Background Paper on Technologies for Adaptation

Background Paper for the UNFCCC Technology Executive Committee (TEC) Workshop on Technologies for Adaptation

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Contents

Executive Summary

The background paper gives an overview of stakeholders and bodies engaged in developing and implementing technologies for adaptation to climate change. Under the UNFCCC, there are a range of different bodies under the Convention working on adaptation and a dedicated mechanism for technology exists in the Technology Mechanism, as well as processes that could be enhanced, scaled-up and better integrated to promote the development and implementation of technologies for adaptation. Outside the Convention, a range of stakeholders have been engaged in adaptation technologies spanning research, private sector, financial organizations, non-governmental organizations (NGOs) and communities. Collaborative learning can draw strengths from different areas of expertise, including local knowledge, and may contribute to mobilizing private investment. Successful technologies are notable in that they often stem from and strengthen what local people have been doing, where a systemic approach is taken, with attention to socio-political issues.

In the agricultural sector, there is a need for communication of climate information, including combining indigenous and conventional knowledge to ensure information meets local needs. There is a need to strengthen and preserve agro-biodiversity as well as diversification to strengthen agricultural production. Farmer-led innovations have great potential to be replicated. Strong local institutions are a critical success factor, and spreading local innovations requires coordination and collaboration between many different stakeholders. Market-related factors and land tenure issues are key barriers, as well as access to water and other inputs for agriculture, demonstrating the need for enabling actions at a broader scale to ensure food security under climate change.

In the water sector, various case studies showed that both local technical factors and broader institutional or governance issues must be considered to ensure successful implementation of technologies for adaptation. Water management has regional or cross-border implications, demonstrating the need for cooperation in development of water strategies, between stakeholders as well as between regions.

For coastal zones, sustainability of technologies relies on local level and community enthusiasm and involvement alongside an in-depth understanding of the historical, environmental, political and social context. Technologies must be flexible under future climate change and it is suggested these should fit into broader coastal management plans.

Overall, the paper confirms the importance of the enabling environment in scaling up and enabling access to adaptation techniques and technologies. Various important cross-cutting structural, international or regional measures could enable adaptation, such as renewed focus on trade regulations and cooperation at the global level to facilitate the trade and diffusion of technologies for adaptation. Better integration into national plans and programmes could also provide for a better enabling environment. Moreover, technological maladaptation can occur with negative indirect effects or trade-offs, demonstrating the need for technology assessment that engages a wide range of stakeholders, and an iterative, flexible approach to adaptive management.

The paper also recommends policies and actions to further promote technologies to enhance action on adaptation to climate change, in the following areas: research, monitoring and evaluation; stakeholder engagement; financing; policies and regulations; planning; institutions and infrastructure; international and regional cooperation; and mainstreaming and integration. Finally the paper also made possible recommendations for actions by the Technology Executive Committee in a number of areas.

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1. Introduction

This paper aims to provide background and context on the evolution of the roles of technology and the application of technology for adaptation to climate change in the following sectors: agriculture, water, and infrastructure and settlements including coastal zones. This paper was commissioned by the United Nations Framework Convention on Climate Change with the purpose of informing the Workshop on Technologies for Adaptation held in conjunction with the 8th meeting of the Technology Executive Committee (TEC) in March 2014.

The objectives of the paper are to provide an overview of the work and contribution from various relevant bodies under the Convention relating to application of technologies for adaptation, as well as reviewing the experiences of various stakeholders outside the Convention. The paper provides an overview and a synthesis on experiences, lessons learned from success and failure stories on the development and implementation of various technologies for adaptation in the three selected sectors. Finally, the paper identifies enablers and barriers for the successful implementation of technologies, and recommends policies and actions to further promote technologies to enhance action on adaptation to climate change

1.1. Context and Scope of the Paper

In 2010 (COP-16), in Cancun, Mexico, the Technology Mechanism was established, consisting of two components, the Technology Executive Committee (TEC) and the Climate Technology Centre and Network, and both are mandated to facilitate the effective implementation of the Technology Mechanism under the guidance of the COP. The Technology sub-programme provides support to the Technology Executive Committee (TEC) in performing its functions.

As part of fulfilling the mandate from the COP, the TEC has established in 2013 an internal task force on adaptation. The TEC also agreed to hold a workshop on technologies for adaptation in conjunction with its 8th meeting, with the support of the Adaptation Committee (AC), with the objective of determining one or more topics for TEC Brief(s) on technologies for adaptation. This background paper is meant to stimulate discussion at the Technology Executive Committee (TEC) Workshop on Technologies for Adaptation, Bonn, Germany, 4th March 2014.

This paper builds on previous UNFCCC papers and work on the topic of technologies for adaptation. Under the UNFCCC, technical assistance has been provided to non-Annex I Parties to conduct technology needs assessments (TNAs). The TNA process is a country-driven process to assist in identifying and analysing priority technology needs, which can be the basis for national projects and programmes. At its thirty-fifth session in Durban 2011, the Subsidiary Body for Scientific and Technical Advice (SBSTA) requested the UNFCCC secretariat to prepare an updated TNA synthesis report, including TNAs conducted by non-Annex I Parties under the Poznan strategic programme on technology transfer. By 31 July 2013, a total of 31 TNA reports were available and the information was synthesized into the

'Third synthesis report on technology needs identified by Parties not included in Annex I to the Convention' (UNFCCC, 2013).

1.2. Relevant definitions

Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate (IPCC, 2012).

