilience of marine and freshwater ecosystems, fishing operations, and communities against the impacts of climate change. These technologies mitigate the adverse effects of changing environmental conditions, such as rising sea temperatures, ocean acidification and increased frequency of extreme weather events, on fish stocks, aquatic habitats, and livelihoods.

Playing an important role in the production stage of the value chain, adaptive fisheries management incorporates climate change considerations into production and site planning, regulation and decision-making to sustain fish populations, maintain ecosystem health and ensure long-term viability. Such considerations could include, for example, integrating climate variables and risks into stock assessments, schemes of tradable fishing rights/allocations to allow flexibility in response to stocks shifting across international borders, and development of new fisheries to capitalize on distributional shifts or enhanced productivity.

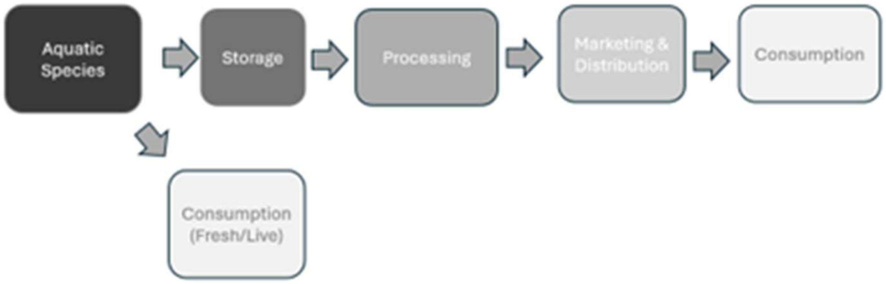
Establishing climate-proofed marine protected areas and other effective area-based conservation measures helps conserve and sustainably use biodiversity, protect critical habitats, and enhance ecosystem resilience to climate impacts by reducing human pressures. Their establishment should always be consulted and co-designed with the local fishing communities, as they can negatively impact the right to food of the communities and small-scale fishers that depend on these resources for their subsistence. Measures such as seasonal closures, area restrictions, and catch limits conserve fish stocks, and maintain ecosystem balance. Preservation and processing practices, such as smoking, drying, freezing, salting and canning, are important in post-production stages, as they reduce loss, spoilage and microbial growth in fishery catches and add value to the products.

Moreover, restoration measures (e.g. mangrove and wetland restoration systems) restore habitat for fish and other aquatic species, mitigate coastal erosion and storm impacts, and enhance blue carbon sequestration. Using renewable energy and improving energy efficiency in fishing fleets, processing facilities and other operations helps to reduce the sector’s reliance on fossil fuels, lowers GHG emissions and decreases operating costs.

2.3.4 Climate technologies and aquaculture

Aquaculture value chains differ from fisheries in the production and harvesting stages due to the use of cultivation methods and technologies. Pre-production activities include building ponds, installing cages in water dams, rivers and oceans, and using pumps, aerators, feeders and filters. Unlike fisheries, aquaculture is mostly market oriented and integrated into regional or international supply chains, with some facilities involved in direct wholesale or retail sales (see Figure 10).

Figure 10. A generic aquaculture value chain



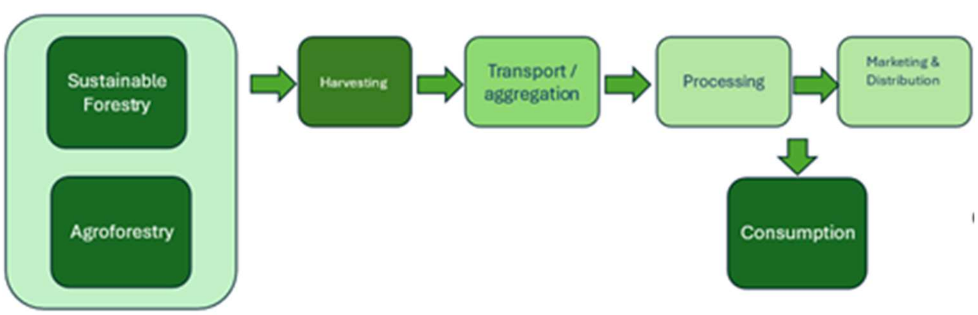
Source: Generated by FAO and TEC authors of present report.

Adaptive technologies for the production stage of aquaculture include the adoption of technologies that reduce exposure to risk and sensitivity and increase adaptive capacity. Strategies such as species diversification to those more tolerant to climate change and the adoption of climate-resilient technologies and practices (e.g. protective infrastructure, changing production cycles, recirculating aquaculture systems, improved water management) can increase aquaculture resilience. Improving feed management and feed quality, together with improving genetic advancement, increases production efficiency and reduces climate risks. Additionally, reducing food loss and waste and integrating renewable energy and energy efficiency measures contribute to climate mitigation by increasing resource efficiency and reducing fossil fuel use.

2.3.5 Climate technologies and forestry

The value chain of sustainable forestry and agroforestry involves bringing wood and non-wood forest products to the final consumer. The stages are production, harvesting, transportation, processing (including value addition where applicable), marketing and distribution, and consumption, with various actors involved.

Figure 11. A generic sustainable forestry and agroforestry value chain



Source: **Forests of the World.** 2021. *Approach to value chains: Giving forests value as an alternative to deforestation.* https://www.forestsoftheworld.org/files/International.forestsoftheworld.org/Working%20Papers/Strategy%20documents/2021-03%20Approach%20to%20value%20chains.pdfhttps://www.forestsoftheworld.org/files/International.forestsoftheworld.org/Working%20Papers/Strategy%20documents/2021-03%20Approach%20to%20value%20chains.pdf

Sustainable harvesting starts with surveying and identifying trees or areas that must be conserved to protect biodiversity, soil, water, and overall ecosystem functionality. In the case of selective logging, specific trees are tagged for removal, and processing may occur on site, with organic matter left to support regeneration and soil conservation. The timber is transported, and the harvested areas are either replanted or allowed to regenerate naturally, with methods like assisted natural regeneration or enrichment planting. Sustainable forest management often applies to natural ecosystems, while sustainable agroforestry management involves more planned systems enriched with specific plantings. Products are transported to processing facilities via various modes of transport, with aggregation centres consolidating loads to reduce costs and environmental impacts.

At processing facilities, raw materials are transformed into value-added products. During this stage, wood residues and other renewable energy sources should be utilized, and energy efficiency measures prioritized. Marketing efforts aim to promote these products both locally and globally. Distribution networks should prioritize minimizing transportation distances to reduce carbon emissions and support local communities by sourcing materials and products from nearby regions.

Consumers of sustainable forestry and agroforestry products include individuals and industries. Promoting sustainable consumption involves choosing certified products, opting for durable items, favouring locally sourced products, and practising responsible recycling or upcycling.

Climate technologies in forestry aim to support forest conservation, restoration and sustainable use. They improve forest health, and reduce climate change impacts on timber production, biodiversity and ecosystem services. These technologies are rooted in sustainable forest management and aim to tackle such challenges as changing climate patterns, increased forest fires, pests and diseases, and habitat alterations.

Key climate technologies for forestry, which contribute both to adaptation and mitigation, include digital technologies, product/process technologies and biotechnologies (FAO, 2024). Digital technologies, such as advances in remote sensing and data management, have helped advance national forest monitoring systems and provide the basis for results-based payments in the context of the REDD+ framework. Product and process technologies involve the use of sustainably sourced wood, including in the building and construction, textile and energy sectors, to help replace fossil fuels and carbon-intensive materials and facilitating a shift towards a bioeconomy. Moreover, as innovation adoption in the forest sector in developing countries is limited, investing in low-tech innovations (e.g. improved grading, logistics, advanced sawmilling, solar dryers and modern bioenergy) could significantly enhance sustainable forest management and value chain efficiency. Tree breeding to increase yields, resistance to diseases and adaptation to climate change is being investigated. These and other forest-sector technologies, which are being used to support climate change mitigation and adaptation efforts, are covered extensively in FAO's latest State of the World's Forests report (FAO, 2024).

Finally, policy, legislation and effective enforcement play a vital role in promoting and ensuring the implementation of sustainable forestry practices. By setting clear guidelines and standards, they help protect forest ecosystems, encourage responsible resource management, and support the long-term health and productivity of forested areas.

Box 4. Reducing food loss and waste in agrifood systems' transformation.

Reducing food loss and waste (FLW) in agrifood systems is both important for adaptation and mitigation purposes and crucial for several reasons. Doing so (i) lowers production costs, (ii) enhances food system efficiency, (iii) contributes to improving food security and nutrition, and (iv) contributes to environmental sustainability and to reducing pressure on the natural resource base. Reducing FLW is essential if the goal of feeding 9.7 billion people in an environmentally sustainable way by 2050 is to be met. Approximately 13 percent of the world's food is lost after harvest, up to but not including the retail stage (FAO, 2022), and an estimated 19 percent is wasted in households, in food services and in retail (UNEP, 2024).) In 2019, the IPCC's Climate Change and Land special report (IPCC, 2022c) estimated that global FLW accounted for 8 to 10 percent of global GHG emissions between 2010 and 2016. The importance of addressing FLW is enshrined in Sustainable Development

Goal (SDG) Target 12.3, which aims to halve per capita global food waste at the retail and consumer levels, as well as reduce food loss along production and supply chains, by 2030.

Effective policymaking for FLW reduction involves aligning interventions with such objectives as economic efficiency, food security, nutrition, and environmental sustainability. Country priorities vary widely, with least developed countries (LDCs) focused on reducing food losses to address food security and sustainable resource management through early supply chain interventions, and upper-middle and high-income countries emphasizing reductions in GHG emissions by targeting the retail and consumption stages of the value chain. Policy coherence is vital to ensure that interventions do not unintentionally harm other objectives. The collection of both macro- and micro-level data on FLW is critical to informing macro and sectoral policies in countries. Adapting the agrifood system to reduce FLW and associated GHG emissions necessitates a comprehensive systems approach. This involves several strategic adaptations to enhance resilience and reduce food losses in a sustainable manner.

Key adaptation strategies:

- **Switching to climate-resilient varieties**: Developing and cultivating crop varieties that are more resilient to climatic extremes, such as drought-resistant or flood-tolerant strains. These varieties can withstand adverse conditions better, thereby reducing crop loss and ensuring food security even during extreme weather events.
- **Protected cultivation**: Utilizing greenhouses, polytunnels and other forms of protected cultivation to shield crops from extreme weather. This approach can mitigate the effects of heavy rains, floods and heatwaves, providing a controlled environment that safeguards crop health and yield.
- **Redesign and relocation of storage infrastructure**: Redesigning dry storage structures for staple crops towards mitigating risks of insect infestation, and strategically relocating these structures to protected areas to minimize the risk of flooding.
- **Development of low-energy cool storage facilities** to extend the storage life of perishable foods and to reduce food losses.
- **Consumer awareness and education campaigns to reduce food waste**, towards reducing the carbon footprint and to prevent food waste from ending up in landfills.

Mitigation strategies:

- **Infrastructure for the circular economy**: Developing systems and facilities that support the circular economy to maximize the use of food through prevention, reduction, reuse, upcycling and recycling, towards reducing GHG emissions.

In **West Africa, in Ghana**, where 1.6 million people are undernourished (The Borgen Project, 2023), traditional mud silos are being used to improve food storage and thus combat hunger. Northern Ghana experiences the highest rates of food insecurity, ranging from 23 to 49 percent, compared with 4 to 10 percent in the south (Greene, 2006). Poor storage facilities lead to significant post-harvest losses, wasting between 20 and 50 percent of crops, or about 3.2 million tons of food annually (Kalita, 2017). Mud silos, which have been used for centuries by ethnic groups such as the Konkombas, preserve grain by blocking out oxygen, thereby keeping the grain dry and preventing rot. These silos can last between 10 and 15 years and reduce food wastage to less than 5 percent (The Borgen Project, 2023). Opportunities: Industrialization Center has built 2,600 silos across Ghana, costing less than USD 25 each, which has helped farmers to maximize their crop yields, thus contributing to food security. By adopting these methods, Ghana's agrifood system can better withstand climate change and ensure a stable food supply [REF].

3. Factors driving capacity needs for climate technologies in agrifood systems[5]

Three important factors that drive capacity needs for climate technologies are as follows: (i) the need for compatibility with the functions and non-climate-related objectives of agrifood system transformation; (ii) the existing capacity in place; and (iii) the nature of the climate risks and associated vulnerabilities. There is considerable variation in all three of these factors in the agrifood systems across and within countries. They affect capacity at individual, institutional and organizational levels. Thus, context-specific approaches to meeting capacity needs at different levels are required.

Developed and developing countries have significant differences in the characteristics of agrifood systems. This gives rise to variations in existing capacities as well as the priorities and constraints faced when managing said agrifood systems. In developing countries (in particular, LDCs), agrifood systems often constitute a major share of GDP and employment, whereas this share is much lower in many developed countries. Many LDCs have large populations of poor and food-insecure people dependent on agrifood systems for their livelihoods (IFAD, 2021). Improving these livelihoods is a major objective in transforming agrifood systems in such contexts. Furthermore, ensuring complementarity between climate technologies and the effort to improve livelihoods dependent on agrifood systems has implications for the capacity needed.

At present, there is a significant global policy push for the transformation of agrifood systems, which entails major changes in functions and outcomes. Articulated in a number of policies and technical works, agrifood system transformation aims to achieve better environmental, nutritional and livelihood outcomes. Such a process necessitates explicit attention to changes that result in improved adaptation and mitigation, as well as the inclusion of such objectives as better nutrition for everyone and equitable value chains that provide decent employment (Barrett *et al*., 2020). To achieve these objectives, transformation processes must promote resilience and sustainability in an inclusive manner. Climate technologies and the way they are deployed represent an important means of enabling such a transformation.

Due to the potential trade-offs and synergies across climate and non-climate change objectives, the presence of multiple objectives in agrifood system transformation is considered a key determinant of the capacities required for successful adoption of climate technology. For example, the need to generate decent employment in agrifood systems in countries with rapidly expanding youth populations in rural areas could be translated into a strong enabling factor for technologies that are labour intensive. However, in the same context, labour-saving technologies could face political and institutional barriers (Cilluffo and Ruiz, 2019).

3.1 Climate risks and vulnerabilities

Exposure to climate hazards is a key determinant of capacity needs for climate technologies aimed at building resilience. The latest IPCC assessment confirmed (with high confidence) that the impacts of climate change put stress on agriculture, forestry, fisheries and aquaculture, which increasingly hinders efforts to meet human needs, with the negative impacts being greatest in some of the world's poorest

[5] Income groupings are commonly used in the analysis of heterogeneity across countries. For agrifood systems, where possible, the analysis should be further detailed based on greater levels of income stratification, as well as additional criteria based on environmental, social and economic variables. As outlined throughout this report, all climate technology uses are highly country, context and agrifood system specific.

areas. These risks threaten the adequacy and accessibility of food, undermining the right to food for many populations. While the effects on crop productivity due to climate change have some positive outcomes in high latitudes, they are mostly negative effects in sub-Saharan Africa, South America and the Caribbean, southern Asia, and western and southern Europe (Bezner *et al.,* 2022).

The urgency and need for adaptation relate to the degree of climate risk present, which in turn is driven by the level of climate change, the dynamic interactions among climate-related hazards, the exposure and vulnerability of affected human and ecological systems, and the responses to these (Ara Begum *et al.,* 2022).

For example, in agrifood systems, women have been found to be more vulnerable to climate hazards than men (FAO, 2023b). This vulnerability, combined with climate change exposure and the hazards themselves, generates high levels of climate risk. The same report finds that a 1° C increase in long-term average temperatures is associated with a 34 percent reduction in the total incomes of female-headed households, relative to those of male-headed households (FAO, 2023b). Lecoutere *et al.* (2023) ranked low and middle-income countries based on the level of climate risk faced by women in agrifood systems (see Figure 12). They found convergence between high exposure to climate risk and high vulnerability due to gender inequalities in Sahelian countries in Central, Eastern and Southern Africa, and in Western and Southern Asia. Their results indicate the importance of taking gender considerations into account in efforts to meet capacity needs.

Figure 12. Map of climate–agriculture–gender inequality hotspot risk index

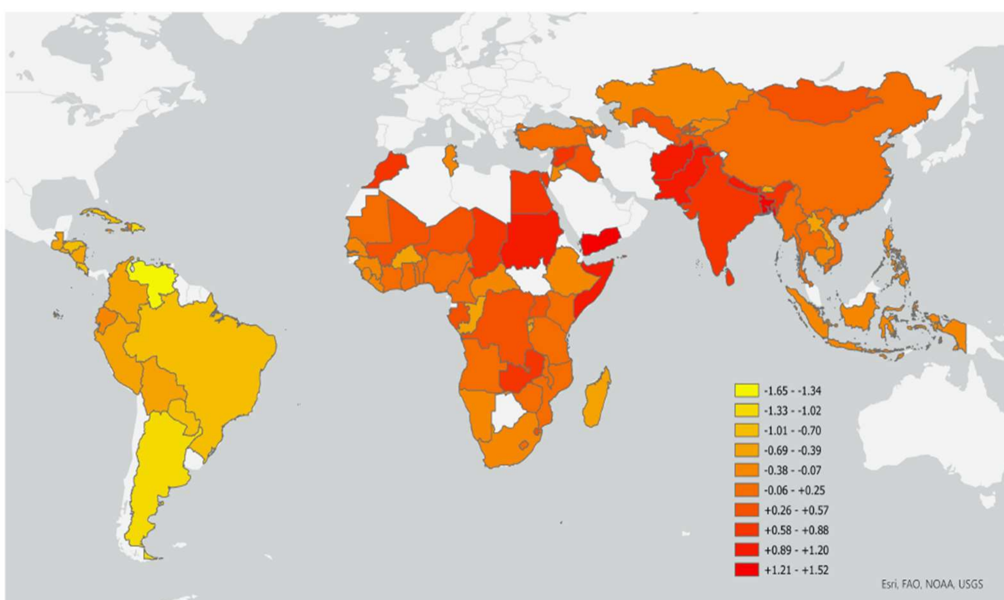


FIGURE 2
Climate–agriculture–gender inequality hotspot LMICs across the globe. Darker orange-colored countries have relatively high climate–agriculture–gender inequality hotspot index values; therefore face higher risk. Lighter orange-colored countries have relatively low climate–agriculture–gender inequality hotspot index values; therefore face lower risk. LMICs with a white color have not been ranked due to data limitations.