Adaptive Capacity

The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities (IPCC, 2012).

Maladaptation

Any changes in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability but increases it instead (IPCC, 2001).

Technology

The practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software', know-how for production and use of artefacts) (IPCC, 2007).

Technology needs and needs assessments

A set of country-driven activities that identify and determine the mitigation and adaptation technology priorities of Parties other than developed country Parties, and other developed Parties not included in Annex II, particularly developing country Parties. They involve different stakeholders in a consultative process, and identify the barriers to technology transfer and measures to address these barriers through sectoral analyses. These activities may address soft and hard technologies, such as mitigation and adaptation technologies, identify regulatory options and develop fiscal and financial incentives and capacity building (UNDP, 2010).

Technology transfer

The exchange of knowledge, hardware and associated software, money and goods among stakeholders that leads to the spreading of technology for adaptation or mitigation. The term encompasses both diffusion of technologies and technological cooperation across and within countries (IPCC, 2007).

Vulnerability

The propensity or predisposition to be adversely affected (IPCC, 2012).

1.3. Background to technologies for adaptation

This paper provides background and context on the evolution of the roles of technology and the application of technology for adaptation to climate change in the following sectors: agriculture, water, and infrastructure and settlements (including coastal zones). Agriculture, water and infrastructure and settlements were the three most commonly prioritized sectors identified by Parties in the third synthesis report of the TNAs; with agriculture prioritised by 84 per cent of Parties, water resources by 77 per cent and infrastructure and settlement (including coastal zones) prioritised by 32 per cent (UNFCCC, 2013). Hence, this paper focuses on these three sectors.

Recognising the difficulty of defining technologies for adaptation, UNFCCC (2005) proposes that an operational definition might be "*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*". The IPCC Special Report on Methodological and Technological Issues in Technology Transfer made the point that technologies can be deployed to assist in any of the four steps that comprise the process of adaptation to climate change (IPCC, 2000):-

1) Information development and awareness raising
2) Planning and design
3) Implementation
4) Monitoring and evaluation

The technology needs identified in the Technology Needs Assessments (TNAs) relating to adaptation included both 'hard technologies' such as dikes and floodwalls, and 'soft technologies' (UNFCCC, 2013). Accordingly, this paper will cover both hard and soft technologies. It has been recognised that a successful adaptation strategy would typically combine hard and soft technologies. For example, an early-warning system relies on hard technologies such as measuring devices and information technology, but also on knowledge and skills to strengthen awareness and promote action when the warning is given (Klein *et al*., 2005). Christiansen *et al* (2011) further categorises the technologies for adaptation into hardware, software, and orgware, where "hardware" refers to hard technologies such as capital goods or seed varieties, "software" refers to processes, knowledge and skills in use of the technology, and "orgware" relates to ownership and institutional arrangements where technologies will be used. Some examples for the three sectors are given in the table below:

Sector/Technology Type	Hardware	Software	Orgware
Agriculture	Selection of crop or crop variety	Farming practices, research on new varieties	Local institutions
Water resources and hydrology	Ponds, wells, reservoirs, rainwater harvesting	Increase water use efficiency and recycling	Water user associations, water pricing
Infrastructure and settlements including coastal zones	Dykes, seawalls, tidal barriers, breakwaters	Development planning in exposed areas	Building codes, early warning systems, insurance

Source: Adapted from Christiansen *et al*., 2011

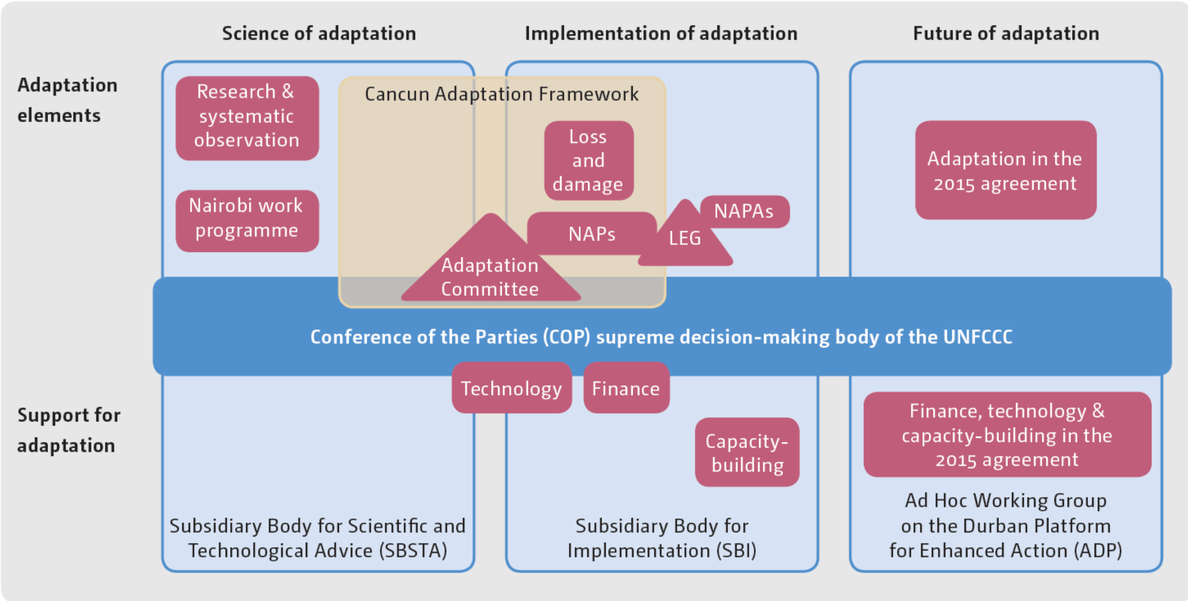
UNFCCC (2006) further distinguishes between traditional technologies, modern technologies, high technologies and future technologies, where traditional technologies are those that have been applied throughout the centuries, such as building houses on stilts, while modern technologies are those since the onset of the industrial revolution. High technologies are those deriving from recent scientific advances, while future technologies are those that have not been invented yet (UNFCCC, 2006). In the TNAs, several Parties prioritised indigenous technologies that could be applied for adaptation, such as traditional designs for housing, bunds, levees, dikes and mangrove plantations (UNFCCC, 2013). In most countries and ecosystems, indigenous knowledge of communities has led to responses to different climate-related challenges, which can potentially be replicated and adopted in areas that are likely to be affected by climate change. There continues to be a great need to recognise the knowledge held by local people (Wilk and Wittgren, 2009). Thus, "technology transfer" comprises the process of learning to understand, utilise and replicate the technology, including the capacity to choose it and adapt it to local conditions and integrate it with indigenous technologies (Klein *et al.,* 2005). In identifying barriers to transfer and diffusion of adaptation technologies, and measures to overcome those barriers, UNEP (2012) provides a further classification of technologies into market and non-market goods, as discussed later.

In this process, it is recognised that adaptation activities run along a continuum from activities that address the drivers of vulnerability, but which are often indistinguishable from development activities, to "discrete adaptation" activities that directly confront the impacts of climate change (McGray *et al*., 2007). Similarly, adaptation to climate change may often involve existing development technologies that build adaptive capacity. Hence, stories of successes and failures in this paper are drawn from multiple case studies ranging across this continuum.

2. Work and contribution from relevant bodies under the Convention

This section provides an overview of work and contribution from various relevant bodies under the Convention on climate change adaptation matters, and analyses the impact of these, if any, to the application of technologies for adaptation to climate change. Furthermore, it discusses the experiences and roles of various stakeholders in the process. Relevant bodies under the Convention relating to adaptation include the work of the Subsidiary Bodies, LDC Expert Group (LEG), the Expert Group on Technology Transfer (EGTT), TT:Clear Gateway, the Adaptation Committee, and the Technology Mechanism (TEC, CTCN).

Institutional Structure on Adaptation under the Convention (Source: AC, 2013)



Subsidiary Bodies: SBSTA and SBI

The two permanent subsidiary bodies established by the Convention are the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI). These parties traditionally meet in parallel twice a year.

SBSTA: The SBSTA's role is to provide the COP with advice on scientific, technological and methodological matters, a key part of which is promoting the development and transfer of Environmentally Sound Technologies (UNFCCC, 2002). The Nairobi Work Programme on impacts, vulnerability and adaptation to climate change (NWP) reports to the SBSTA.

SBI: The role of the SBI is to give advice to the COP on all matters concerning implementation of the Convention, including reviewing financial assistance given to the non-Annex I Parties to help them implement Convention commitments (ibid). The LDC Expert Group reports to the SBI (UNFCCC, 2002).

Implementing action through NAPAs and NAPs

National Adaptation Programmes of Action (NAPAs) provide a process for the Least Developed Countries (LDCs) to identify priority activities for urgent and immediate needs with regard to adaptation to climate change. As of January 2013, 50 LDCs had submitted their NAPAs to the UNFCCC Secretariat. NAPAs are action-oriented, country-driven, flexible and based on national circumstances, and the priority sectors addressed were agriculture and food security, water resources, coastal zones, and early warning and disaster management (AC, 2013). Many countries have used the NAPA process to guide national adaptation planning, including projects which include implementation of technologies for adaptation. Bangladesh's experience, for example, shows the NAPA process can be useful to establish institutional arrangements to address climate change (*ibid*). Funding for NAPA implementation comes from the Least Developed Countries Fund (LDCF). However, a joint independent evaluation of the LDCF reported problems in NAPA implementation caused by lack of predictable finance for the LDCF, as well as noting institutional and bureaucratic barriers to NAPA implementation (GEF, 2009).

Following the NAPA process, Parties recognised the need for LDCs to also identify medium and long-term adaptation needs and to develop and implement adaptation strategies and programmes through **National Adaptation Plans (NAPs)**. Consequently, the Cancun Adaptation Framework (2010) established a process for LDCs to formulate and implement National Adaptation Plans. The invitation was also extended to other developing countries to employ the modalities formulated to support their own NAPs (AC, 2013). The guidelines for NAPs have been developed by the LEG into full technical guidelines. In June 2013, the NAP Expo was held in Bonn to facilitate sharing of experiences relating to the NAP process. The SBI noted in the Report of the SBI in December 2013 (Document FCCC/SBI/2013/20) that the Parties can begin to access resources from the Least Developed Countries Fund (LDCF) and Special Climate Change Fund (SCCF) in support of the NAP process, through existing GEF modalities.

Convention Bodies

Under the Convention, there are various bodies that work on technology transfer issues and adaptation to climate change, including the LEG and the Adaptation Committee.

Least Developed Countries Expert Group (LEG)

The LEG was established by the COP in 2001.The LEG is requested by the COP to provide technical support and advice to the least developed countries (LDCs) on national adaptation programmes of action (NAPAs) and the LDC work programme, and provide technical guidance and support to the national adaptation plan (NAP) process. The LEG meets twice a year and supports LDCs through a variety of modalities including training workshops, development of guides, tools, technical papers, publications and databases, reviewing draft NAPAs upon request or providing direct advice.