Source: **Lecoutere, E., Mishra, A., Singaraju, N., Koo, J., Azzarri, C., Chanana, N., Nico, G. & Puskur, R.** 2023 Where women in agri-food systems are at highest climate risk: a methodology for mapping climate– agriculture–gender inequality hotspots. *Frontiers in Sustainable Food Systems,* 7: 1197809. https://doi.org/10.3389/fsufs.2023.1197809

3.2 Existing capacity in place

A recent review by Rose (2023), which focused on the factors affecting the adoption of climate-smart agricultural technologies, identified a range of different capacities deemed important. These include characteristics of the individual adopting the technology (e.g. gender, age, educational level, ethnicity) as well as institutions and organizational capacity, such as community-based groups. Likewise, the presence of facilitating infrastructure (e.g. electricity, mobile connectivity, agricultural extension services, financial institutions) is important. Developing countries (in particular, LDCs) have less capacity in place for many of these factors.

For example, the energy infrastructure in LDCs is often quite weak, with limited coverage and capacity. This gap offers an opportunity to deploy climate technologies that support low-emission electricity generation. However, it can also pose a problem in situations where climate technologies rely on energy availability. For example, the rural areas of sub-Saharan Africa have particularly limited access to electricity, with 28 percent of rural residents (approximately 476 million) having such access compared with 78 percent in urban areas in 2020 (Parada, Pirlea and Wadhwa, 2023). Ensuring energy availability and accessibility is an important capacity need in this context.

Mobile broadband coverage and internet connectivity is a form of infrastructure essential to the successful functioning of many climate technologies for agrifood systems. Digital technologies have radically changed the way in which information is transmitted. Across the African continent, farmers are using digital technologies to improve yields, transport goods, receive and deliver services, learn new skills, and connect themselves across widely dispersed geographic areas (TEC, 2022). This is largely due to the increased capacity of mobile telephone connections and the declining costs of accessing and using digital information. Farmers are using Facebook and WhatsApp, among other social media platforms, for information sharing on such topics as farming advice and prices.

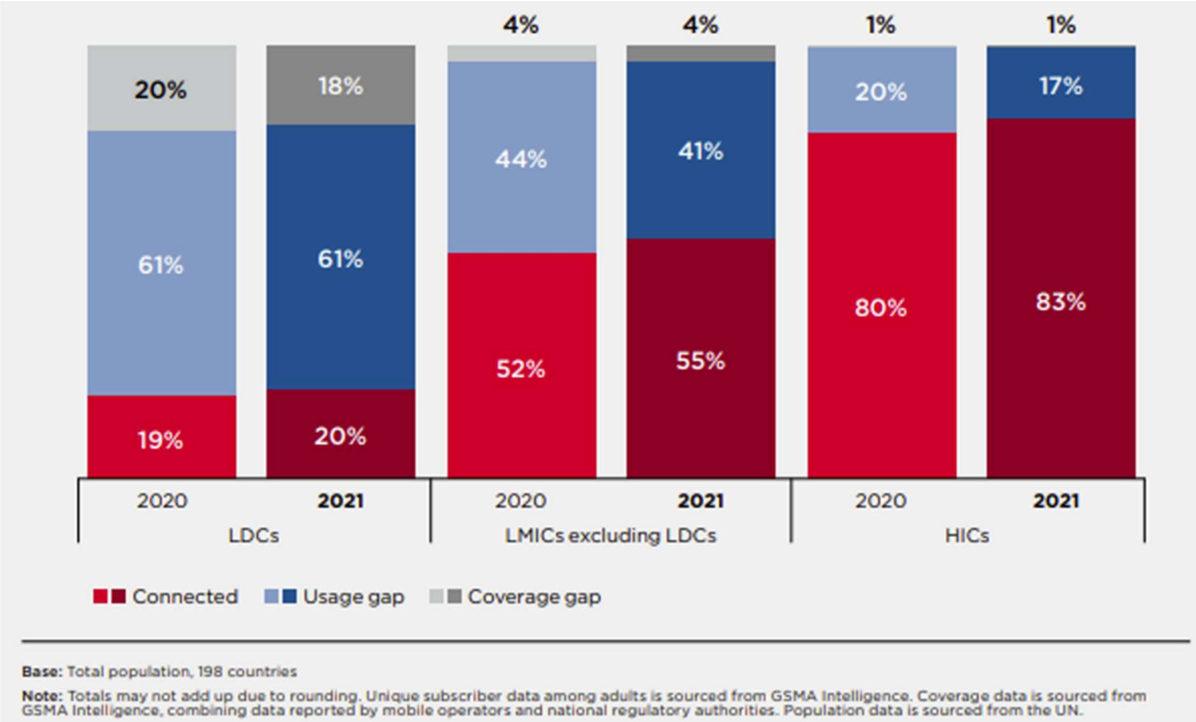
AA recent report by GSMA[6] (2023) on the state of mobile connectivity found that 94 percent of "unconnected" people live in LMICs. Furthermore, at the end of 2021, only 20 percent of the population in LDCs were using mobile internet, compared to 55 percent in other LMICs (excluding LDCs) (GSMA, 2023). There is a divide here between rural and urban areas, with adults in rural areas being 33 percent less likely to use mobile internet than those living in urban areas (GSMA, 2023). Likewise, gender matters; women in LMICs are 16 percent less likely to use mobile internet than men (GSMA, 2023).

It is important to note, however, that this is not solely an issue of missing infrastructure. For example, 44 percent of adults in LMICs still do not use mobile internet, despite being covered by a mobile broadband network. Other barriers persist, including knowledge and skills, affordability, safety and security concerns, and a lack of relevant content and services.

Figure 13 indicates the significant gaps in using mobile connectivity in LDCs, for both broadband coverage and usage. Since mobile connectivity can play a game-changing role in promoting the successful adoption of climate technologies, these gaps deserve immediate attention. The fact that the usage gap is larger than the coverage gap for mobile connectivity indicates a clear priority for enabling access to users.

[6] Global System for Mobile Communications Association.

Figure 13. Mobile connectivity in LDCs, LMICs and HICs, 2020–2021



Source: Reproduced as shown in . **GSMA.** 2022b. *The State of Mobile Internet Connectivity 2022.* https://www.gsma.com/r/wp-content/uploads/2022/12/The-State-of-Mobile-Internet-Connectivity-Report-2022.pdf?utm_source=website&utm_medium=download-button&utm_campaign=somic22

The GSMA report indicates that poor rural women are more likely to experience financial difficulty in acquiring mobile connectivity. The cost of an entry-level internet-enabled handset is a higher barrier for women in LMICs, representing a median of 25 percent of monthly income, compared with 15 percent for men. In LMICs, women are also more likely to lack digital literacy or any type of literacy. Both factors were cited as major barriers to usage (FAO, 2023c). In half of the countries surveyed by GSMA, illiteracy is still reported as an important barrier by at least a quarter of those who do not use mobile internet despite being aware of it.

Box 5. Building the case for prioritizing rural women's access to, and use of, information and communication technologies (ICT) for adaptation

It is estimated that closing the gender gap in farm productivity, as well as the wage gap in agrifood system employment, would increase global gross domestic product by 1 percent (or nearly USD 1 trillion), and reduce the number of food-insecure people by 45 million (FAO, 2023b).

Each day of extreme high temperatures reduces the total value of crops produced by women farmers by 3 percent relative to men (FAO, 2024a).

Internet access has helped improve the production efficiency of maize and rice growers in Bangladesh (Das, Munshi and Kabir, 2017), rice growers in Viet Nam (Kaila and Tarp, 2019) and banana growers in China (Zheng *et al*., 2021; cited Li *et al.,* 2024).

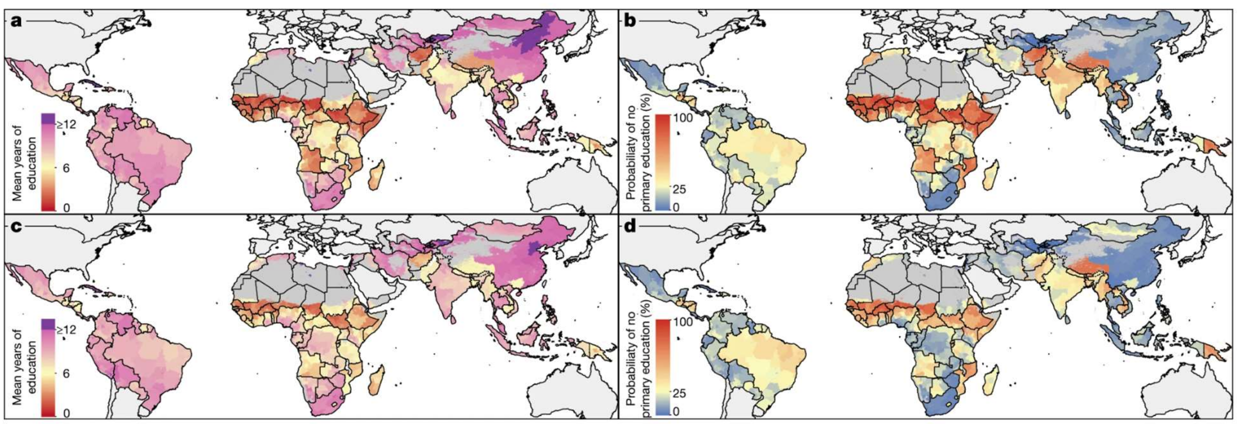
In LMICs, 900 million women still do not use mobile internet, with almost two thirds living in South Asia and sub-Saharan Africa. Women in these regions remain the least likely to use mobile internet compared to men, with gender gaps of 41 percent and 36 percent, respectively (GSMA, 2023). Against this backdrop, large-scale initiatives specifically focused on equipping rural women with digital literacy and skills are rare (FAO, 2023c).

As demonstrated in the discourse around the adoption of digital technologies, literacy rate is a form of capacity that facilitates adoption of new technologies. Such a factor is also highly variable across countries, being influenced by gender, age and ethnicity.

Figure 14 shows the results of a recent study analysing access to education in LMICs for men and women. The maps on the left-hand side show the difference between women and men in years of education, while those on the right show the proportion of women with no primary education compared to men. The results indicate a significant lack of educational capacity in LMICs, particularly for women.

Figure 14. Access to education

From: Mapping disparities in education across low- and middle-income countries



a–**d**, Mean educational attainment for women (**a**) and men (**c**) and the proportion of individuals with no primary school education for women (**b**) and men (**d**) aged 15–49 years in 2017. Maps were produced using ArcGIS Desktop 10.6.

Source: Reproduced as shown in **Local Burden of Disease Educational Attainment Collaborators.** 2020. Mapping disparities in education across low- and middle-income countries. Nature. 577(7789): 235–238. doi: 10.1038/s41586-019-1872-1

3.3 Institutional needs for climate technology adoption

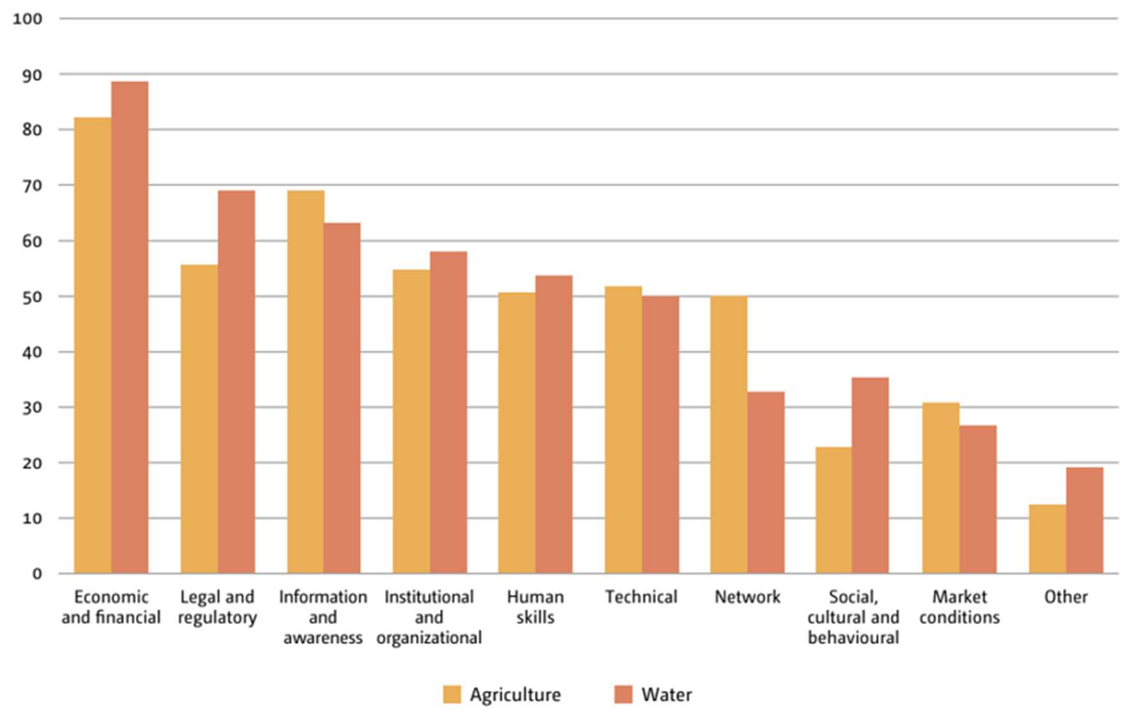
Based on surveys and country submissions, several recent reports from TEC[7] outline the barriers and enablers identified by countries when adopting climate technologies. These give clear indications of the institutional changes that can enable climate technology adoption – and those that hinder it. Economic and financial barriers were consistently identified as the most (or among the most) important for both mitigation and adaptation technologies. This was true at a general level and also in the cases where technologies specific to the agriculture and water sectors were reported (see Figure 15). In these two sectors, legal and regulatory challenges were identified as the second most significant barrier, followed by information and awareness.

Data from the Climate Technology Progress Report 2022 (UNEP-CCC, UNFCCC and TEC, 2022) indicates that direct government allocations for climate technologies are much lower in developing countries than in high-income countries (HICs), with all indicators showing a strong positive correlation between expenditure and rising income levels.

[7] See TEC, 2013; TEC, 2018; TEC, 2023.

The structural constraints faced by developing countries as they seek to adopt new technologies, including limited local technological capacities and know-how, are caused by low public funding for research and development (R&D), limited infrastructure and institutional strength.[8]

Figure 15. Enablers identified in the adaptation sectors: agriculture and water



Source: Reproduced as shown in **TEC.** 2022. *Enabling Environments and Challenges to Technology Development and Transfer Identified in Technology Needs Assessments, Nationally Determined Contributions, and Technical Assistance Provided by the Climate Technology Centre and Network.* https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/tec_enablingenvironments/d611c896c4dd44c79c79ec8938625a88/b8730b2990284c17887b1f511b5a2f7c.pdf

Similar results come from the fourth synthesis of technology needs identified by Parties not included in Annex I to the Convention (UNFCCC, 2020). For the agriculture sector the most commonly identified types of barriers were economic and financial (reported by 100 per cent of the Parties) and policy, legal and regulatory (98 per cent) (UNFCCC, 2020). Strengthening existing or creating new financial mechanisms, policies, incentives and subsidies were identified as ways of overcoming economic and financial barriers, as were reviewing price competitiveness and creating an allowance in national budgets.

Policy, legal and regulatory barriers are commonly cited in terms of climate technology adoption, second only to financial and economic barriers in most cases (TEC, 2022; TEC, 2023). Findings from the fourth synthesis report provide insights into the issues here. The most frequently reported issues in this category include insufficient legal and regulatory frameworks or insufficient enforcement of those already in place. Less importance was given to bureaucracy or clash of interests between proponents of old and new technologies (under 20 percent in each case). Thirty-two percent of the respondents said the establishment of a comprehensive agricultural development policy was key to overcoming the policy, legal and regulatory barriers. Through revised policy frameworks, improved access to land and fishery grounds, better recognition and prioritization of extension services, establishment of quality control systems and

[8] See United Nations Conference on Trade and Development [UNCTAD], 2003; UNCTAD 2004

expansion of certification schemes were also cited as enabling measures to facilitate the uptake of adaptation technologies in agriculture. Awareness campaigns, farmer and fishers training, strengthened R&D programmes and the establishment of participatory coordination and communication channels among concerned partners were also commonly identified.

3.4 Financial institutions as barriers and enablers to climate technologies

While inadequate financing is a significant barrier to effective climate technology adoption, the presence of weak and poorly functioning financial institutions is an equally important factor to address. Focusing on financing levels, this section aims to investigate the shortcomings of financial institutions and the ways that capacity needs to be enhanced to support climate technologies in the context of agrifood system transformation.

A recent review (Khan *et al.,* 2024) of constraints to agricultural financing offers insights into capacity (both the demand and supply side) in terms of climate technology adoption in agrifood systems. On the demand side, a lack of collateral and guarantees, as well as a lack of awareness of financing opportunities, are significant constraints. On the supply side, complicated procedures, lack of suitable products, high transaction costs and asymmetric information are particularly relevant. The overall weaknesses of infrastructure to support efficient financing – including poor communication and monitoring capacity, risk management and market regulation – are also cited as important constraints (Khan *et al.,* 2024).

One noteworthy issue is managing lending risk to those entities operating in the informal sector and that lack collateral. The high risk of lending to informal small and medium-sized enterprises (SMEs) in agricultural value chains indicates a need for financial institutions to provide guarantee and risk-sharing services; something that, at present, is lacking. One such example is given in Box 6.

Box 6. Asset-collateralized loans to finance adaptation for small-scale dairy producers

Products funded by asset-collateralized loans represent a highly promising innovation through which to finance assets for adaptation. However, despite the potentially high returns for farmers and important adaptation benefits, their use remains rare in many low-income rural agricultural settings. An example of this productive asset is the use of water tanks to harvest rainwater or store intermittent piped water.

Dairy cattle require 50-100 litres of water per day for consistent milk production. However, securing financing to acquire such tanks is difficult for many small-scale producers due to weak local financial institutions and financing options. Would-be borrowers are often subject to tight restrictions, such as high deposits or the need for a guarantor to co-sign any necessary documentation. These requirements prevent many from accessing credit and obtaining assets to support adaptation. For example, farmers in East Africa are commonly organized in savings and credit cooperatives (SACCOs), which offer loans to members to purchase productive assets. The terms of these loans are often restrictive, requiring guarantors to fully cover loan balances.