Expert Group on Technology Transfer (EGTT)

In the past the Conference of Parties (COP) were supported by the Expert Group on Technology Transfer (EGTT), which was established in 2001 at COP-7 to work on the issues of technology development and transfer under the Convention. The EGTT was established as an institutional arrangement to facilitate the implementation of the technology transfer framework until the establishment of the Technology Mechanism in 2010 (as described below). EGTT collaborated with the Global Environment Facility (GEF), UNDP, UNEP and the Climate Technology Initiative (CTI) to provide technical assistance to non-Annex I Parties to conduct technology needs assessments (TNAs) The EGTT mandate was terminated at the conclusion of COP16 in decision 1/CP.16.

Adaptation Committee (AC)

As part of the Cancun Adaptation Framework (2010), Parties established the Adaptation Committee to promote the implementation of enhanced action on adaptation in a coherent manner under the Convention, inter alia, through the following functions:

1. Providing technical support and guidance to Parties;
2. Sharing relevant information, knowledge, experience and good practices;
3. Promoting synergy and strengthening engagement with national, regional and international organizations, centres and networks;
4. Providing information and recommendations, drawing on adaptation good practices, for consideration by the COP when providing guidance on means to incentivize the implementation of adaptation actions, including finance, technology and capacity-building;

5. Considering information communicated by Parties on their monitoring and review of adaptation actions, support provided and received.

The Adaptation Committee's first Adaptation Forum was held on 19 November 2013 in Warsaw, Poland, aimed at raising awareness and profile of adaptation globally by highlighting ideas on what a resilient future should be. In 2013, the Adaptation Committee issued its first thematic report on the State of Adaptation under the UNFCCC. Promoting coherence of adaptation action under the Convention is paramount to the work of the Adaptation Committee (AC, 2013). The report notes that the Committee has thus embarked on establishing relationships with other Convention bodies such as the LEG, SCF, TEC and CTCN, the CGE and the Board of the GCF (AC, 2013).

Technology Mechanism

The new Technology Mechanism was established by the Cancun Agreements in December 2010. The Technology Mechanism consists of the Technology Executive Committee (TEC) and a Climate Technology Centre and Network (CTCN). The mechanism represents a step to move beyond the 'conventional' approach to technology transfer under the Convention, based on capacity building and TNAs, to a more 'dynamic' arrangement geared towards fostering public-private partnerships; promoting innovation; catalyzing use of TRMs or action plans; mobilizing national, regional and international technology centres and network; and facilitating joint R&D (UNFCCC, 2013b).

Technology Executive Committee (TEC)

The Technology Executive Committee (TEC) is the policy component of the Technology Mechanism. The key functions of the TEC are to consider and recommend actions to promote technology development and transfer in order to accelerate action on mitigation and adaptation; to provide an overview of technological needs and catalyze the development and use of TRMs or TAPs at international, regional and national levels through collaboration with relevant stakeholders (UNFCCC, 2013b). The TEC aims to engage a broad range of stakeholders. For instance in 2012 the TEC called for inputs on ways to promote enabling environments and address barriers to technology development and transfer (ibid).

Climate Technology Centre and Network (CTCN)

The mission of the CTCN is to stimulate technology cooperation, to enhance the development and transfer of technologies and to assist non-Annex I Parties in this regard. This is done in order to build or strengthen their capacity to identify technology needs, and facilitate the preparation and implementation of technology projects and strategies. United Nations Environment Programme (UNEP) was selected at COP19 as the host organization of the CTC, as the leader of a consortium of partner institutions. The modalities and procedures of the CTCN were adopted at COP19. Under decision 25/CP.19, the COP requested the CTCN, in executing its modalities and procedures, to work in conjunction with the TEC to ensure coherence and synergy within the Technology Mechanism. As of January 2014, 52 countries, 40 of them developing countries, have nominated their National Designated Entities (NDEs).

2.1. Work and activities under the Convention

TT:Clear Technology Transfer Information Clearing House

TT:CLEAR is a Web based technology transfer information clearing house (http://ttclear.unfccc.int) acting as a gateway to technology information enabling users, including practitioners and private sector users, to find information on many issues related to technology transfer (UNFCCC, 2013b). The website currently hosts information relating to TEC meetings, TNAs, the CTCN, and a Technology Portal enabling users to search for technology briefs or roadmaps by using a keyword search.

Technology Needs Assessments (TNAs) and Technology Action Plans (TAPs)

Since 1999, Parties not included in Annex I to the Convention have been conducting and reporting their TNAs to identify, prioritize and highlight their adaptation and mitigation technology needs in various sectors. TNAs have drawn attention to specific barriers to technology transfer and suggested measures to address them. However there are some concerns that the prioritisation and selection of technologies for adaptation are biased towards 'hard' technologies (Christiansen *et al*., 2011). This perhaps reflects the initial focus on mitigation technologies under the UNFCCC.

There have been efforts to link the TNA process with NAPAs and NAPs (TEC, 2013). Many Parties noted in their TNAs that these drew on completed NAPAs, and 25 per cent of Parties identified outputs of TNAs that could serve as inputs to their national communications, NAMAs or national adaptation plans (NAPs) (UNFCCC, 2013). However, further linking and integration with NAPA and NAP processes has been encouraged which would avoid duplication of planning processes (TEC, 2013).