One way to overcome this barrier is through the use of asset-collateralized loans; a process that is widely used in HICs for large purchases such as houses and cars. An example of this approach can be found in Kenya, where the asset-collateralized loan model adopted by Nyala Vision (a SACCO serving dairy farmers) has increased the take-up of loans for rainwater-harvesting tanks tenfold to twentyfold. Furthermore, water storage capacity has increased by 59 percent, and milk sales revenue has increased by 6 to 8 percent. It is common for such increases to occur after the loan repayment has ended, thus suggesting a persistent boost in productivity. Overall, approximately 10 percent of household monthly expenditures benefit from this increase in revenue (Jack *et al*., 2023). The evidence also suggests that school attendance improved among girls in these households, perhaps due to reduced time spent fetching water.

Asset-collateralized loans programmes for dairy farmers can be financially sustainable and/or profitable once they are established. For example, the aforementioned Nyala Vision SACCO programme had a tank repossession rate of less than 1 percent; in this scenario, the down payment was set at 4 percent, with no defaults under a 25 percent down payment (Jack *et al*. 2023). The SACCO benefited from technical assistance and a capital infusion to launch its programme. Now, eight years after the technical assistance concluded, the programme is still running successfully, thus suggesting that the model is sustainable once it is established. Despite the success in this context, however, the model remains rare among banks, microfinance institutions, and financial cooperatives serving farmers in LMICs, with most continuing to offer restrictive cash-collateralized loans or loans with short durations, as well as other high barriers to entry.

It is not only dedicated financial institutions that can play an important role in overcoming financial constraints; other institutions can assist too. For example, value chain finance can be provided by input suppliers, non-profit organizations, development finance institutions and private sector investors (International Institute for Sustainable Development, 2015; FAO and AFRACA, 2020). Furthermore, the financing may be channelled through different local organizations, including producers' organizations, women's groups, youth organizations or other community-based organizations.

For example, in Chile, climate technologies for agrifood SMEs include energy-efficient lighting and ventilation systems; drip irrigation; pre-coolers and heat recovery systems for refrigeration energy; and solar energy for power generation, the heating of water, biodigesters and air drying. In this context, planning has been supported by the Government of Chile, which formulated a clean production agreement (CPA) under the Nationally Appropriate Mitigation Action. Here, the CPA leverages the social capital of a business association with its associates, thereby building trust, sharing knowledge and aggregating technology demands, all of which stimulates investments in the sector (TEC, 2023).

In LMICs, the use of social protection is an innovative and increasingly widespread approach to inclusive climate action that can reach the poorest and those in the most vulnerable situations, with potential for financing and to supporting the uptake of climate technologies. Box 7 describes some recent cases.

Box 7. Role of social protection in facilitating uptake of climate technologies

Social protection is a set of policies and programmes that, throughout their life cycle, aim to prevent and protect all people against poverty, vulnerability and social exclusion, placing a particular emphasis on groups in vulnerable situations (Social Protection Inter-Agency Cooperation Board, 2019). It encompasses interventions such as cash transfers, public works programmes, social insurance and vocational training and is increasingly acknowledged as a key tool for inclusive climate action (IPCC, 2022a). One way in which social protection contributes to climate adaptation is by facilitating the adoption of climate-adaptive agricultural practices and technology. Poor rural households may lack the skills and resources necessary to adjust their production methods to confront and adapt to climate-related challenges. For example, producers might need to shift to drought-resistant crops, adopt livestock breeds more resilient to climate change, or implement agroforestry and water-efficient irrigation methods. Barriers include resource and liquidity constraints, limited access to essential services, skills and knowledge, uncertain returns, long gestation periods, and the challenge of balancing immediate needs with long-term investments.

In Paraguay, the Green Climate Fund's Poverty, Reforestation, Energy and Climate Change project addresses these challenges by combining environmentally conditioned cash transfers with tailored technical support to assist small-scale farmers (including poor women and Indigenous Peoples) in adopting sustainable agroforestry practices. Through the programme, families are provided with supplies, machinery and external technical assistance, which is used in combination with ancestral knowledge to support climate-resilient agricultural practices (FAO, 2018b).

There is also evidence of positive impacts at both the household and community levels of skills and knowledge transferred through public works programmes such as India's Mahatma Gandhi National Rural Employment Guarantee Act, 2005 and Ethiopia's Productive Safety Net Programme (Fischer, 2019; Kaur *et al*., 2019; Scognamillo *et al*., 2022). Through water and land management works (such as restoring canals, building rainwater storage tanks, checking dams, and overseeing tree plantations), these programmes have led to increased water availability, maintained groundwater levels, reduced soil erosion and increased soil organic carbon content. Social protection can thus also contribute to natural resource management and ecosystem restoration, which are integral to climate adaptation. However, there are sometimes trade-offs between the time spent on public works, and the expense of time and labour invested in land management practices on one's own land. The evidence suggests that social protection programmes need to explicitly incorporate skills, knowledge and technology co-creation and sharing components to minimize these trade-offs and enhance climate impacts (Bhalla *et al*., 2024).

3.5 Legal and regulatory institutions

According to TEC (2022), legal and regulatory issues are the second most important enabler of climate adaptation technologies in the agriculture and water sectors. This particular topic is vast, with considerable variation across different countries and agrifood system types. Here, two main aspects of legal and regulatory systems common to the agrifood sector will be investigated.

3.5.1 Informal institutions

In many developing countries, informal institutions are widely found in the midstream of agrifood systems (IFAD, 2021). In this context, the informal sector comprises businesses and employment without formal contracts and registration, often with no legal recognition or protection (Termeer *et al*., 2024). In Africa and South Asia, for example, 98 percent and 99 percent of agricultural workers are employed informally, respectively (Ruggeri Laderchi *et al.,* 2024).

In terms of working for informal institutions, perceptions and experiences are mixed, as are the implications for the capacity needed to support climate technologies. On the one hand, the lack of government regulation and enforcement can result in exploitative labour conditions, unsafe food quality, low productivity and low capacity to invest in technology (Termeer *et al.*, 2024; Ruggeri Laderchi *et al.,* 2024).

On the other hand, informality can support inclusiveness, particularly for women, who are dominant in this sector in many countries' agrifood systems. Liverpool-Tasie *et al.* (2021) found that SMEs in food value chains operating in the informal sector also provide a wide set of complementary services to farmers, such as credit, inputs and technical assistance. However, though most interactions between SMEs and farmers were deemed positive, it is worth noting that some negative impacts were found, relating to a lack of trust and high transaction costs.

Formalizing the informal sector has been a prominent response to its perceived and documented shortcomings. However, this report recognizes two problems with such an approach. First, since regulations for formal sector agrifood systems have been developed based on the fossil-fuel-intensive agrifood system concept, their adoption can result in undesirable technology "lock-ins". Second, the adoption of such regulations can reduce inclusivity, since many informal sector participants might struggle to meet the requirements.

The IFAD Rural Development Report 2021 on transforming agrifood systems notes the substantial benefits of adopting a facilitative approach towards informal businesses in agricultural value chains. This can include technical assistance, training and behaviour change, as well as public support to provide financial incentives for compliance with food safety standards (IFAD, 2021).

3.5.2 Technological lock-ins and path dependency

Although wealthier countries with industrializing and modernizing agrifood system types are better equipped with infrastructure and human capital, they face significant capacity constraints. These come in the form of technology "lock-ins"[9] and path dependency, which Conti, Zanello and Hall (2021) (in their survey of factors inhibiting change in agrifood systems) describe using the example of the overuse of chemical pesticides. In this example, a permissive regulatory environment allowed agrichemical companies to develop a highly successful business model of low price, ease of access and technical support to farmers. Private R&D investments supported the continuance of this profitable model, thus creating path dependency. However, uptake of any adjustments has been slow, despite conditions significantly changing since the inception of pesticide use. Ultimately, existing institutional arrangements (including intellectual property rights and food-labelling regulations) have "locked in" incentives and a pattern of behaviour that is aligned with past conditions, as opposed to the current objectives of agrifood system transformation (Conti, Zanello and Hall, 2021).

Magrini, Béfort and Nieddu (2019) observed the effects of lock-ins as a barrier to crop diversification, which itself is an important means of adapting to climate change. More specifically, their study investigated the barriers to including pulses in crop rotations in France. They found that lock-ins for fertilized cereals arose in the French agrifood system following World War II. This occurred due to several interconnected events: (i) R&D focused on improving wheat yields; (ii) technical advisory services therefore focused on that crop; (iii) farm equipment was developed to specialize in the crop; and (iv) payments were incentivized for wheat. Along with trade barriers, this created a lock-in whereby specialization in wheat was favoured, resulting in a barrier to diversification.

Overcoming technological lock-ins and path dependency requires a comprehensive approach to change, including the research, advisory services and equipment, and market policies relating to it. Creating links to related transition processes (e.g. linking agrifood transition to efforts aimed at energy transition and dietary transition) is a means to achieving this (Magrini, Béfort and Nieddu, 2019). Engaging local communities and their knowledge is an important enabler of change as well.

3.6 Information and awareness

3.6.1 Information exchange through South-South Cooperation

South-South Cooperation (SSC) helps developing countries to exchange information on climate technologies in agrifood systems and the conditions needed for their successful implementation (Costa Vasquez, 2016). Since the technologies, expertise and institutional conditions are likely to be more similar for countries at similar levels of agrifood system development, sharing and exchanging of lessons learned across said countries can be particularly valuable. In SSC case studies, examples of the type of transferred information include how to access climate financing and how to overcome legal and regulatory barriers to climate technologies (Costa Vasquez, 2016). There is a need to enhance the ability of countries to identify potential sources of knowledge transfer through SSC mechanisms. The United Nations Technology Facilitation Mechanism could help advance SSC in those adaptation technologies that use integrated approaches to the WEF nexus (Costa Vasquez, 2016).

[9] Technological lock-in is the idea that, as economic and cultural advantages accrue to existing incumbent technologies, barriers are created to the adoption of potentially superior or at least as valuable alternatives (Foxon, 2014).

3.6.2 Agricultural extension

Agricultural extension services play an important role in disseminating information about climate change, adaptation and mitigation options, resource requirements and financing options, as well as the market conditions that affect the business case of adopting climate technologies (IPCC, 2019). According to IPCC (2019), improving agricultural services to better integrate climate information and enhance access of groups in vulnerable situations is one of the most frequently cited ways of improving capacity for climate response in the agriculture, land and food sectors.

There are several forms of agricultural extension, which encompass private, community-led and public-sponsored systems. Box 8 describes one innovative form of extension developed and promoted by FAO.

Box 8. Farmer field schools: An effective platform to empower smallholder farmers in responding to climate change

Over the past three decades, the farmer field school (FFS) approach has focused on people-centred learning, with the goal of creating a risk-free environment for knowledge exchange among small-scale producers, including farmers, foresters, pastoralists, Indigenous Peoples and local communities. Building participants' technical and decision-making skills, FFS incorporates principles from adult education, emphasizing self-directed, experiential learning.

In Malawi, the FFS programme works with local communities to develop climate-sensitive, catchment-specific FFS adaptation and mitigation interventions for hotspots. Within a catchment, several locations could be a "hotspot", i.e. a place that exhibits climate-related vulnerability/variability issues and indicators of critical degradation such as the presence of gullies, flooding, deforestation, riverbank cultivation, soil erosion, and extensive mining. Land degradation hotspots in the targeted communities are profiled and mapped, and micro-catchments are delineated within a geographic information system so that appropriate site-specific catchment interventions can be zoned and planned. A community adaptation plan is generated, from which each FFS group established in the catchment selects the strategies suitable for their location to design site-specific interventions through a group adaptation plan (FAO, 2021c).

4. Financial flows and needs for climate technology, in general and in relation to agrifood systems

Financing for climate technologies in agrifood systems is an important, if not central, element to ensure that technologies can be implemented in the field. The data available to assess the amount of financing required and the current amounts of financing going into climate technologies is sparse and at times not completely consistent across the limited sources. This section attempts to outline some of these elements based on the data currently available for climate financing and agrifood systems.

At the time of writing, there is no single source of information or data about the finance flowing to climate technologies in agrifood systems, nor is there a standard way to analyse the costs of fully meeting the technology demands needed to achieve the Paris Agreement objectives. As such, analysis of these issues currently requires the use of different sets of analysis and databases, which have a range of assumptions, data sources and interpretations. Consequently, the information derived from this today remains fragmented; any efforts to draw a conclusion should be seen as a first attempt.

This section of the report utilizes the three main sources available for climate finance: (i) the data and analysis of the Climate Policy Initiative (CPI) (which includes data from the Development Assistance Committee [DAC] of the Organisation for Economic Co-operation and Development [OECD], as well as data from other sources); (ii) data from the OECD DAC climate-related development finance dataset and patent database (OECD, 2024); and (iii) the published literature (i.e. analysis of data from NDCs). It is important to note that the data used by CPI is not open source, meaning only results from its analyses can be presented. While CPI focuses on climate finance (i.e. all finance globally going to climate change), OECD DAC focuses on climate-related development finance, resulting in both a wider climate focus and a narrower set of countries compared to CPI.

4.1 Climate finance flows to climate technologies in agrifood systems

According to CPI (2023),[10] in 2019/2020 only 4.3 percent of the global climate finance tracked at the project level (or 28.5 USD billion) went to agrifood systems, with this share dropping to around 1 percent when referring only to adaptation finance. In the same period, only 20 percent of the tracked venture capital investments in agrifood technology went to companies focusing on climate change[11], amounting to an annual average of USD 4.8 billion (Climate Focus, 2023; CPI, 2023). The report of CPI (2023) shows that, in 2019/2020, 85 percent of tracked project-level climate finance for agrifood systems came from public sources (primarily from development finance institutions), amounting to USD 24.2 billion, with the remaining amounts coming from private sources.

Due to the aforementioned data limitations regarding climate finance, special care should be taken when interpreting the aggregate figures contained in CPI (2023), particularly when comparing with other data reported here. This is even more important when considering that CPI's analysis not only accounts for the entire architecture of climate finance, but includes a broader range of financial aspects related to climate change, including public and private sector investments, and domestic and non-developmental private climate finance.

[10] CPI (2023) mentions significant limitations in relation to the reported data. This means that immediate comparisons with other data sources, as well as interpretation of the provided data, should be performed with care. Furthermore, as explained in the introduction, financial flows from different reports rely on different sources and are, therefore, not directly comparable.
[11] CPI (2023) complements project-level data with data on venture capital investments from private sources into agrifood tech companies for the period 2019-2020.

The following sections will analyse climate-related development finance flows, first by focusing solely on international public finance, and then by taking a broader approach to climate finance.

4.1.1 Flows of climate-related development finance to agrifood systems-related technology

In order to assess the amount of climate finance currently going to agrifood systems and climate technologies, this section uses the OECD DAC climate-related development finance dataset (OECD, 2024). This dataset is open access and includes official development assistance, other official flows, private grants, and private amounts mobilized, as reported by DAC and non-DAC members, including multilateral institutions and private philanthropy. For the purpose of this analysis, the definition of "agrifood systems"[12] (which includes agriculture development, crop production, nutrition, cross-cutting, energy, fishery, aquaculture, food security, forestry, livestock, environment and biodiversity, and emergency/resilience) is based on a selection of the OECD purpose codes compiled in consultation with FAO technical departments.

The definition of "agrifood systems-related technology" derives from the selection of 22 agrifood systems codes,[13] all of which pertain to activities involving varying degrees of technological integration. It is important to note that not all flows to each specific code directly correlate with technology. While the technology-related codes provide a framework for understanding the technological aspects of agrifood systems, they are not exclusively dedicated to technology-related activities. Instead, they serve as proxies or indicators of technological integration within broader agricultural, biodiversity and food-related practices.

In the period 2013–2022 (2022 being the latest reported year), climate-related development finance to agrifood systems-related technology totalled USD 50 billion, representing 29 percent of total climate-related development finance to agrifood systems in the same period (OECD, 2024). Between 2016 and 2017, this amount doubled, increasing from an average of USD 3.2 billion annually in the period 2013–2016, to an average of USD 6.2 billion annually in the period 2017–2022. The higher flows in 2017 were a result of the increased contributions to the agricultural water resources subsector, with large projects financed by Japan in Indonesia and India for the modernization and rehabilitation of existing irrigation systems, and in Viet Nam to prevent salinity water intrusion. Further increases can be seen in the environment and biodiversity sector, with Germany as the main contributor in the period 2017–2022, and in the forestry sector, with higher contributions from the Green Climate Fund, Japan and European Union institutions during the same period.

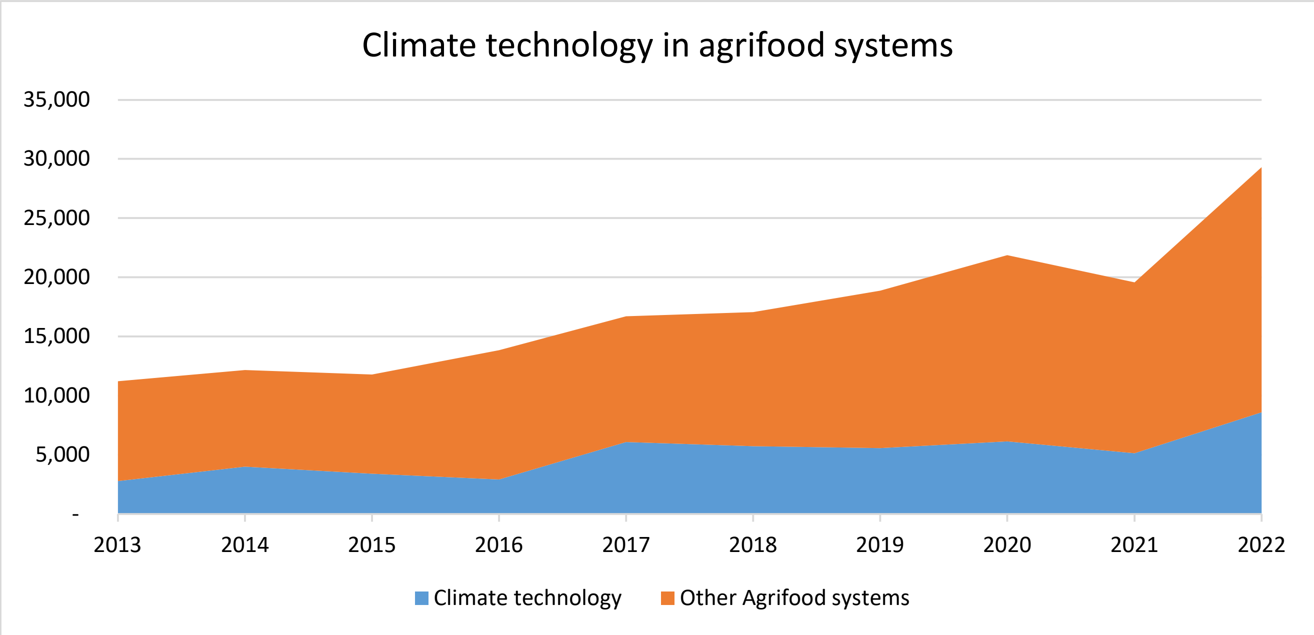
Between 2020 and 2021 (Figure 16), contributions to agrifood systems experienced a general decline, decreasing by 12 percent, which also affected flows to climate-related technology. However, in 2022, contributions grew significantly, with flows to climate-related technology in agrifood systems reaching USD 8.6 billion and continuing to trend positively. Between 2021 and 2022, contributions to climate-

[12] For the full list of codes used to define agrifood systems, please refer to Galbiati *et al.* (2023).

[13] 31150 Agricultural inputs; 31130 Agricultural land resources; 31182 Agricultural research; 31140 Agricultural water resources; 32161 Agro-industries; 14031 Basic drinking water supply; 14030 Basic drinking water supply and basic sanitation; 41030 Bio-diversity; 32165 Fertilizer plants; 31320 Fishery development; 31382 Fishery research; 43073 Food safety and quality; 32162 Forest industries; 31220 Forestry development; 31282 Forestry research; 31192 Plant and post-harvest protection and pest control; 23231 Solar energy for isolated grids and standalone systems; 23181 Energy education/training; 23270 Biofuel-fired power plants; 31261 Fuelwood/charcoal; 32173 Modern biofuels manufacturing; 32174 Clean cooking appliances manufacturing.

related technology in agriculture more than doubled, driven by investments from the World Bank (Galbiati *et al.,* 2023).

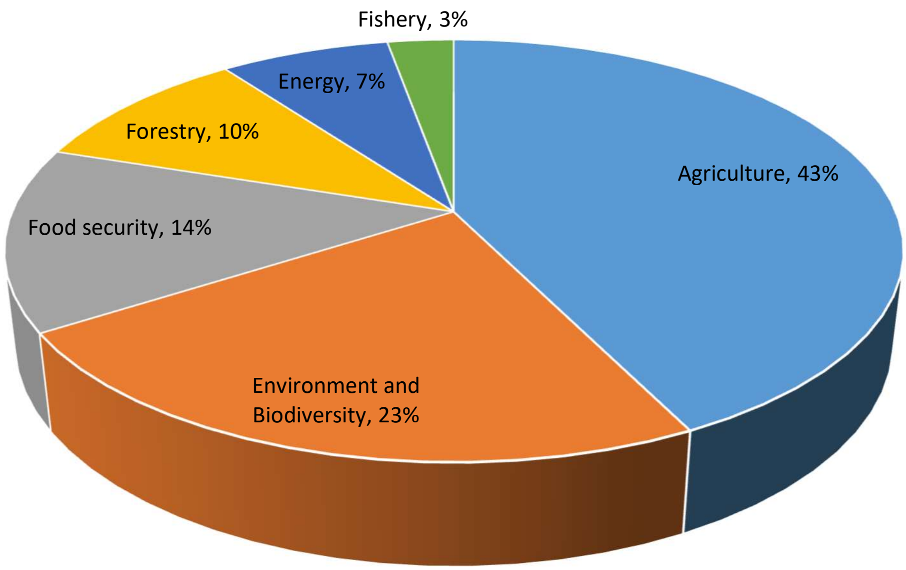
Figure 16. Climate technology in agrifood systems (2013–2022)



Source: Authors' own calculation, based on OECD DAC data.

With regards to the composition of the flows, in the analysed period 2013–2022, 43 percent of total contributions to agrifood systems-related technology were directed to agriculture (Figure 17), followed by the environment and biodiversity (23 percent) and food security (14 percent). Some of the highest-financed projects within the agriculture sector include irrigation modernization, erosion and watershed management, as well as support to agro-industries. In terms of the environment and biodiversity sector, the highest-funded projects include the mainstreaming of biodiversity in agriculture practices through improved territorial management mechanisms, as well as support to reduce emissions related to deforestation, with clear impacts on biodiversity and social development. Food security attracted its largest contribution through a project related to basic drinking water supply infrastructures.

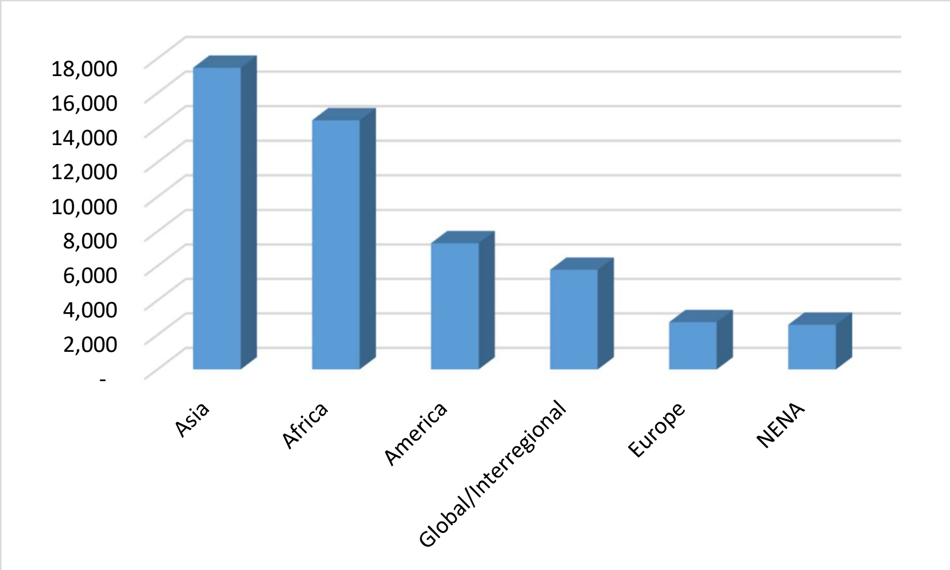
Figure 17. Main financed sectors for climate technology in agrifood systems (2013–2022)



Source: Authors' own calculation, based on OECD DAC data.

Analysing geographical distributions (Figure 18) shows that Asia attracted the most climate-related development finance flows to agrifood systems-related technology in the assessed period, reaching USD 17 billion (or 36 percent of total contributions). This is followed by Africa with 29 percent, America with 15 percent, and Europe, and Near East and North Africa (NENA) with 5 percent, respectively. Global and interregional projects attracted 11 percent of total contributions, or USD 5.7 billion. Agriculture is the most financed sector in Asia, Africa, Europe, and NENA, while in Latin? America, projects relate primarily to the environment and biodiversity, especially in Colombia, Mexico and Brazil, where there is a particular focus on forest management and restoration (OECD, 2024).

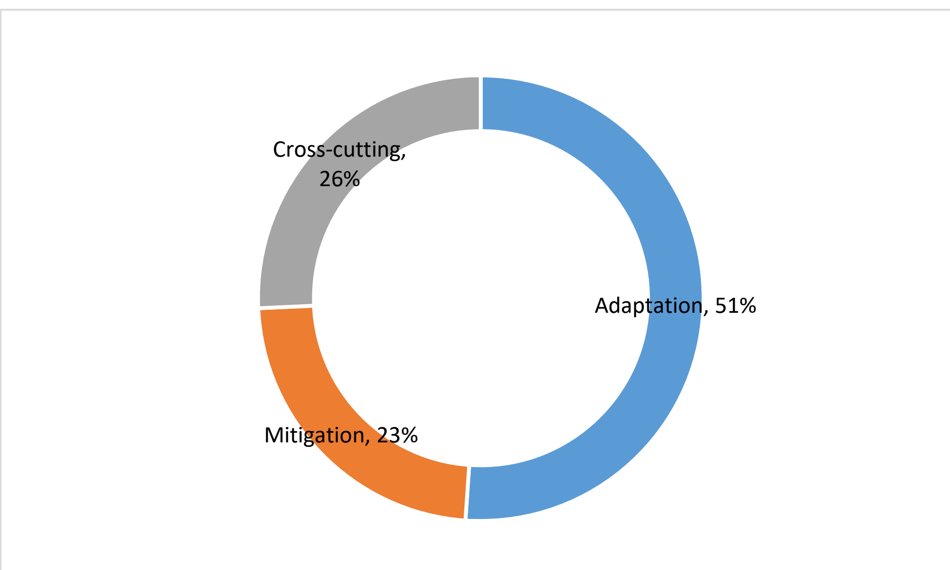
Figure 18. Geographical distributions of flows to climate technology in agrifood systems (2013–2022)



Source: Authors' own calculation, based on OECD DAC data.

The analysis of climate objectives is in line with the analysis of general climate-related development finance for agrifood systems (Figure 19). Here, for technology-related projects, adaptation is the most targeted climate objective, attracting 51 percent of flows, compared with 23 percent for mitigation and 26 percent for cross-cutting. There are substantial differences between sectors, with 80 percent of flows for food security projects being dedicated to adaptation, compared with only 9 percent allocated to mitigation. This is followed by agriculture and fishery, with 71 percent and 68 percent of flows going to adaptation, respectively. Projects related to energy and forestry have the highest share of mitigation focus, while projects related to environment and biodiversity attract mainly cross-cutting flows.

Figure 19. Climate objective of climate-related development finance to technology-related projects (2013–2022)



Source: Authors' own calculation, based on OECD DAC data.

From a regional perspective, NENA has the highest share of flows related to adaptation (65 percent compared with 21 percent to mitigation). Examples of adaptation projects in the region include revitalizing oasis agroecosystems through a sustainable, integrated and landscape approach, and rehabilitating irrigation and drainage facilities for agricultural land. In Africa, 59 percent of flows are directed to adaptation (18 percent to mitigation), with large projects dedicated to erosion and watershed management, as well as regeneration of degraded lands.

4.1.2 Investments in R&D

Financing for R&D is an important indicator of technology development and the enhancement of endogenous capacity. United Nations Environment Programme Copenhagen Climate Centre (UNEP-CCC), UNFCCC and TEC (2022) show that domestic public R&D expenditure as a whole features significant asymmetries across countries: in absolute terms, R&D expenditure in 2020 was, on average, USD 814 per capita in HICs, and USD 76 per capita in upper-middle-income countries. The corresponding figures for LMICs and LICs are significantly smaller, amounting to USD 9 and USD 3 per capita, respectively.

Allocated government budgets for R&D may be an underestimate of total R&D expenditure, as such an approach neglects private sources. Nonetheless, based on OECD data, the above- mentioned report highlights that the share of climate-related public expenditure in R&D devoted to agriculture in OECD countries for the period 2015–2019 was slightly larger than 3 percent of total government budget allocation to R&D.

Though data are quantitatively not comparable, the conclusion of a low share of R&D expenditure in the agriculture and food sector is confirmed in a recent report by Ruane and Ramasamy (2023). Focusing on public expenditure, Table 4 reports the corresponding values in 1981, 2000 and 2016, with a distinction across high, middle and low-income countries.

Table 4. Public sector agricultural R&D spending (2011)
(Billions of 2011 PPP USD)

Countries	1981	2000	2016
High income	12.8	18	18.6
Middle income	7.9	12.4	27.3
Low income	0.4	0.5	0.8
Total	21.1	30.9	46.8

Source: Reproduced as shown in Ruane and Ramasamy (2023, Table 2, p. 11).

Note that the amount invested in LICs is substantially lower than in high and middle-income countries. Also, according to data from Pardey *et al*. (2016), the difference between agricultural R&D spending in high-income and low-income countries is getting larger over time.

4.1.3 Estimated investment gaps

In relation to adaptation needs, a report by UNFCCC (2021) suggests that, according to information available from the national reports produced in the context of the UNFCCC processes (including TAPs and TNAs), adaptation needs are mostly focused on agriculture, water, and disaster prevention and preparedness. Specifically, as the report highlights, needs related to agricultural sector adaptation are linked to several aspects, including crop diversification, development of resistant crops, land and soil, and livestock management.

Rosegrant, Sulser and Wiebe (2022) find that a significant investment gap exists for the agricultural R&D and innovation needed to meet the Paris Agreement objectives and SDG 2.[14] According to the paper's results, the estimated gap is USD 10.5 billion per year; this includes investments from several sources that are directed to agricultural R&D investments and climate-friendly practices. Based on a similar modelling strategy as in the aforementioned paper. Rosegrant *et al*. (2023) conducted a cost-benefit analysis of increased investment in agricultural R&D (USD 5.2 billion per year over the 2022–2056 time horizon). Benefits include a 10 percent increase in agricultural output, reduced hunger and food prices, and a 4 percent increase in per capita income, with a net economic surplus of USD 2.1 trillion. These figures exclude environmental co-benefits (e.g. from reduced deforestation) which, if considered, would further increase the overall benefits (Rosegrant *et al.*, 2023).

Baldos, Fuglie and Hertel (2020) model the relationship between R&D investments, knowledge stock accumulation and the related impacts in terms of productivity growth, focusing on public adaptation investment to offset climate change damages in global agriculture by 2050. The results indicate that, between 2020 and 2040, climate-driven crop yield losses require a 16 to 118 percent increase in investments compared with the current investment trend. Despite the notion that, in this subset of the modelled scenarios, economic benefits may not be enough to outweigh the related adaptation costs, the study suggests that additional co-benefits related to the reduced impacts of climate change on food prices, land use and GHG emissions, provide sufficient rationale for adaptation investments related to R&D.

In the case of aquatic food, FAO estimates that the costs of adaptation for the aquatic food sector in all developing countries amount to USD 4.8 billion per year by 2030. However, the international public finance flows to the aquatic food sector have averaged only USD 0.224 billion per year in the period 2017–2021, underscoring a significant adaptation finance gap (FAO, 2024).

The presence of investment gaps highlighted in the examples provided does not necessarily imply that there is little financing flowing to the sector, but rather, that current financial flows are possibly misdirected. Indeed, CPI (2023) underlines, quoting various sources, that finance accruing to the agrifood system-related sector is significant; for example, on the basis of World Bank data, public subsidies for agriculture and fisheries can be estimated at USD 670 billion per year. A substantial redirection of these funds is needed; in particular, moving them away from environmentally harmful practices. Furthermore, CPI (2023) reports an estimated amount for private capital sources devoted to investment in food systems of USD 630 billion per year. An important means of addressing investment gaps is through a refocusing of existing public and private flows.

4.1.4 An assessment of agriculture-related climate innovation via patents

Patents in relevant technologies

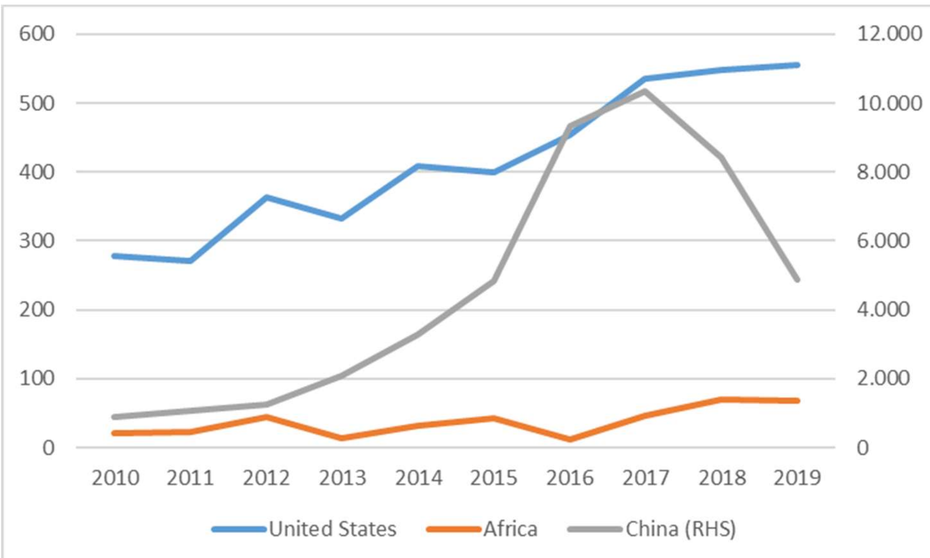
Climate patents related to agriculture can be a measure of the intensity of R&D efforts in the context of mitigation and adaptation domains. Figures 20 and 21 report the number of patents related, respectively, to mitigation and adaptation climate-related technologies linked to agriculture,[15] covering selected parts of the world; namely, the United States, China and aggregated data for African countries that are included

[14] See Rosegrant, Sulser and Wiebe (2022), in particular Table 1, for details on the modelled scenarios. The adopted baseline scenario features average annual investments of almost 10 billion 2005 USD.

[15] More specifically, the following technologies are reported for mitigation (Figure 20): Technologies relating to agriculture, livestock or agroalimentary industries. For adaptation (Figure 21): Technologies in agriculture, forestry, livestock or agroalimentary production. For full details, see the section on technology diffusion at the following link: https://data-explorer.oecd.org/?fs[0]=Topic%2C1%7CEnvironment%23ENV%23%7CTechnology%20and%20innovation%23ENV_TEC%23&pg=0&fc=Topic&bp=true&snb=5

in the OECD dataset. In both figures, the number of patents is reported on the left vertical axis for African countries and the United States, and on the right vertical axis for China. For both types of technologies, recent years show a slowing down, or at least not significantly increasing, pattern, which is surprising if compared with the "boom" of, for example, AI-related patents (Parteka and Kordalska, 2023). The innovation effort reported for aggregated African countries appears to fall significantly short of those in other parts of the world considered. Although available data for African countries are limited (i.e. not all countries are included), this seems to suggest that LICs may suffer from a "property right" issue, as most mitigation patents are outside their national boundaries.