Box: Technology Action Plans (TAPs)

Almost all of the 31 Parties (90 per cent) which had their TNA reports analysed in the third synthesis report had also developed Technology Action Plans (TAPs). These consisted of groups of measures to address the identified barriers to the development and transfer of a prioritized technology (UNFCCC, 2013). This is a major evolution from the second synthesis report of 2009 (UNFCCC, 2009) in which Parties only elaborated on the identification of possible next steps to address barriers. The Technology Action Plan (TAP) may include measures at the national level, sectoral level or at the technology-specific level (UNFCCC, 2013). Most Parties prepared TAPs for the agriculture and water sectors consistent with the profile of sectors prioritised in the TNA, and some prepared overarching TAPs for the sector while others focused on a selection of prioritised technologies (UNFCCC, 2013). Some TAPs have been developed at the technology-specific level. For example, Côte d'Ivoire created a TAP for the diffusion and rapid multiplication of plantain and cassava varieties tolerant to water stress, identifying four measures to address financial barriers, technical barriers and barriers related to information sharing and awareness (*ibid).*

Most Parties (more than 85 per cent) included in TAPs the information on targets, budgets and actors responsible for the actions, while some included details of ways to secure funds or of MRV requirements (UNFCCC, 2013). For adaptation, the total estimated accumulative budget requirement of Parties for their TAPs was USD 2.4 billion (*ibid*). Many of the Parties' (87 per cent) identified project ideas as part of their TNA processes, while only 35 per cent had done so as at the time of the second synthesis report (*ibid*). USD 12.2 billion was estimated by Parties to be required for project ideas relating to adaptation projects (UNFCCC, 2013).

The Technology Action Plans developed by Parties in 2012-2013 have been specific to countries' situations, and are variable in terms of detail and scope. Some examples of TAPs are given in the box below.

Box: Examples of Technology Action Plans (TAPs) for adaptation developed by Parties

Azerbaijan	Technology Action Plan for flood warning technology
Bangladesh	TAP for Monitoring sea level rise, tidal fluctuation, and salinity intrusion, sedimentation and coastal erosion
Cambodia	Technology Action Plan for the Transfer and Diffusion of Small Dams, Small Reservoirs, and Micro Catchments
Cote D'Ivoire	Technology Action Plan for the rapid multiplication of varieties of plantain and cassava varieties tolerant to water stress
Kenya	Technology Action Plan for Drought Tolerant Sorghum Varieties
Lebanon	Technology Action Plan for Water Users' Association (including cost-benefit)
Rep. Moldova	Technology Action Plan for medical emergency care and prompt rehabilitation during critical periods
Sri Lanka	Technology Action Plan for Crop Diversification and Precision Farming
Thailand	Technology Action Plan for seasonal climate prediction
Zambia	Technology Action Plan for Boreholes/Tube Wells

Technology Roadmaps (TRMs) could also be used to promote adaptation technologies. A review has been undertaken of TRMs (see box below).

Box: Review of Technology Roadmaps (TRMs)

The UNFCCC "Background Paper on Technology Roadmaps" (UNFCCC, 2013a) reviewed 159 publicly-available Technology Roadmaps (TRMs) for adaptation and mitigation. Only 11 out of 159 TRMs were for adaptation, with 8 of these focusing on water resource management (UNFCCC, 2013a). This may reflect the limited resources spent on adaptation compared to mitigation at present. However, the difference may also originate from adaptation being less focused on 'hard' technologies than for mitigation. Due to the relatively few adaptation TRMs, only tentative conclusions could be drawn. It was found the attention on technology R&D was limited, with the central focus of the TRMs on water being on policy and resource management (UNFCCC, 2013a). The only TRM with a clear technology focus was the Australian TRM on desalination (ibid). The review of TRMs observed that:-

- TRMs are a useful tool when development and transfer of technology needs activation; and this seems most suitable for 'hard' technologies.
-Due to the links with development, a strong diversity of stakeholders needs to be engaged.
-Adaptation TRMs must deal strongly with the inherent element of uncertainty.
-Adaptation TRMs are most relevant at the national level in order to accomplish specific (quantifiable) goals. These efforts could perhaps be linked to TNAs and TAPs (UNFCCC, 2013a)

Implementation of various activities that were identified in the TNA process will require the coordination and engagement of different government ministries and bodies, as well as engagement of local government. An example from Indonesia is shown in the box below.

Box: Implementation of Coastal Zone Protection in Indonesia's TNA

Indonesia's TNA (2010) identifies coastal protective structures, specifically seawalls and revetments, and coastal reclamation. Whilst regulations are in place for coastal protection measures, in the form of the 2010 Ministers Regulation and Circulars regulation for coastal reclamation, namely the President of the Republic of Indonesia's Decree on Reclamation on in Coastal area and Small islands, was waiting to be signed at the time the TNA was published. Coordination will be conducted by the Ministry of Public Work and the Ministry of Marine Affairs and Fisheries, whilst the responsibility of executing the plans is divided between the Central and Local Government, depending on the specific site location. This latter decision has been made in an attempt to ensure contextually specific knowledge of the area of implementation.

2.2. Engagement of Stakeholders in UNFCCC Processes relating to adaptation

Stakeholder groups engage in various different ways in adaptation processes under the UNFCCC. The Adaptation Committee has civil society observers in its meetings as it was decided under decision 2/CP.17 meetings shall be open to attendance by admitted observer organizations, except where otherwise decided by the Adaptation Committee, with a view to encouraging a balanced representation of observers from Annex I and non-Annex I Parties.