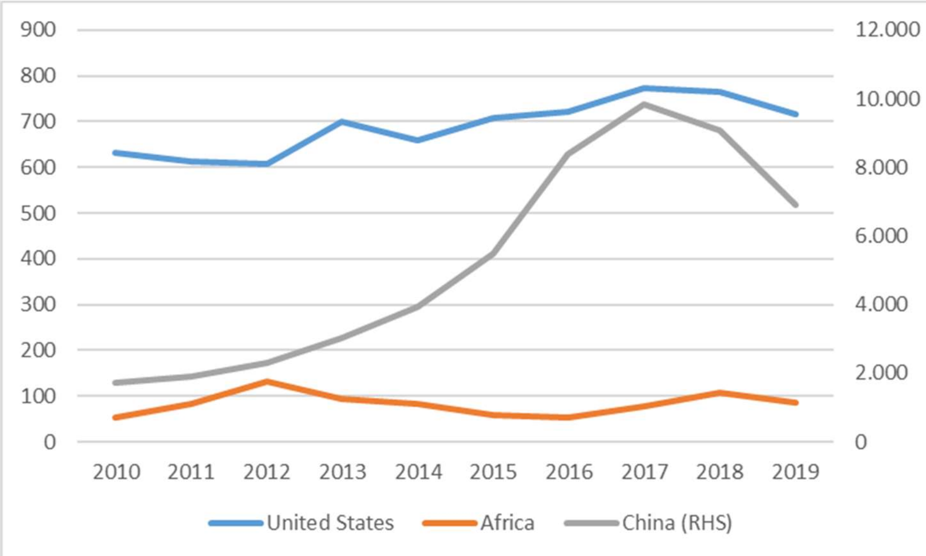
Figure 20. Number of patents for mitigation technologies by country/aggregation



Source: Authors' own calculation, based on OECD patents data.

Acknowledging the significant caveat that only a partial picture can be obtained from these data, Figure 21 reports similar conclusions for adaptation. In terms of patents for technologies relevant to this report, the innovation activity does not appear to be significantly increasing (especially in the case of adaptation), and research efforts are mostly patented outside developing countries, suggesting the possibility of problems related to lack of access to relevant innovation.

Figure 21. Number of patents for adaptation technologies by country/aggregation



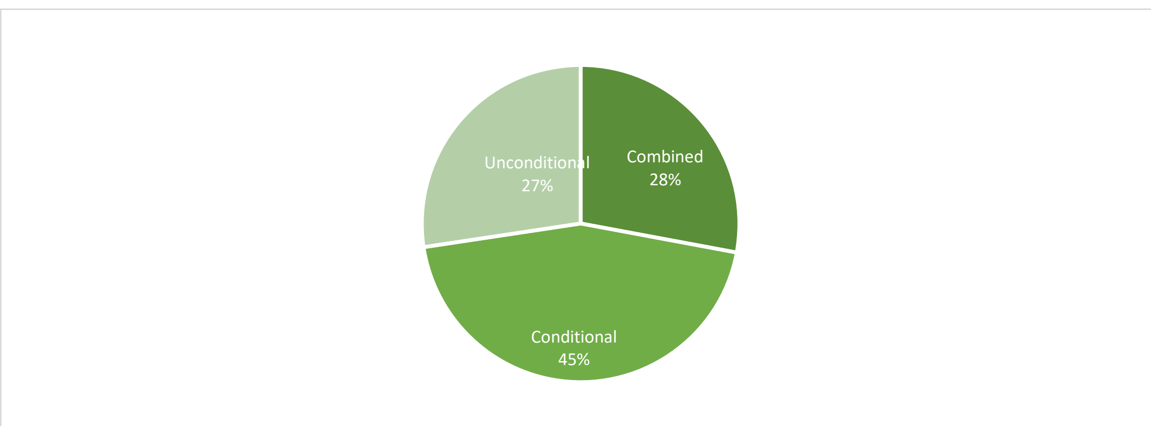
Source: Authors' own calculation, based on OECD patents data.

4.2 Demand for technology investments in agrifood systems expressed in NDCs

Agrifood systems play a significant role in national strategies for achieving both climate adaptation and mitigation (Crumpler *et al.*, forthcoming). Out of the latest 167 NDCs submitted (as of 31 December 2023), 94 percent include adaptation and 86 percent include mitigation efforts in agrifood systems.

Out of the 6,437 agrifood system-related climate technologies included in the NDCs, only 14 percent are costed with a source of finance identified (i.e. international or domestic finance). Amongst those with finance sources specified, almost half (45 percent) of agrifood system climate technologies are fully dependent on the provision of international finance. In LICs, around 80 percent of climate technologies for agrifood systems are either partially or fully conditional to the provision of international finance (Figure 22).

Figure 22. Financial conditionality of climate technologies for agrifood systems (% of technologies)



Source: **Crumpler, K., Angioni, C., Prosperi. P., Roffredi, L., Salvatore, M., Tanganelli, E., Umulisa, V., et al**. (forthcoming). *Agrifood systems in Nationally Determined Contributions: Global Analysis*. Rome, FAO.

Figure 23. Financial conditionality of climate technologies for agrifood systems (% of technologies), by country income level

Source: **Crumpler, K., Angioni, C., Prosperi. P., Roffredi, L., Salvatore, M., Tanganelli, E., Umulisa, V., et al**. (forthcoming). *Agrifood systems in Nationally Determined Contributions: Global Analysis*. Rome, FAO.

5. Country-specific examples of climate technologies and agrifood systems

Covering a range of country and regional examples, this section aims to illustrate how and why climate technology interventions in agrifood systems have been implemented on the ground, and what was achieved. A range of applications are presented to account for regional differences, variations in agriculture contexts (crops, livestock, forestry, fisheries and aquaculture) and the different stages of the value chains to illustrate the diversity of climate technology applications within agrifood systems. Each case study provides a specific example from each subsector, as well as aspects of smallholder inclusion and Indigenous Peoples' technologies.

5.1 Adapting to water scarcity in Lebanon and the potential of treated wastewater for agrifood systems.

Technology name: Use of treated wastewater in agriculture

Agrifood value chain: Crop production

Country context: Lebanon

Country context

Situated on the eastern Mediterranean, Lebanon has been facing numerous challenges, including economic crises, the recent pandemic, the Port of Beirut explosion, environmental disasters, and political deadlock. Water scarcity, worsened by poor management and climate change, affects over 71 percent of the Lebanese population, including 1 million refugees. Key priorities include enhancing agricultural productivity (which contributes around 5 percent to GDP), minimizing groundwater use, and bolstering resilience to drought. Lebanon's agriculture features a diverse range of crops, including market vegetables, bananas, olives, and almonds, with significant income generated from sugar beets, cereals, and vegetable cultivation in Al-Biqā.

The agriculture sector in Lebanon is heavily impacted by climate change, mainly through water scarcity during droughts, posing significant challenges to productivity. In 2021, the Government submitted a revised NDC under the Paris Agreement, outlining climate action plans up to 2030, including a National Adaptation Plan to integrate climate adaptation across governance structures and enhance community resilience.

Key climate technologies

The project introduced in Lebanon aims to enhance irrigation network efficiency with drip irrigation and use of treated wastewater (TW). To raise awareness, over 150 farmers participated in training and upskilling sessions, with the project actively reaching local communities. Wastewater management and reusing treated wastewater in agriculture offer viable solutions to mitigate freshwater depletion. Traditional irrigation methods surpass water needs by 25 to 40 percent, exacerbating water stress. TW is a promising solution, treating wastewater to a high standard by removing pathogens and contaminants, and using it for irrigation. This technology addresses water scarcity and soil fertility, increasing agricultural productivity by providing a reliable water source during dry seasons.

Key advantages

- TW enriches the soil with essential nutrients, improving soil health and fertility, and leading to increased crop yields. This results in better economic outcomes for farming households, including those led by women.
- The project also enhances irrigation network efficiency with drip irrigation, allowing farmers to achieve up to a 40 percent boost in irrigation efficiency through minor adjustments.
- Farmers who participated in the training reported reduced costs for water, fuel and fertilizers. Some also noted a decreased need for pesticides and labour, further lowering costs.

Reflections and next steps

A participatory-based approach was adopted, including all multi-stakeholders, and involving surveys, interviews, workshops, and panel discussions to gather inputs on this technology. This inclusive methodology allowed for a comprehensive understanding of the challenges and needs of all involved parties and facilitated informed dialogue, innovative ideas, and effective strategies for sustainable water management.

Positive outcomes of the project include involving stakeholders in the decision-making process, providing workshops and panel discussions to help stakeholders become engaged in and informed about this technology, and enhancing food security, thereby highlighting how TW could be one of the best solutions to be implemented for sustainable water management and sustainable agriculture. Furthermore, agricultural communities in water-stressed regions, such as the Central Plain of Bekaa, and a significant proportion of women within the agriculture sector, have benefited from TW irrigation, particularly during the dry season. Lastly, 42 percent of farmers highlighted the enhanced food quality as a significant benefit of installing water-saving technologies.

Constraints to the implementation of the technology include: (i) high infrastructure and maintenance expenses; (ii) food safety concerns (since some types of TW might include high levels of microbiological pollutants and heavy metals); (iii) lack of water reuse standards and regulatory gaps from the government; and (iv) operational challenges due to non-functional or quasi-functional treatment plants available in Lebanon. Addressing these constraints requires collaborative efforts and strategic interventions to overcome barriers and ensure sustainable water management practices.

Finance and adoption

Implementing TW irrigation systems requires investment in infrastructure for wastewater treatment plants and irrigation networks, such as drip irrigation systems, along with operational and maintenance costs. However, the long-term benefits, including improved agricultural productivity and climate resilience, outweigh these initial investments.

Financial viability and sustainability of TW irrigation technology can be improved through cost quantification, revenue projection, and public-private partnerships. These initiatives aim to make the technology affordable for target beneficiaries, including vulnerable groups such as small-scale farmers, while promoting long-term sustainability.

Box 9. Adapting to climate change by improving irrigation practice in Vipava Valley, Slovenia

The Vipava Valley in Slovenia is known for its favourable conditions for intensive agriculture, yet it faces significant climatic challenges such as droughts, floods, frosts and strong winds (Climate ADAPT, n.d.-b). These issues have become more frequent due to climate change, posing serious threats to agriculture in the region. Projections indicate that the valley will experience more heatwaves and prolonged dry periods, increasing the water demands for crops. Farmers will also face more extreme precipitation events, which can lead to soil erosion and difficult growing conditions.

Key climate technologies

To address these challenges, extensive measures have been implemented to improve irrigation reliability during dry periods. These adaptation measures include enhancing water availability from reservoirs, using micro and drip irrigation, cultivating heat-resistant plants, employing greenhouses and monitoring agrometeorological variables. In 2016, the LIFE VIVaCCAdapt project launched a decision support system for irrigation (DSSI) to promote these measures and optimize their effects. Through the DSSI, farmers receive daily irrigation advice, which helps reduce water consumption.

Key advantages

The DSSI provides irrigation recommendations based on weather forecasts, soil water retention properties, real-time soil water content, plant water requirements and the type of irrigation system. Soil water content sensors collect data from parcels and send it to a central server, which then calculates the optimal irrigation schedule. This information is provided to farmers for a five-day period, along with graphs showing soil water content and plant growth stages. Farmers can access this data via email or a web-based interface on various devices.

Reflections and next steps

By reducing irrigation duration, farmers use less energy and emit lower levels of CO_2, thus contributing to climate change mitigation while adapting to its effects. Over the six-year project, farmers gradually adopted the DSSI, shifting from traditional irrigation methods to data-driven decisions. A mid-term evaluation in 2019 indicated that continued use of the DSSI could reduce total irrigation water consumption by 25 percent, energy requirements by 24 percent, and CO_2 emissions by 24 percent. However, challenges remain in implementing and maintaining the DSSI. These include the proper functioning and maintenance of on-field equipment, the availability of irrigation water, and future funding for the system's maintenance and development.

Finance and adoption

The ViVaCCAdapt project had a total budget of EUR 869,028, with 60 percent funded by the European Commission, 20 percent by the Slovenian Ministry of the National Resources and Spatial Planning, and the remaining contributions from project partners.

After the project concluded, the DSSI was transferred to the national level, managed by the Slovenian Environment Agency. The system is now publicly available and free of charge for all Slovenian farmers. The DSSI not only helps save water but also brings energy savings, cost reductions and increased awareness of climate change among farmers.

5.2 Protected cultivation systems for climate adaptation

Technology: Protected cultivation systems

Agrifood value chain: High-value fruits and vegetables at the planning stage

Country context: Caribbean: Saint Kitts and Nevis, Antigua and Barbuda, and Jamaica; Africa: Semi-arid regions in Djibouti

Protected cultivation systems

Protected cultivation involves the use of structures and covering materials to create favourable environments for crop growth and efficient natural resource use. When farmers are confronted by climate challenges, this technology provides solutions for adaptation and mitigation, such as extending the productive season, saving water in arid areas and protecting crops from heavy rains in humid areas. This technological intervention emphasizes the responsible use of plastic, including the life-cycle assessment for the materials involved and the use of high-quality and durable materials.

Features and benefits

Protected cultivation systems have a number of key features that help promote farmer productivity while limiting and adapting to the impacts of climate change:

1. **Micro-tunnels**: Temporary structures used during specific growing periods to protect vegetables from rain, cold, excessive heat or light, as well as pests adapting to changing climatic conditions.
2. **Top covers**: Structures above plant canopies with foldable coverings to protect crops from rain, hail, excessive light or other weather shocks that can be destructive to the crops.
3. **Tunnels and greenhouses**: Durable structures providing seasonal or year-round protection, with the aim of enhancing environments so that high-value vegetables can be grown. Features include air vents and shade cloths for temperature and humidity control. Using thermal crops can save up to 30 percent of energy when heating in cold environments.

Key advantages

In terms of climate change and production, the practice has the following key advantages:

- **Climate control**: Mitigates extreme weather impacts, including frost, heavy rainfall and high temperatures.
- **Pest and disease management**: Reduces pest and disease incidence, lowering the need for chemical pesticides.
- **Water efficiency**: Incorporates efficient irrigation techniques (crucial in water-scarce regions).
- **Extended growing seasons:** Allows farming beyond typical climate-limited growing periods.
- **Enhanced crop quality and yield**: Leads to increased yield and improved crop quality by protecting from extreme climate events.

Interventions in the Caribbean

Tropical regions are increasingly vulnerable to extreme weather events such as destructive tropical storms, flooding and drought events, all of which lead to heat stress and the destruction of crops. Protected cultivation shields crop from solar radiation, rain and wind, and optimizes freshwater use. In Saint Kitts and Nevis, Antigua and Barbuda, and Jamaica, smallholders use greenhouses to stabilize high-value vegetable production, thereby reducing dependency on imports. Greenhouses also facilitate simplified soilless production, which enhances resilience to tropical storms and achieves significant water savings.

Interventions in arid and semi-arid Africa: Djibouti

Located in the Sahel region, Djibouti is categorized by desert conditions, in which climate change has led to increased water stress and soaring temperatures. In arid regions like Djibouti, shade houses combined with drip irrigation allow for the cultivation of leafy greens, tomatoes and cucumbers for four to five months a year, and melons year round without active cooling. This technology enables the production of high-value vegetables that would otherwise be unfeasible in such harsh climates.

Financing and adoption

Since structures are typically low cost and use locally sourced materials such as timber and bamboo, combined with the increasing accessibility of durable plastic covering materials, their use can be expanded to marginal and economically depressed rural areas, including urban and peri-urban zones. This technology is usually employed by farmers seeking to produce high-value and highly nutritional fruits and vegetables.

Box 10. Crop diversification and improved soil management for climate adaptation in Segovia (Spain)

As part of the LIFE AgriAdapt project, over 120 pilot farms are testing sustainable adaptation measures to boost resilience to climate change, reduce GHG emissions and improve competitiveness (Climate ADAPT, n.d-a). One pilot area is in Melque de Cercos, Segovia, Spain, on a 110-hectare rainfed organic farm. The farm's primary crops are six-row winter barley, fodder vetch, rye, sunflower, and soft winter wheat, with 5 percent of the land left fallow annually. The small plots are adjacent to semi-arid vegetation, and the farm faces challenges such as extreme temperatures, heatwaves, droughts, desertification, soil degradation, increased pests and diseases, and biodiversity loss.

Key climate technologies

A climate risk assessment at the farm level was conducted within the project's framework, leading to proposed adaptation measures, some of which are being implemented. These measures include cultivating local crop varieties with higher resistance to climatic stressors, improving crop rotation, growing associated legumes and cereals in forage crops, and adjusting sowing dates to avoid high-risk climatic periods. Additionally, farmers leave stubble to prevent bare soil and apply manure biennially to boost soil organic matter. Multifunctional field margins have been created to reduce soil erosion and enhance biodiversity, benefiting pollinators and other beneficial insects.

Key advantages

The adaptation measures are expected to increase production efficiency, reduce farming costs, improve soil conservation, enhance soil carbon sequestration and nitrogen content, and develop native vegetation around field perimeters to provide habitats for beneficial insects and pollinators, with the ultimate goal of enhancing local biodiversity.

Reflections and next steps

The farm owner in Melque de Cercos was already aware of climate change risks and was eager to adopt measures to mitigate their impacts. The presence of livestock on the farm facilitated specific soil management practices. However, the implementation faced challenges due to a lack of local data and the need to test measures before full-scale application. For instance, changes in sowing dates and the use of traditional varieties and new legume crops such as carob were initially tested on small plots due to the perceived risks. Monitoring the benefits of these measures involved continuous communication with farmers to gather feedback and assess yields throughout the project.

Finance and adoption

The vulnerability assessment and action plan for sustainable adaptation measures were financed by the AgriAdapt project, funded by the European Commission through the LIFE Programme, and cofinanced by Fundación Biodiversidad from the Spanish Ministry of Ecological Transition. The total cost for the assessment and action plan for the Melque de Cercos farm was EUR 5,000. Although a precise cost estimate for the adaptation measures is not yet available, most measures are expected to incur minimal additional costs, with some potentially resulting in savings.