Momentum for Change Initiative

The Momentum for Change Initiative is an UNFCCC secretariat initiative to highlight case studies by outside stakeholders, including showcasing the work of stakeholders at COP conferences. The initiative is supported by the Bill and Melinda Gates Foundation, Rockefeller Foundation and the World Economic Forum, focusing on various areas in the context of adaptation with emphasis on the role of the urban poor, women, ICT solutions and finance for climate-friendly investments.

Source: https://unfccc.int/secretariat/momentum_for_change/items/6214.php

Involvement of stakeholders has also been crucial to the Technology Needs Assessment (TNA) process from the start. The UNEP Handbook for conducting TNAs highlights the importance of identifying and engaging stakeholders (UNDP, 2010). The handbook states successful engagement of stakeholders is important because it can "lead to transfer of new knowledge, especially local knowledge, and insights on specific technology challenges and opportunities that might otherwise be missed", and it will also be easier to implement recommendations from this process, as stakeholders will have already been exposed to proposed actions and provided some level of buy-in *(ibid)*. Thus, the National TNA committee includes representatives from academia, civil society and the private sector.

Under the Nairobi Work Programme, the SBSTA encourages active engagement and participation of adaptation stakeholders in implementation of the NWP. The example of private sector engagement in the PSI is given in the box below.

Box: Case of the Nairobi Work Programme's Private Sector Initiative (Source: UNFCCCb)

Under the Nairobi Work Programme (NWP), the Private Sector Initiative (PSI) seeks to involve the private sector in the wider adaptation community. The PSI provides a platform for businesses to contribute in a sustainable and profitable manner to a strong and effective response. Partnership in the initiative brings a number of benefits to companies, including the possibility to take part in activities mandated under the NWP, but also include networking opportunities, reputational advantages and increased visibility. Several companies have shared best practice adaptation activities as 'Action Pledges' under the NWP which are included in the relevant partner profiles on the website.

The **Green Climate Fund (GCF)** is the centrepiece of long term financing under the UNFCCC and will mobilize climate finance of $100 billion per year for both adaptation and mitigation by 2020. The Green Climate Fund Board has 2 dedicated observers from the private sector and 2 from civil society (NGOs). Private sector finance will be catalysed by the proposed PSF, below.

Box: Case of the Green Climate Fund's Private Sector Facility (Source: www.gcfund.net)
The purpose of the Green Climate Fund (GCF)'s Private Sector Facility (PSF) is to scale up private sector finance. According to the Governing Instrument for the GCF, the Fund will "have a private sector facility that enables it to directly and indirectly finance private sector mitigation and adaptation activities at the national, regional and international levels". The Governing Instrument also states that the Private Sector Facility will "promote the participation of private sector actors in developing countries, in particular local actors, including small and medium-sized enterprises and local financial intermediaries". One adaptation opportunity that is highlighted in the Business Model Framework (June 2013) is that a PSF partner financial instrument(s) could "bid out access to first-loss provisions on a scale that would enable the insurance industry to develop new products and make insurance affordable to more farmers".

2.3. Conclusions

There are a range of different bodies under the Convention working on adaptation and a dedicated mechanism for technology exists in the Technology Mechanism. However, the experience of NAPAs has shown that not all project ideas get funded or implemented and there are various barriers to implementation of projects, including predictability of financial resources (GEF, 2009). This demonstrates the importance of scaling-up adaptation finance, including for technologies for adaptation to climate change.

Stakeholder engagement has been a key issue for adaptation under the UNFCCC. The TNA process has recognised that stakeholders provide valuable and essential input to the TNA process (UNDP, 2010). The Technology Executive Committee (TEC) has also engaged with stakeholders, for example in calling for inputs. This stakeholder engagement could be better enhanced through engagement with a wider range of stakeholders. The new Climate Technology Centre and Network (CTCN) provides an opportunity for new partnerships and alliances with academic and research institutes, and public-sector and private-sector organisations working on adaptation technologies.

Further, it has been suggested that the prioritisation and selection of technologies for adaptation under the TNA process is biased towards 'hard' technologies (Christiansen *et al.*, 2011). A narrow focus on 'hard' technology may miss some legal, structural or 'soft' aspects of technology development and dissemination. This might reflect the initial bias towards mitigation under the UNFCCC Convention. There is a need for the technology mechanism to work for adaptation too. Moreover, it can be argued that the TNA processes need to be better linked with NAPA and NAP processes. Better integration will avoid duplication of efforts and provide for better implementation of adaptation actions (TEC, 2013). One of the main tasks of the Adaptation Committee will be to promote better coherence of adaptation action under the Convention, so this integration of NAPs and TNAs could be facilitated by the work of the Adaptation Committee.

3. Experiences of Various Stakeholders outside the Convention

There are a vast range of stakeholders outside of the UNFCCC developing, using, evaluating and encouraging the adoption of various adaptation technologies. These stakeholders span research institutes, private sector organizations, financial and funding organizations, non-governmental organizations (NGOs) and local community groups. Each has their own approach, motivations and individual experiences that can offer lessons both for their own improvement, and for external organizations. Similarly, these stakeholders can learn lessons from other stakeholders, including those under the convention, to inform improved approaches to designing, applying and adopting new adaptation technologies.

3.1. Research organizations

Various research organizations contribute to the initial stages of the technology transfer process, devising new technologies and testing their implementation in context. In order for this contribution to be effective, global scientific and technological partnerships are required, along with the adequate dissemination of results (Rabbinge, 2009).

Innova is a consortium encompassing three organisations that partner together to test agricultural adaptation technologies in order to find ways in which supply and demand for farming technology can synchronize (Bentley and Thiel, 2008). In a pilot study conducted between 2002-2006, they tested technologies directly with farmers in three sites in Bolivia that are at different altitudes (4000m, 3000m, 2000m) and therefore produce different types of crops. The process allows local reactions to be witnessed and the contextual impacts on technology use to be recorded. In doing this it increases understanding between stakeholders and allows in-situ adaptation, validation and adoption of technologies. The adaptation of the technologies implemented by the farmers included changing the planting schedule and area, and irrigation methods for purple clover, according to traditional agricultural customs, in order to achieve a better yield. Similarly, the yield of potatoes was doubled through using a traditional technique known as 'high-hilling up' (Bentley and Thiel, 2008: 118), in which the ground in which the potatoes are planted is raised. These examples illuminate the success achieved by integrating the expertise of both the farmers and the researchers through a flexible adaptation process to ensure that new technologies are maximized according to the context of their application. Importantly, the experience highlights the importance of collaboration between innovators and users, alongside comprehensive monitoring and evaluation processes, to inform continuous adaptation of technology needs to changing environments (Bentley and Thiel, 2008).

A further example of research for agricultural adaptation technologies comes from the Consultative Group on International Agricultural Research (CGIAR). In response to known and expected climatic impacts, CGIAR are conducting research to improve the ability of crops to withstand heat, drought and submergence in saline water (Rabbinge 2009). Refer to the agriculture section 4.1 for the example of drought-tolerant maize in Africa. Their experiences have indicated that technological innovation in isolation is not enough to elicit adaptation. Instead, it must be accompanied by the adaptive capacity of the community within which it is being introduced. Similarly to Innova, CGIAR highlight the importance of collaboration in research endeavors and continuous assessment and monitoring. Their research program on Climate Change, Agriculture and Food Security (CCAFS) brings together agricultural, climate, environmental and social science researchers with the overarching aim to comprehensively inform action towards ensuring agricultural adaptation (see http://www.ccafs-climate.org). Collaboration is also important at the other end of the research scale, for those research institutions that provide climatic information. For example, meteorological stations can work together to achieve and provide more accurate climate information and forecasts. Such knowledge can support research institutions who aim to find solutions for local-level adaptation, such as Innova, CGIAR, and many more.

Appropriate policy and funding should also be considered as necessary for researching and applying effective adaptation technologies (Rabbinge, 2009). Research and development (R&D) for technologies for adaptation can be publicly or privately funded. In agriculture, there is a lack of public investment in R&D in developing countries (Lybbert and Sumner, 2010). While patents can incentivize private investments, private companies use patents to restrict access to technologies relevant to R&D efforts for resilient crop varieties (Mba et al., 2012). Publicly funded research, on the other hand, can help to ensure that tried and tested innovations are available to those who require them for adaptation. A key challenge is ensuring that publicly-funded research achieves the maximum possible societal benefit (Wright and Pereira, 2012). As such, R&D partnerships are necessary to ensure innovations are moved along the technology cycle (ICTSD, 2010). Though IPRs are thought to incentivize innovation that supports action in developing countries, country-specific policies are needed to ensure that technologies are made available (Maskus and Okediji, 2010).

3.2. Private sector

The private sector has the potential to make a significant contribution to climate change adaptation to support not only internal resilience but wide-reaching multi-stakeholder resilience. Organizations can help to secure the financial and non-financial resources required for adaptation (CSR Asia, 2011). Moreover, involvement of the private sector in the pursuit of sustainable climate change adaptation will help to sustain national economies through maximizing business opportunities and supporting the widespread adaptation of other stakeholders (Welford, 2011). However, heightened awareness within the business sector is required to incentivize involvement, particularly in developing countries (Klein, 2007; UNISDR, 2010; Welford, 2011). This awareness could include the losses businesses themselves can incur from climate change, such as risks to core business operations, supply chain, local communities (i.e. consumers) and risks from economic and social changes (CSR Asia, 2011). Similarly, the provision of more geographically and industrially specific climate information is deemed necessary to build private sector capacity for engagement (CSR Asia, 2011). There is a need to provide business incentives and demonstrate the benefits in adaptation involvement by private businesses (CSR Asia, 2011; UNISDR, 2010; Welford, 2011). Corporate Social Responsibility programs based in community-led innovation, community investment programs and unbiased supply chain management have been recognized as a way forward for the private sector in adaptation involvement (CSR Asia, 2011). Within the private sector, we can differentiate a wide range of actors which range from large multi-national corporations to small enterprises, including smallholder farmers. While some corporations are investing in making their operations more climate-resilient, small enterprises such as smallholder farmers lack the capacity, resources or information to prepare for climate impacts.