5.3 Climate technologies and the TNA process in the livestock sector in Mongolia

Technology: Seasonal prediction systems, selective breeding, and sustainable pasture management

Agrifood value chain: Livestock (cattle, sheep, goats) in the planning stage

Country context: Mongolia, North Asia

Country context

With a strong nomadic pastoral tradition, Mongolia has seen its livestock population grow from 33.1 million in 2010 to 71.8 million in 2019. This growth, along with climate change, has led to the degradation of grazing pastures, which are critical for household livelihoods. Forage yields have declined from 284 kg per hectare in 2011 to 198 kg per hectare in 2020, and livestock carcass weights have decreased by 13.9 percent and cattle by 30 kg from 1990 to 2016. With climate change being a key driver in the sector’s decline over the past 70 years, Mongolia’s 2 °C temperature increase and declining rainfall have created a vicious cycle for the nearly 30 percent of the population who are nomadic herders, forcing them to increase their livestock numbers as pasturelands become less productive. The Government of Mongolia has prioritized climate adaptation technologies for the revival of the country’s livestock sector, with the aim of mitigating the impacts of climate change on this vital industry.

Key climate technologies

To promote sustainable, climate-resilient livestock farming in Mongolia, it is essential to raise awareness, build capacity, and provide financial incentives for those adopting these technologies. In 2013, Mongolia completed a TNA to identify and prioritize climate adaptation technologies for the livestock sector. Three key technologies were selected:

1. **Seasonal prediction and livestock early warning system (SPLEWS):**
   - **Purpose:** Provides precise seasonal information to prepare for natural disasters (drought, “dzud” [extremely cold situation], floods, storms).
   - **Components:** Risk knowledge, monitoring and prediction, information dissemination, and response.
2. **High-quality livestock through selective breeding and animal disease management:**
   - **Purpose:** Improves livestock quality through selective breeding and disease control, thereby reducing overgrazing and desertification.
   - **Components:** Selective breeding, core herds, and disease control measures.
3. **Sustainable pasture management:**
   - **Purpose:** Restores degraded land and ensures healthy, resilient soils, thereby providing adequate fodder for livestock.
   - **Components:** Activities and practices aimed at sustainable natural resource management.
   - From November 2021 to May 2023, Mongolia participated in a Climate Technology Centre and Network (CTCN) technical assistance project, which aimed to strengthen climate-resilient livestock farming in Bayantümen of the Dornod Province. A comprehensive pasture assessment led to several recommended practices and technologies:
   - **Forage and fodder development**: Training and extension materials for improving forage production.
   - **Livestock health and genetic improvement**: Disease control, veterinary training, and selective breeding programmes.
   - **Market linkages and policy support**: Strengthening connections between herders and markets, and analysing policies for sustainable livestock farming.

Key advantages

- **Enhanced resilience:** SPLEWS provides critical information to prepare for and respond to natural disasters, thereby reducing their impact on livestock.
- **Improved livestock quality:** Selective breeding and disease management improve livestock productivity and reduce the environmental impact of overgrazing.
- **Sustainable land management:** Sustainable pasture management practices restore degraded land, thus ensuring long-term viability of grazing resources.

Adoption and financing

With support and financing from the Swiss Agency for Development and Cooperation, the Government of Mongolia implemented the Green Gold project to enhance rangeland management and improve pasture health. This project involves more than 15,000 herder households, organized into 740 pasture user groups. These groups implement solutions to rangeland issues identified in the Rangeland Use Agreement; an important tool for enforcing grazing and herd management plans.

Taken together, it is expected that these approaches enhance resilience, productivity and livelihoods while contributing to climate adaptation and mitigation efforts.

5.4 Agroforestry parklands for climate adaptation in Senegal

Technology: Agroforestry in Faidherbia parklands

Agrifood value chain: Rainfed crop smallholder agriculture at the production stage

Country context: Senegal, Sahelian zone

Country context

Senegal has a population of 16.7 million, of which 25 percent reside in Dakar and 40 percent in rural areas (World Bank, 2024). The climate is dry and tropical, and dominated by mining, farming and fishing. Despite 60 percent of the workforce being in agriculture, 70 percent of the population faces hunger due to low rainfall, soil degradation and limited access to quality seeds and fertilizers (UNEP, 2024; World Bank, 2024). Overall, 75 percent of households live in poverty (World Bank, 2024; UN Women, 2024). Senegal is seeking to address its climate vulnerability through NDC focused on resilience and sustainable development. A key facet of this is through the equality of women, who produce 80 percent of the country's food, thus making their empowerment crucial for agricultural productivity and rural development (World Bank, 2024; UNEP, 2024). Smallholder systems are diverse, but largely comprised of rainfed smallholder agriculture relying on traditional grains (millets, sorghum and fonio), legumes (cowpeas and groundnuts) and vegetables, as well as extensively managed livestock.

Agroforestry has emerged as a key technique to help farmers adapt to the increasingly dry climate conditions. One example of such an intervention is the Faidherbia parklands system and management practice, which has been promoting soil health and enabling farmers to better utilize their yields. Faidherbia parklands are commonly found in the Sahelian zone in West Africa, notably in Senegal, where heat, low rainfall and drought are typical limiting factors in agricultural production.

Faidherbia parklands

Originating in the Sahel, the agroforestry system of Faidherbia parklands is now widely adopted across the Sudan-Sahelian zone of Africa, reaching as far east as the Rift Valley in Ethiopia. This specific type of agroforestry parkland system includes the intentional integration of the species *Faidherbia albida*, a deep-rooting, leguminous tree that provides farming communities with a wide range of benefits, such as nitrogen fixation, nutrient cycling, erosion control, microclimate regulation and long term food security.

Faidherbia agroforestry systems are principally a climate adaptation strategy, used to help stabilize yields and reduce water stress in hot and dry conditions. Faidherbia systems can also contribute to climate change mitigation through their significant potential to store carbon in biomass above and below ground. The Faidherbia systems are generally characterized as low input and low output, for use in areas plagued by drought and climate variability.

Features and benefits

1. **Reverse phenology**: Maintain foliage during the dry season, Faidherbia trees provide shade and a beneficial microclimate to help adapt to dry climatic conditions. Since they shed leaves in the rainy season, competition with crops is reduced, and organic deposits from leaves form a mulch that stabilizes water status and soil temperatures, while improving soil health.

2. **Soil health enhancement**: Faidherbia trees enrich soil with nutrient-rich leaf litter, fix nitrogen through biological processes, and provide shade in the dry season, which encourages livestock to congregate and enrich soils with their manure. Improved soil health enhances crop resilience and productivity, and helps to mitigate climate change through increased biological processes that result in the creation of carbon sinks in the soil.

3. **Multipurpose benefits**: The trees offer fodder (during the dry season), nectar for bees, wood for fuel, and various domestic uses. These benefits enhance resilience, promote biodiversity and improve the productivity of agricultural systems.

Reflections and next steps

From the 1960s to the mid-1980s, Faidherbia parklands declined in western Senegal due to state-subsidized peanut production that favoured cash crops and monocultures. When these subsidies ended, farmers reverted to cereal production and the regeneration of Faidherbia. This shift not only illustrates how this system was a success, it highlights the need for informed agricultural policies that balance income generation and sustainable management. Through participatory approaches and appropriate technologies, research and investment are necessary to optimize tree–crop integration and to address challenges to mechanization.

Financing and adoption

Adopting Faidherbia parklands and thus leveraging natural regeneration requires low upfront investment, without the need to purchase seeds or saplings. The system and management practice has reached farmers in the local region through extension officers, who have provided farmers with the key tools and information. However, more reach is necessary; farmers need knowledge and care during tree establishment so that they can avoid damage during agricultural activities and manage tree pruning responsibly.

Box 11. Indigenous agroforestry systems in Central and Latin America

Technology name: Indigenous agroforestry techniques

Agrifood value chain: In the production stage for coffee, quinoa, cocoa, timber, etc.

Country context: Central and Latin America

In northern Belize, the dominant sugarcane industry, along with conventional farming and cattle production, has led to deforestation, soil degradation and water contamination. Since 2017, Sustainable Harvest International (SHI)-Belize has partnered with 90 rural families to restore the region. Through training in regenerative agricultural techniques, SHI-Belize is working to improve the environment, as well as the health and livelihoods of Indigenous communities. Partner groups help led the project by implementing agroforestry systems, through which hardwood trees and subsistence crops are intercropped without the use of agrochemicals. Traditional community approaches are used to improve soil fertility, increase crop yield and enhance food production. The project has resulted in the planting of hardwood trees, fruits, root tubers and spices, and has generated additional income for the families involved. The project demonstrates that farmers can improve their livelihoods while restoring the environment. By reforesting the land and mitigating climate change, Indigenous communities can earn an income and enhance their well-being, with a total of USD 3 million for partnering farmers being projected as the potential financial benefit. SHI-Belize plans to replicate this restoration project in other communities, with the aim of expanding land restoration efforts and increasing carbon sequestration.

In Peru's San Martín region, deforestation for cattle ranching, industrial agriculture, illicit coca plantations, and mining have posed significant threats to the Amazon rainforest. To address this, an alliance of community organizations and companies has joined forces to protect and restore this biodiversity hotspot. Through environmental education programmes and enhanced local governance, Asociación Amazónicos por la Amazonía (AMPA) has been working with farmers to promote sustainable crop production, resulting in over 143,000 hectares of land being protected and restored. AMPA has supported farmers in cultivating organic quinoa (a traditional Indigenous crop that does not degrade the land) as an economic alternative to expanding ranching pastures. Additionally, Red de Energía del Perú has supported AMPA's beekeeping programme, which has provided a new source of income while contributing to land conservation. The project's participatory approach has created eight jobs and trained 40 local people in biodiversity monitoring. The availability and quality of water in the upper basin of the Huayabamba River, which supplies water to downstream communities, has improved. The project also has significant carbon sequestration potential, estimated at over 2 million tons of CO_2.

Colombia's Cimitarra and Tierralta regions have faced decades of civil war, poverty and cattle grazing, all of which has caused significant damage to the land. To address this, Initiative 20x20 supports local partner UMAU Cacao in accessing the carbon credit market and restoring 3,081 hectares of land with local farmers. The project focuses on Indigenous agriculture systems by growing trees on farms to reintroduce endangered native species and produce sustainable cocoa and timber; a process that has significantly increased steer volumes for local rural farmers. This agroforestry system enhances biodiversity, boosts soil nutrients, prevents erosion and creates resilient ecosystems. The project also protects the area's exceptional biodiversity, fights climate change by storing up to 233,000 tons of CO_2 and works closely with local communities to ensure lasting positive social impact. Educational programmes, stable jobs in cocoa farming, improved health services, and home improvements have benefited 176 families, including 80 women workers (of which 60 are female heads of households).

5.5 Climate technologies and capacities of small-scale producers through farmer field schools on forestry and agroforestry

Technology: Farmer field schools (FFS) for sustainable agriculture and forestry

Agrifood value chain: Small-scale farming, forestry and agroforestry in the planning stage

Country context: Global, with applications in Africa, Asia and the Americas

Country context

Current global agrifood systems face significant challenges due to unsustainable practices and resultant deforestation, land degradation and biodiversity loss. More specifically, deforestation is cited as the cause of up to 10 percent of present climate-related impacts, with agriculture expansion accounting for nearly 90 percent of global deforestation and small-scale farming being responsible for 71 percent of said expansion between 2000 and 2018. Despite operating on only 12 percent of all agricultural land, small-scale farms produce 35 percent of the world's food. These farmers are particularly vulnerable to climate change and often face chronic food insecurity and poverty. Enhancing the capacities of smallholders is crucial for transforming agrifood systems and accelerating climate action.

Key climate technologies

- Strengthening the capacities of small-scale producers through FFS on forestry and agroforestry is an effective approach to fostering sustainable agriculture and forestry practices. FFS offer a "discovery learning", capacity building and extension approach, which empowers smallholders to innovate, share knowledge and build social skills. Key aspects include:
- **Production of seedlings through community nurseries**: Establishing community-based nurseries to produce high-quality seedlings for the establishment of smallholder agroforestry systems.
- **Establishment of agroforestry systems**: Using multi-strata models that intercrop timber, fruit, and multipurpose tree species with annual crops.
- **Supporting smallholder farmers with subsidized seedlings**: Providing farmers with high-quality seedlings through e-vouchers.
- **Comprehensive farmer-to-farmer trainings**: Strengthening the knowledge and skills of farmers on the preparation, establishment, management and monitoring of agroforestry systems, as well as in the utilization of their products and services through FFS peer-to-peer learning.
- **Connecting FFS groups with business partners**: Facilitating the connection of FFS groups with local businesses to purchase additional agroforestry products, such as fruit, and international partners to offset carbon credits in voluntary markets.

Key advantages

- **Enhanced knowledge and skills**: FFS build technical and decisional skills, thereby enabling smallholders to adopt sustainable production practices.
- **Empowerment and social cohesion**: FFS strengthen participation among women and youth, thus fostering community and social cohesion.
- **Sustainable land management**: FFS promote practices that restore degraded land, increase tree cover, improve soil health and restore ecosystems.

Case study: PROMOVE Agribiz Project in Mozambique

The PROMOVE Agribiz Programme supports over 22,000 small-scale farmers in Mozambique in advancing agroforestry systems and accessing carbon credits from voluntary carbon markets. Participatory and beneficiary farmers are organized into FFS groups. This initiative highlights how FFS can enhance climate action by integrating agriculture and forestry practices to reduce GHG emissions while diversifying production, creating income generating opportunities and improving food security.

Reflections and next steps

To scale climate action and transform agrifood systems, it is essential to invest in capacity development services for small-scale farmers. FFS provide an effective platform through which to enhance digital literacy and thus enable farmers to adopt ICT systems relevant to their needs. By mobilizing FFS, smallholders can contribute significantly to global climate goals through resource conservation, sustainable agriculture and forestry production, thereby enhancing terrestrial carbon sequestration and reducing GHG emissions.

Finance and adoption

Since 1989, FFS have empowered over 20 million farmers from 119 countries through the approach of people-centred, self-directed and experiential learning. Agroecosystem analysis is incorporated into FFS to allow participants to observe and monitor elements of their ecosystems. In so doing, FFS enables independent decision-making and fosters an understanding of ecological functions in agriculture and forestry. FFS can act as a platform to increase the digital literacy needed for farmers to adopt and use ICT systems that are both relevant to their needs and readily available.

5.6 Climate technology in post-harvest fisheries in Papua New Guinea

Technology: Cold storage and ice-making using renewable energy

Agrifood value chain: Fisheries and fish products in the post-harvest stage

Country context: Papua New Guinea, South Pacific

Country context

Papua New Guinea is a diverse country with a population of over 10 million, of which 85 percent live in rural areas. The economy is dominated by agriculture, forestry and fishing, as well as the minerals and energy sectors. Despite its rich natural resources, socioeconomic prosperity is limited, with 40 percent of the population living in poverty and only 20 percent having access to electricity. The country faces numerous natural disasters, such as cyclones, droughts, and floods, with climate change expected to increase the frequency and intensity of these. The country's NDC focuses on maintaining forest cover, green growth, and sustainable adaptation strategies to combat these climate challenges.

Fisheries sector

Papua New Guinea has the largest fisheries zone in the South Pacific (2.4 million km^2), holding 18 percent of the world's total tuna stock. Fish is crucial for the local diet and economy; however, this sector faces a number of challenges, including poor fishery management, quality issues, and inadequate processing and storage, all of which hinder the sustainable development of the riverine fisheries value chain. Against this backdrop, adaptation strategies are being implemented to react to a changing environment and to reduce the use of fossil fuels in the fisheries value chain. More specifically, cold storage technologies using renewable energy are being operationalized as a way to increase productivity and resilience, and to improve the livelihoods of small-scale fishers through post-harvest processing and increased market access.

Features and benefits

1. **Cold storage technologies**: Essential for preserving perishable fish and fish products by maintaining low temperatures. This extends shelf life, ensures food safety, and enhances market access by maintaining product quality. Cold storage functions as a climate technology in that it reduces the impacts of food loss/waste by helping farmers adapt to hot climatic conditions. The use of solar energy (as opposed to fossil fuels) enables longer preservation and the mitigation of emissions.

2. **Ice-making technology**: Enhances cold chain management, allowing fishers to preserve their catch and maintain quality during transportation to markets. Solar ice-makers and freezers are particularly beneficial for remote areas in that they reduce reliance on fossil fuels.

3. **Improved food security**: Enables households to store food longer, plan and ration consumption better, and reduce time and money spent on frequent food purchases. This stability is crucial during fluctuations in fish catches. Improved cold storage can enhance the adequacy of food by reducing spoilage and ensuring that more people have access to fresh, nutritious fish.

4. **Renewable energy**: Solar-powered cold storage reduces fossil fuel use, providing an off-grid solution for isolated rural areas and thus contributing to climate mitigation efforts.

Key advantages

- **Enhanced post-harvest processing**: Cold storage and ice-making improve the handling and processing of fish, thereby reducing losses and maintaining quality.
- **Market access and income:** Prolonged storage increases market opportunities and adds value to fishery products, improving income for fishers, processors and traders.
- **Nutrition and food security**: Better preservation of nutrient-rich fish supports food and nutrition security, and promotes healthier diets, especially for vulnerable such as women and children, thus contributing to the realization of the right to food for groups in vulnerable situations.
- **Climate mitigation**: By reducing the carbon footprint of the fisheries value chain, solar-powered technologies are aligned with green growth initiatives.

Financing and adoption: Successes

In collaboration with the National Fisheries Authority and provincial divisions, the European Union-funded Programme for Support to Rural Entrepreneurship, Investment and Trade in Papua New Guinea has supported various beneficiaries, including:

- **100 small-scale fishers**: Enhanced post-harvest processing, market access and trading activities.
- **320 groups**: Improved household income, food, and nutrition security in smallholder aquaculture and fisher households. The programme focuses on promoting nutrient-rich diets, particularly for women of reproductive age and children under 2 years, and raises awareness about cold storage technology opportunities.

Raising awareness and incentivizing the uptake of cold storage technologies through policy, capacity building, and financial initiatives is crucial for sustainable fisheries development in Papua New Guinea. This approach will enhance resilience, productivity and livelihoods while contributing to climate adaptation and mitigation.

5.7 Supporting climate action by reducing food loss and waste in micro, small and medium-sized food-processing enterprises in Thailand

Technology: Climate technologies to reduce food loss and waste

Agrifood Value Chain: Germinated rice and food processing, distribution, and retail in the post-production stage

Country Context: Thailand

Country context

Thailand’s economy relies heavily on agriculture, which employs a third of the workforce despite accounting for only 10 percent of GDP. Land in Thailand is subject to a tropical climate condition, which is associated with increased issues such as wildfire, water stress, landslides, and flooding. The agriculture sector faces challenges such as small farm sizes, an ageing workforce, rising production costs, and increased frequency of extreme weather events due to climate change. These issues disproportionately affect vulnerable groups such as landless farmers, women and ethnic minorities. The Thai food-processing sector is dominated by micro, small and medium-sized enterprises (MSMEs), which make up 99 percent of the industry. However, many of these MSMEs sustain high levels of FLW, which contributes significantly to GHG emissions. By 2030, Thailand’s population is expected to reach between approximately 71 million and 77 million, with a growing number residing in urban areas. Furthermore, its economy heavily relies on the industrial and service sectors.

Key climate technologies

To address FLW, simple climate technologies and capacity-building measures can be introduced. These can help MSMEs improve process control and reduce FLW, thereby contributing to climate mitigation, enhancing food security and building resilience in the Thai agrifood system:

1. **Process control technologies:**
   - **Thermometers:** Monitors the temperature and time during the cooking process.
   - **Moisture meters:** Monitors the moisture content of the rice paddy during solar drying (itself used to improve control of the drying process).
2. **Packaging and transportation innovations:**
   - **Vacuum sealers:** Reduces losses due to spillage during distribution and waste due to spoilage of the product in retail.
   - **Reusable plastic crates:** Minimizes package damage during transportation, and waste in retail.
3. **Renewable energy sources:**
   - **Firewood and solar energy:** Used as primary energy sources in processing operations to reduce carbon footprints. By decreasing reliance on fossil fuels, it achieves a cited reduction of 41 percent.

Implementation and benefits

A case study on the processing of germinated brown rice by a women-led MSME in north-eastern Thailand demonstrated significant benefits from these technologies. The MSME measured reductions of around 41 percent in distribution losses and 7 percent in food waste due to current intervention, which helped to improve the process control and packaging.

Key advantages:

- **Reduced carbon footprint**: The use of renewable energy and better process control technologies lowers GHG emissions.
- **Improved product quality**: Enhanced packaging and transportation methods reduce product spoilage and waste.
- **Empowerment of women and smallholders**: Capacity building and technology transfer empower women-led enterprises and smallholder farmers.

Key actors and stakeholders

The project implementation involved a collaborative approach, bringing together government agencies (which provided financial support and policy guidance), academia and FAO (which offered technical expertise and training). A bottom-up approach ensured direct engagement and involvement of responsible government agencies and provided hands-on training for the (women-led) MSMEs, which implemented the technologies and processes.

Reflections and next steps

The initial lack of awareness among MSMEs about FLW in their operations posed a significant challenge. Increasing dissemination through social networks and promoting awareness are crucial for broader uptake. Future initiatives should focus on:

- **Promoting awareness:** Educates MSMEs on the benefits of reducing FLW.
- **Climate finance:** Supports the acquisition of climate technologies.

- **Capacity building:** Trains MSMEs to maximize FLW reduction in a sustainable manner.

By addressing these challenges, MSMEs can collectively contribute to climate mitigation and improve the sustainability of the Thai food-processing sector.

Finance and adoption

The Government of Thailand financed the solar dryer dome, while other process control technologies were funded by the project and handed over to beneficiaries during training sessions. This support enabled MSMEs to engage in climate action, generate climate mitigation benefits, reduce their carbon footprints, and improve their operational efficiency.

The project empowered a women-led MSME to contribute to climate action by building its capacity to apply climate technologies to reduce FLW. In the process, it has contributed to uphold the right to food of rural and urban consumers, by providing them access to better-quality, affordable and nutritious foods.

5.8 Gender-sensitive technologies for climate action in Africa

Technology name: Low-cost regenerative solutions
Agrifood value chain: Agricultural educational programmes in planning, production and post-production stages
Country context: Kenya and Uganda

Kenya's "Shamba Shape Up" and Uganda's "Mpeke Town" are agricultural programmes developed by Mediae: a social enterprise that focuses on female empowerment, climate resilience, and food security across Kenya and Uganda. These programmes transmit practical skills and advice via the television to their audiences, demonstrating ways to grow productively while adapting to climate change. This is supplemented by female-only WhatsApp groups, which provide further mentorship. Over 428,000 households benefit directly in Kenya alone, thereby showing how the programmes have been successful in actively promoting women's participation in agriculture. A viewer survey in Uganda revealed that 56 percent of farmers have adopted different agricultural practices after watching "Mpeke Town", indicating that the programmes have been effective in disseminating climate-smart techniques.

The programmes emphasize practical, low-cost regenerative solutions through which community resilience to climate change can be strengthened. Moreover, dairy farmers who adopted new practices through "Shamba Shape Up" increased the value of their milk by over USD 24 million, while those in the maize sector of Murang'a in Kenya saw their gross margins quadruple, thus demonstrating the programmes' significant contributions to food security and income generation. Overall, Mediae's female-driven approach to agricultural education, supported by impactful statistics and figures, plays a pivotal role in building more resilient and food-secure communities in East Africa, with a 0.79 inclusivity rate further illustrating the positive impacts on low-income farmers.

Technology name: AfTrak and Tiyeni: Deep-bed farming tractors
Agrifood value chain: Agricultural training and equipment for the production stage
Country context: Malawi

The collaboration between AfTrak and NGO Tiyeni seeks to implement deep-bed farming through innovative community solar microgrids and portable deep-bed tractors, with the overarching aim of improving agricultural productivity in Malawi while helping to adapt to ever-changing climate conditions. Land preparation is mechanized through the use of microelectric tractors, which are powered by solar arrays and can break hardpan soil, which helps to safeguard soil fertility and increase crop yields. Such an approach aligns with SDG 7 in that it ensures access to affordable, reliable, sustainable and modern energy, with potential impacts including a 300 percent increase in crop yield and a 1,200 percent increase in income. Sustainable results through deep-bed farming can also be seen through the conservation of soil health, as well as other transformative benefits in terms of crop growth. The initiative's focus on designing portable tractors in a female-friendly manner promotes gender equality and enhances inclusivity within the agriculture sector. So far, the programme has led to an approximately 30 percent increase in food security within Malawi, with Tiyeni providing deep-bed training to over 30,000 farmers, with a particular focus on uplifting female farmers and groups in vulnerable situations.

Technology name: Solar-powered milk chillers

Agrifood value chain: Dairy storage equipment in the post-harvest stage

Country context: Uganda

With Uganda's dairy sector representing 6.5 percent of the country's agricultural GDP, Heifer International's initiative looks to improve rural communities' economic, nutritional, and employment opportunities in this field. However, challenges such as limited milk production and vulnerability among dairy farmers persist due to limited access to electricity, which affects around 72 percent of Uganda's population. As a result, Heifer partnered with the Carbon Trust to introduce solar-powered milk-chilling solutions to rural dairy cooperatives, focusing on women within the community in particular.

Migina Milk Collection Centre eliminated around USD 30,000 in annual expenses on diesel generators. This switch not only reduced milk losses to zero but allowed for the chilling of 197,321 litres of milk monthly, resulting in substantial increased earnings for farmers while reducing the impact on the environment. With subsequent installations in other cooperatives, the project aims to enhance efficiency, reduce carbon emissions, and promote cleaner and safer milk production. Furthermore, aligned with Uganda's goal to electrify the nation by 2030, Heifer's project complements government efforts in transitioning to clean renewable energy, thus contributing to sustainable development and empowerment within the dairy sector. Throughout the project, Heifer has carried out gender-equity training, and provided women with direct access to resource markets and credit, thereby helping to ensure that their livelihoods improve.

Box 12. Bank of practical and technological low-cost climate solutions in the agriculture sector in Latin America and the Caribbean

Launched at COP25, the Platform of Latin America and the Caribbean for Climate Action on Agriculture (PLACA) emerged in response to the need for a regional mechanism of voluntary collaboration among agriculture ministries. This platform aims to strengthen institutional capacities to support the implementation of domestic policies and promote agricultural development that is adaptive to climate change effects, resilient and low in GHG emissions.

PLACA currently has 16 member countries: Argentina, Bahamas, Brazil, Chile, Colombia, Costa Rica, El Salvador, Ecuador, Guatemala, Haiti, Mexico, Panama, Paraguay, Peru, the Dominican Republic, and Uruguay. It is the only platform in the region focused on fostering a collaborative network of shared knowledge to strengthen capacities. In so doing, it aims to support agriculture ministries in enhancing climate action towards the implementation of their commitments under the Paris Agreement.

One of the fundamental pillars of PLACA is the Thematic Working Groups (TWGs). This regional community of practice promotes a collaborative and interdisciplinary ecosystem with a unified goal: to assist all countries in standardizing methodologies and procedures, and in sharing experiences related to agriculture and climate change. The four working groups are: Adaptation and Mitigation (TWG1), Public Policies (TWG2), Knowledge Management (TWG3), and Research, Development, and Technological Innovation (TWG4).

Specifically, the TWG3 has conducted a regional contest for three consecutive years titled "Practical and Technological Low-Cost Solutions for Climate Action in the Agricultural Sector." This initiative aims to highlight experiences in Latin America and the Caribbean that help increase productivity and improve the sustainability of agrifood systems, contributing to adaptation and/or mitigation to the effects of climate change.

To date, over 150 practices from 20 countries have been documented at the local level. These projects are characterized by identifying a problem and implementing creative solutions using available resources, which generate change in the environment, whereby conventional uses of those resources are often rethought. The inputs used are local, accessible, and leverage traditional or local knowledge, promoting income generation.

These local experiences are systematized and available on the PLACA website under the resources section: PLACA Technological Solutions.

6. Policy gaps and opportunities

6.1 Policies to address capacity needs and institutional requirements of climate technologies in agrifood systems

A wide range of policies, from local to national and international levels, can affect the deployment of climate technologies in agrifood systems. These include policies specific to agrifood systems and climate change, as well as biodiversity such as the convention on biological diversity, but also those broader in scope that deal with trade, market governance, education and social protection. In terms of which policies are the most relevant and to be considered ultimately depends on the local context. In short, a huge breadth of policies exists, with any number having the potential to affect the deployment of climate technologies in agrifood systems. Covering all of these is outside the scope of this work. Instead, this section focuses on policy issues arising from the analysis presented in section 3 on capacity needs and institutional requirements for climate technology deployment. Here, the emphasis shall be on policy opportunities available to organizations and individuals seeking to enhance the use of climate technologies in agrifood systems, i.e. the policies that users may have some control over in achieving their aims.

Three major opportunities for building an enabling policy environment emerge from the analysis in section 3: (i) enhanced coordination between agrifood system and climate change policies; (ii) mobilization of the informal sector in agrifood systems to support climate technology deployment; and (iii) the overcoming of technological lock-ins and path dependencies. The bulk of this section focuses on the first issue; in particular, on ways of improving the integration of climate change and agrifood system transformation in the next round of NDCs. The second two issues are touched upon briefly in the following paragraphs.

Section 3 pointed out the importance of engaging with the informal sector of agrifood systems in the deployment of climate technologies. This is because of the high participation of low-income and people in vulnerable situations in this sector, as well as its potential to become an engine of transforming agrifood systems to a more desirable state. This therefore raises the questions: what implications does this have for policy? Where are the opportunities?

A first opportunity comes from recognizing the agrifood sector's potential in deploying climate technologies and in actively seeking out engagement to ensure that target groups can access the technologies. The collaboration between CTCN and the Women and Gender Constituency in capacity-building workshops and mentoring (Women Gender Constituency, n.d.) provides an example of how such efforts may be structured. Another approach is to enhance the way in which the informal sector operates, such as improving food safety quality control or employment conditions through the design of a technology transfer programme. An example of this is the CTCN technical assistance to the Bahamas in organizing the informal sector of street food vendors into a more formalized sector that has adaptation and mitigation benefits. The project includes assistance to develop a framework and feasibility study for implementing standardization of stalls and a sustainable programme for the establishment of open green market spaces for the vendors (CTCN, 2021). Another option is to change formal sector policies and regulations that work against climate action in agrifood systems. This opportunity is highly related to the issue of overcoming technological lock-ins and path dependency.

Technological lock-in is a term used to explain the resistance of systems to change technology (Foxon, 2014). It has been applied in many contexts, including the energy transition from fossil fuels to alternative sources, as well as in transforming agrifood systems (Unruh, 2000; Costanza *et al.*, 2021). The idea is that once a technology is adopted, a set of interactions (such as the acquisition of skills, sunk investments, changes in institutions, and cognitive patterns) creates benefits to maintaining that technology – even if there are other potentially superior options. This benefit creates a lock-in or barrier to making changes that new technologies would have to overcome. Overcoming the barriers requires action throughout social, institutional and political dimensions (Goldstein *et al.,* 2023). For example, the high level of corporate concentration in the agrifood sector is considered a driver of technological lock-in (Clapp, 2021). In highly concentrated sectors, firms can exert power over technology and innovation agendas, shaping markets as well as policy and governance regimes (Clapp, 2021). Overcoming technological lock-ins generated in this context requires efforts across a variety of different institutions and policy areas.

Building a coalition to address the breadth of the issues and entry points for change is one approach to overcoming technological lock-ins; for instance, groups mobilizing around the issue of agrifood system transformation at the national and international levels. The COP28 Declaration is an example of a coalition uniting agrifood system transformation and climate actions. Coordination between climate change and agrifood system policies could also be a means to identifying and building such coalitions. This issue is explored further in the following section.

6.2 Coordination of agrifood system and climate change policies for NDCs 3.0

The need to consolidate climate action and the planning, implementation and financing of agrifood system development is becoming increasingly urgent. This is more so evident at a time when the high costs of climate-related damage to the agrifood sector are already being recorded (FAO, 2023a), where the need for adaptation is growing but consistently underfinanced (UNFCCC, 2023a), and where agrifood sector development is recognized as essential in reaching global food security and poverty eradication goals (FAO, 2017). Climate technologies in the agrifood sector are an essential means of accelerating needed progress on adaptation.

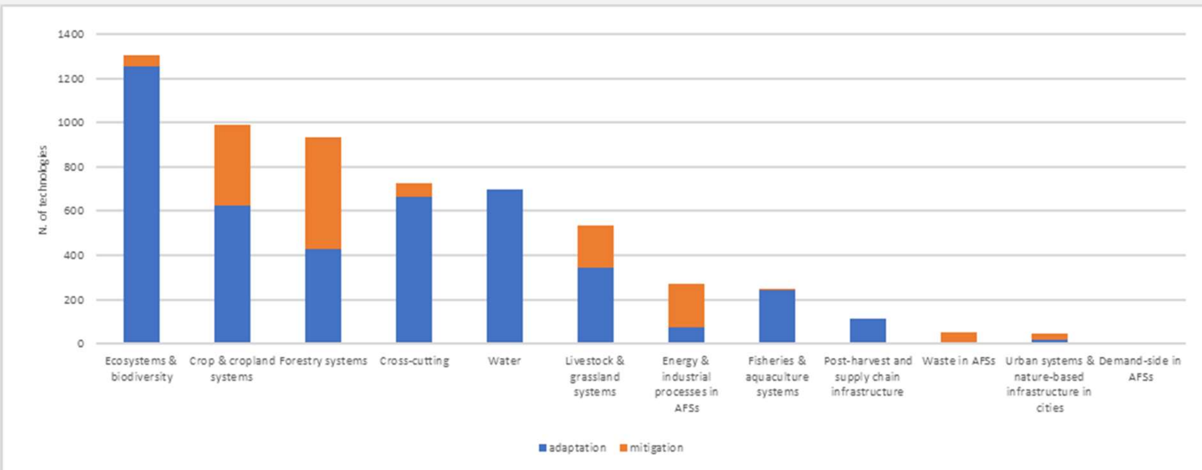
The importance of climate technologies in agrifood systems is well recognized in the latest NDCs (described in Box 13). Most countries included information on climate technologies in the agrifood sector, but the level of detail varies considerably.

Box 13. Technologies for agrifood systems identified in NDCs

FAO analysis of NDCs points to the significance of agrifood systems in national strategies for achieving both climate adaptation and mitigation goals. Out of the latest 167 NDCs submitted (as of 31 December 2023), 94 percent include adaptation and 86 percent include mitigation efforts (Crumpler et al., forthcoming). NDCs serve as an important source of information for understanding climate technology needs for agrifood system transformation at the national level.

Technology needs for adaptation and mitigation are spread over the entire agrifood system (see Figure 24), and cover all agricultural subsectors, nodes of the value chain, rural and urban dimensions, and supporting ecosystems and biodiversity. The majority of climate technology needs mentioned are concentrated in crop-based and forestry systems (after supporting ecosystems and biodiversity).

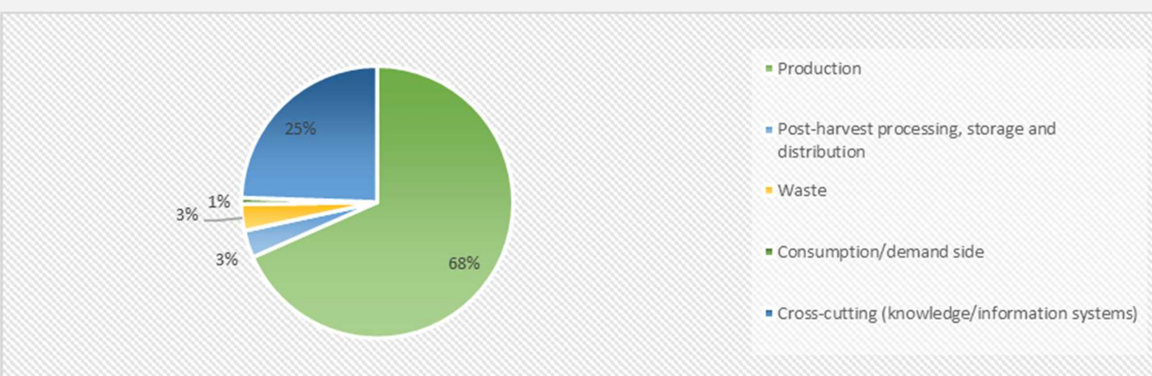
Figure 24. Climate technology needs for agrifood systems included in NDCs, by sector/system and purpose (adaptation/mitigation)



Source: **Crumpler, K., Angioni, C., Prosperi. P., Roffredi, L., Salvatore, M., Tanganelli, E., Umulisa, V., et al.** (forthcoming). *Agrifood systems in Nationally Determined Contributions: Global Analysis*. Rome, FAO.

As seen in Figure 25, most technologies mentioned across the agrifood value chain are related to the agricultural production stage (68 percent), whereas a very small share relates to downstream nodes of the agrifood value chain, including post-harvest processing, storage and distribution (3 percent) and waste (3 percent). Around a quarter of all technologies mentioned relate to knowledge and information systems that cut across the entire value chain (e.g. climate services, monitoring systems).

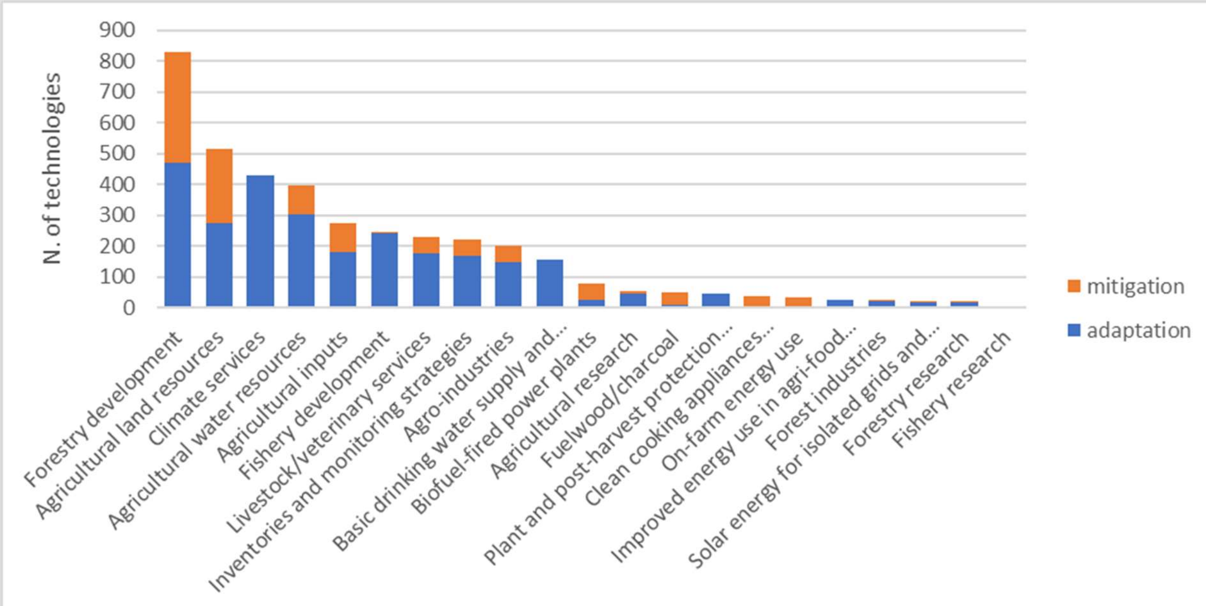
Figure 25. Climate technology needs for agrifood systems included in NDCs, by value chain stage



Source: XXXX

Looking at the types of climate technologies for agrifood systems mentioned in the NDCs, the majority are related to forestry development, agricultural land resources, climate services, agricultural water resources and agricultural inputs (Figure 26).

Figure 26. Climate technology needs for agrifood systems included in NDCs, by type and purpose (adaptation/mitigation)



Source: **Crumpler, K., Angioni, C., Prosperi. P., Roffredi, L., Salvatore, M., Tanganelli, E., Umulisa, V., et al.** (forthcoming). *Agrifood systems in Nationally Determined Contributions: Global Analysis*. Rome, FAO.

Two important points emerge from the analysis in Box 13. First is that adaptation is given high priority in the technology needs related to the agrifood sector. Second is that the potential for technologies in non-production stages of the value chain is not well recognized in the NDCs. Both of these points are important when organizing future efforts to coordinate the planning and implementation of policy on agrifood systems and climate change.

Despite rising climate impacts, as well as the associated costs, progress on climate adaptation planning, implementation and finance has been inadequate (UNEP, 2023). This is especially the case in the agrifood sector, where coordination between agriculture sector policy, planning and investments, and climate change action is lacking. Coordination amongst climate change and agriculture policies is emerging in some of the long-term low-emission development strategies (LT-LEDS). All LT-LEDS highlighted that technologies and innovation are fundamental to addressing climate change and economic growth.

Box 14 describes a recent effort to improve coordination between climate change and agrifood system transformation policies.

Box 14. The Climate Resilience Food Systems Alliance

Emerging from the 2021 United Nations Food Systems Summit and hosted by UNFCCC, the Climate Resilience Food Systems (CRFS) Alliance plays a crucial role in fostering collaboration among diverse stakeholders, including both United Nations and non-United Nations actors with specific comparative advantages, field presence, expertise and resources. Since its inception, the CRFS Alliance has actively engaged with its country members by discussing gaps in, and opportunities for, the building of climate-resilient agrifood systems.

Between 2022 and 2024, the Alliance carried out a rapid assessment of climate policies, disaster risk reduction strategies, and national development plans focused on agriculture and food systems in eight countries (Bangladesh, Belize, Ethiopia, Fiji, The Gambia, Lesotho, Panama, and Pakistan). This work identified opportunities for climate policy integration between climate mitigation and adaptation strategies (including NDCs, NAPs and LT-LEDS, along with biodiversity strategies and disaster risk reduction plans. Furthermore, the Food Systems Summit called for countries to outline “national food system pathways” to achieve the 2030 Sustainable Development Agenda. These documents also provide an opportunity for policy integration between climate and food, whereby food systems pathways include context-specific climate action in alignment with the Paris Agreement.

In 2024, the CRFS Alliance agreed to double its efforts in promoting synergies across the Rio Conventions (UNFCCC, the Convention on Biological Diversity, and the United Nations Convention to Combat Desertification) by focusing on building climate-resilient food systems across processes and practices. Looking at eight climate-vulnerable countries, the diagnostics made by the Alliance and its core partners highlighted shared priorities that call for the mobilization of climate technologies in agrifood systems to support the implementation of NDCs and NAPs. These priorities include:

- Multi-hazard early warning systems and comprehensive risk management approaches in Belize, Ethiopia and Lesotho.
- Innovations for youth and women in agrifood systems, with a focus on reducing post-harvest loss (Belize).
- Ecosystem restoration and upscaling ecosystem-based adaptation techniques (in Belize and The Gambia).

Despite progress, challenges exist in effectively integrating climate technology into policies and practices for adaptation and mitigation. Gaps in planning and a lack of investments in climate technology within NAPs, NDCs and LT-LEDS may result in insufficient attention to agrifood sectors. Furthermore, inadequate data and information on climate risks and impacts, and technology requirements within these climate policies, hinder the development of effective strategies. Government agencies may lack the capacity to integrate climate technologies effectively into agrifood policies, programmes and investments. Lack of coordination between relevant ministries and diverse stakeholders further hinders progress, leading to fragmented decision making and missed synergies to connect the portfolio of climate actions or solutions. Moreover, weak regulatory frameworks and enforcement mechanisms undermine the effectiveness of NAPs, NDCs and LT-LEDS in promoting climate technology adoption in the agrifood sectors. Finally, limited access to finance and resources diminishes efforts to scale up climate technology adoption.

COP28 noted the insufficient transfer and deployment of technology in developing countries and invited TEC and CTCN to provide technical assistance to support the implementation of the Paris Agreement[16] (Fuxue and Usman, 2024).

Box 15. Climate technologies for agrifood systems in Panama’s NDC and national policies

Capacity and technology transfer in agrifood systems is an important feature of a country’s NDC. This priority is reflected in various national policy instruments; in Panama, for example, the Vision for the State of Panama 2030 is its National Strategic Vision. This plan includes a strategic axis of “growing more and better,” which aims, among other goals, to diversify agricultural technology. Panama’s latest relevant policy for climate resilience is the National Climate Change Policy (2023), a core aspect of which is to transform the primary sector by promoting climate-smart agriculture for food security through diversification and technology adoption. One of the pillars of the National Climate Change Plan for the Agricultural Sector of Panama (2019) prioritizes research, development, innovation and transfer. This includes implementing activities such as developing accessible technology for small-scale producers and ensuring the availability of nutritious food. Additionally, the plan promotes knowledge exchange to enhance food security in the face of climate variability.

[16] See Decision -/CP.28 and Decision -/CMA.5, paras. 3 and 9.

Lessons from the experience of developing TNAs and TAPs provide insights into how they can contribute to a better integration of climate change and agrifood sector policy in the NDCs.

The TNA process calls for a first phase of identifying the decision context of technologies (Haselip *et al.*, 2019). This entails an understanding of how climate technologies and the TNA process relate to other national processes, including long-term development priorities. If the TNA is well run, this is the point at which policy priorities related to agrifood system transformation should be identified. That in turn requires the inclusion of the appropriate stakeholders involved in agrifood system policy and planning. Box 16 describes how The Gambia's TNA process relates to agrifood system policy priorities.

Box 16. Climate technologies identified in The Gambia's Technology Needs Assessment

In The Gambia, agriculture (particularly groundnuts) plays a pivotal role in the economy, accounting for 30 percent of foreign exchange and fulfilling 50 percent of national food requirements (Segnon, Zougmoré and Houessionon, 2021). Due to its economic and social importance in the country, technology transfer for building resilient food systems is a top priority for The Gambia, and this commitment is evident in its policy instruments and initiatives. The role of technology is highlighted in documents such as its NDC, the National Climate Change Policy of The Gambia, the Strategic Programme for Climate Resilience (pillars 3 and 4), the second Gambia National Agricultural Investment Plan (axes 1 and 3), and the Adaptation Technology Needs Assessment.

In 2018, the Adaptation Sectoral Working Group carried out the adaptation technology needs assessment, in which technology for the agriculture, coastal resources and water resources sectors were characterized and prioritized. In terms of the agriculture sector, the most relevant technology needs were the conservation of agriculture, tidal irrigation and aquaculture.

There are, however, barriers to the adoption of these technologies. For example, irregular rainfall and high initial costs and labour are major barriers to tidal irrigation systems. Meanwhile, the high cost of installation and maintenance limits the widespread adoption of drip irrigation systems in rice-based production systems.

The TNA process involves the establishment of technical working groups that are often sectoral based and chaired by the national institution with a political mandate over that sector (Haselip *et al.,* 2019). In the case of agrifood systems, this would commonly be the agricultural ministry but may also involve others involved with various aspects of agrifood value chains. In this way, ownership of the agrifood sector in terms of climate technologies is ensured in the relevant specific sector.

Focusing on barriers to adoption in the TNA/TAP process brings more attention to the issue of access to technologies; something that is critical for developing countries. Aligning the results of the TNAs and TAPs with the investment criteria of international public climate finance is an effective way to increase the likelihood of obtaining financing.

Conducting TNAs prior to formulating a country's NDC has clear advantages, as illustrated in the case of Mauritius (Deenapanray and Traerup, 2021). Adaptation contributions are justified on the basis of a robust TNA that is fully budgeted. However, it has not always been the case that TNAs precede NDC development. This is partly due to TNAs being dependent on the availability of funds from the Global Environment Facility (Deepanray and Traerup, 2021).

Synthesizing the advantages and shortcomings of the TNA/TAP process indicates a way forward to achieve better coordination between agrifood systems and climate change policy and planning, as well as improved flows of finance to support needed adaptation. Scaling up and institutionalizing the process could address its ad hoc nature and heavy dependence on consultants. Establishing a permanent technical working group on climate technologies for agrifood systems, chaired by the agricultural ministry (or other relevant ministries), could increase ownership of the agrifood sector, thereby promoting climate technologies and expanding capacity. Expanding international technical backstopping to include that of FAO as well as the UNEP Copenhagen Climate Centre could expand its technical capacity in this area. Focusing on the development of bankable projects in the TNA/TAP process could produce an immediate pipeline of investments and also give greater transparency to the demand for financing. Ensuring financing for an expanded TNA/TAP process as outlined above, to precede development of the country's NDCs, could be an important means of improving the quality of NDCs and their capacity to capture the priorities and challenges of the agrifood sector in taking climate actions.

Box 17. Technology action plans and technology needs assessments supporting transformation in the forestry sectors of Uganda and Somalia

Technology needs assessments and Technology Action Plans can provide guidance for broad agrifood system transformation efforts that include but go beyond climate actions. Two examples from Uganda and Somalia illustrate this effect.

The Technology Action Plan in Uganda (UNEP 2021) set out incentives and steps to achieve successful implementation of prioritized climate technologies. These efforts are mainly aimed at improving access to inputs and services related to the technologies, targeted awareness raising, strengthened policy implementation, enforced support for climate technology implementation, and institutional capacity building (UNEP, 2020). The TAP called for funds to be mobilized through strategic partnerships. One example of such a partnership comes from the USD 15 million, five-year Sustainable Wood-Based Value Chains in Uganda in collaboration with donors and technical partners, including FAO. The goals of the project are to increase investments in sustainable forestry and forest-based value chains, ensure the legal production of wood raw materials, and enhance processing capacities by providing access to finance and business management advisory support. The project also aims to reduce pressure on natural resource systems in Uganda, increase the effectiveness of forestry value chains by aggregating the country's smallholder tree farmers and wood processors, and achieve economies of scale.

In December 2022, with support from the UNEP Copenhagen Climate Centre, the Ministry of Environment and Climate Change in Somalia conducted a TNA for mitigation (UNEP, 2022a), through which it prioritized climate technologies in the forestry sector. The implementation of prioritized technologies in the forestry sector in Somalia requires the development of enabling policies and the strengthening of institutional frameworks. International climate finance and investment play important roles in achieving the goals of combating climate change issues. Comprehensive support for capacity building and awareness raising for various institutions and stakeholders will also strengthen these efforts. In July 2023, Somalia became the 36th member to join the African Union-led Great Green Wall Initiative, which aims to address desertification, climate change, and biodiversity loss across the Sahel to the Horn of Africa. The Initiative intends to do this by restoring 910 million hectares of degraded land by 2063 while sequestering 250 million tons of carbon and generating 10 million green jobs. By uniting its efforts with the programme, Somalia has committed to investing USD 10 million to combat desertification and prevent biodiversity loss in the country while achieving the Green Somalia Initiative goal of planting 10 million trees.

7. Conclusions

As the world moves forward in its fight against poverty, hunger and climate change, agrifood systems will need to play an active part in climate action, through both mitigation and adaptation actions. In addition to providing food for a growing global population, agrifood systems are an important source of income and livelihoods, employing around 1.23 billion people in 2019 (FAO, 2023).

While closely tracking vulnerabilities, ensuring economic and social inclusion when transitioning towards a climate-resilient development pathway will be central to achieving the desired outcomes. As reported in IPCC (2022a), 3.3 billion people live in countries classified as highly or very highly vulnerable to climate change. Climate technologies are a specific enabler of climate actions in agrifood systems. This has been reflected in the first Global Stocktake through the pledge for increased commitment to strengthen the climate technology uptake and deployment and for the call for the new Technology Implementation Programme.

If current trends of drivers affecting agrifood systems do not change, the sustainability and resilience of agrifood systems will be under increasing threat, with food crises likely to increase in the future. Interconnected socioeconomic and environmental drivers can shape the future of agrifood systems and contribute to determining their outcomes. In this setting, climate technologies are essential to accelerating urgently needed adaptation in agrifood systems, while supporting mitigation efforts. At present, they are underutilized due to barriers and insufficient incentives.

It is important to recognize the context specificity of climate change technology impacts on adaptation and mitigation as well as broader effects, especially on the potential for achieving a just transition to climate-resilient development pathways. Climate technologies generate multiple impacts. Ideally, they are synergistic; for example, where climate action also contributes to improved livelihoods. However, there can also be trade-offs between them; for example, technologies for adaptation may have trade-offs with mitigation, mitigation technologies may have trade-offs with livelihoods, and so on. Building a broad understanding of the impacts of climate technologies across different contexts is still emerging, strengthened by the findings of the Global Stocktake and other recent efforts. The specificity of impacts mandates careful assessment of climate technologies and the capacity needed to realize desired outcomes in the overall context of agrifood system transformation. The report has shown how the assessment elements for climate technology use within agrifood systems need to be strengthened. Since climate technologies are context and system specific, not all technology options are universally applicable. As such, accurate and context-specific assessments of the local agrifood systems are needed to define and underpin the climate technology options to be used, deployed, taken up and expanded. The assessments need to reflect the high degree of heterogeneity across different sectors of agrifood systems (crops, livestock, fisheries and aquaculture, and forestry), as well as along the different stages of the value chain (production, processing, distribution, packaging and storage), meaning context-specific solutions are required.

The assessment blocks need to be tied to a clear capacity needs and capacity-building strategy and effort: climate technologies cannot be deployed or taken up if the suitable and correct skill sets are not in place. The report shows that, improvements in human skills (basic and/or digital literacy) and institutional structures are required, particularly for people in vulnerable situations with low skill sets and low uptake potential. This is also needed to ensure that institutions in the countries can access the needed financing sources and opportunities. Due attention needs to be paid to the informal sector; the report shows how access to climate technologies for smallholders and for people from the more vulnerable and Indigenous segments of the population often involves interacting with the informal sector. This integrated approach would support people’s right to food by ensuring that food systems are resilient and capable of providing sufficient, safe and nutritious food for all and that local technological know-how and needs are considered.

Finance flows to technology need to be increased and further targeted, building in particular on the technology assessment blocks and on the capacity needs of the country. Doing so will also ensure sustainability of the financial investments and encourage further multiplier effects. On a related note, financing climate technologies in agrifood systems can have a multiplier effect on poverty reduction, economic growth and climate action. Most of the world’s poor people rely on agrifood systems for some share of their livelihoods, and growth in this sector has proven to be the most effective means of poverty reduction in recent times.

Overall efforts at the policy level need to be coordinated across sectors and in a participatory manner, clearly targeting climate change, agriculture, development and the environment. The next round of NDCs and its revisions can be a vehicle to support coordination and to ensure that the evidence built at the assessment level feeds into the policy process and the NDCs, and then acts as a driver for livelihood improvement, sustainable growth and appropriate transition.

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