The private sector can contribute to adaptation processes through technology donation in the form of hard and soft technologies, as well as right through the technology cycle from R&D to commercialization and dissemination of technologies. An example of private sector engagement in adaptation technology is found in coastal protection schemes, due to the benefits they provide for business endeavours linked to tourism and marine transportation (Klein, 2007). Whist the government often take much responsibility for coastal protection measures, the planning, design and implementation of associated technologies is often undertaken by private sector agencies (Klein, 2007). However, investments made in contributing to adaptation through long-term technological provisions without an immediate return such as such as water technologies and index based insurance, lack persuasion (CSR Asia, 2011). As such, alternative business activities take priority (Klein, 2007) and access to the existing technological knowledge of private companies can be restricted, in part due to ownership protection concerns and reservations about appropriate use and liability (Syngenta, n.d.). Hence, it has been suggested that the greatest private sector contributions to technology are those that provide the physical technology and accompanying knowledge alongside permission to utilize privately owned knowledge and innovations (Syngenta, n.d.). This can allow the public sector liberty to continue to operate without direct involvement from the private sector. Such a situation has been exemplified by Syngenta's donation of golden rice technology to The Golden Rice Humanitarian Board in 2005. Here, a mutually beneficial interaction with farmers was sought in order to find solutions to crop production through technology innovation.

In South and South-East Asia, private sector engagement is in the early stages, and focus is much more on mitigation than adaptation (CSR Asia, 2011). As in other regions, within the private sector, there is a lack of awareness of risks, responses and opportunities. Accompanying this is a private sector reliance on government interventions and a reactive rather than strategic response approach (Klein, 2007). However, some strategic measures exist in agriculture and agro-forestry. For example, new crop varieties and increased crop diversity are experimented with. Yet the approach to informing such a strategy is not wholly comprehensive and long-term, and therefore it lacks in sustainability (CSR Asia, 2011).

The strategic elements of the private sector could be beneficial to adaptation. Bottom of pyramid business strategies sell to, source from or distribute to the poor. Engagement in such strategies could serve to increase access to services, product and technologies crucial for adaptation, such as the use of mobile phone networks for adaptation (as seen in the Bangladesh case study), insurance and climate-resistant agricultural resources (CSR Asia, 2011). These kinds of public-private partnerships (PPPs) can strengthen climate resilience (APEC, 2010). Already some collaboration exists between private and government sectors, or private sector and NGOs (UNISDR, 2010), although capacity building for all stakeholders is needed (APEC, 2010). Collaboration between private partners and NGOs is exemplified through the disaster resilience program established by Coca-Cola and Red Crescent in Thailand in 2007 (APEC, 2010). Here, the logistical business resources of Coca-Cola are utilised alongside Red Crescent's volunteer training, to provide a disaster response network throughout the country. It has been estimated that the program has so far benefitted over

80,000 households, buy providing them with water, tents and other necessary equipment in times of disaster (APEC, 2010).

3.3. Financing Organizations

Financing for climate adaptation comes from a range of private and public sector funds of various sizes (Clapp *et al.,* 2012). Due to limitations in public sector funds, the private sector is expected to make huge contributions to adaptation financing. Negotiating organizations, such as the Climate Technology Initiative's Private Financing Advisory Network (CTI-PFAN), seek to find appropriate mechanisms and channeling for such contributions (Naidoo *et al.*, 2012). Much like private sector engagement, financial investment requires the potential to earn a return that reflects the risks engaged in. As such, an investor's evaluation of an adaptation project is the same as that of any other investment project (Naidoo *et al.*, 2012). Hence, here again the significance of long-term benefits must be advocated for. Capacity and awareness building can help investors recognize and exploit opportunities in adaptation (Naidoo *et al.*, 2012).

In support of adaptation endeavours, the Asian Development Bank (ADB) mobilizes concessional resources through a number of mitigation and adaptation funds, catalyses private sector investments and maximizes the use of market-based mechanisms (ADB, 2013). Yet securing funds is not something that works without encouragement. Instead some leverage and incentives are required. For example, the ADB work through the carbon market program to emphasize the role of the private sector in public development, encourage the use of PPPs and produce context specific knowledge solutions to complement investment operations (ADB, 2013). Moreover, the ADB have set up the Urban Climate Change Resilience Partnership (UCCRP) with the UK Department for International Development (DFID) and the Rockefeller foundation to fund 25 Asian cities. The partnership seeks to secure funding for climate change resilience projects in these cities (Dayal, 2013). Examples of their approach include securing loans for more resilient urban infrastructure and providing finance to improve responses to urban floods. The partnership exemplifies positive experiences in financing and supporting adaptation technologies. For example, in the city of Surat in Western India, PPPs invested in early warning systems and upstream reservoir management, which provided effective prevention of detrimental impacts to the lives and livelihoods of residents during subsequent flood incidents (Dayal, 2013). Such experiences can provide examples for scaling up technology to benefit wider areas. They can also lead the way for additional collaborations to be made that encourage adaptation investment plans to secure the funding needed to implement such technological innovation (Dayal, 2013).

Micro-insurance is another venue through which financial organisations support climate adaptation. Within these schemes, financing organisations themselves utilise technologies in order to monitor climatic patterns upon which to base payments. Allianz are an insurance company who have initiated a livelihood protection policy in the Caribbean. In order to calculate payments they measure points around the islands to devise payment thresholds, which are used to determine compensation in the event of a climatic event (Grimm, 2013). They also lead a crop-based insurance program in the Sahel. Payments are based on measurements of drought using satellite technology to determine losses in crop growth and development according to categorically defined zones (Grimm, 2012). Another example is index-based crop insurance in Ethiopia under the HARITA programme as described in the agriculture section (4.1). Such insurance schemes can be packaged together with micro-credit, as lack of access to credit inhibits adoption of adaptation measures and technologies. Lack of financial services is a general barrier to adaptation and technology diffusion for poorer households.

As such, there are various ways in which financial organisation can contribute in the adoption of adaptation technologies, either for their own use or in providing the finances that encourage use amongst other stakeholders. The main lessons learnt in reviewing involvement is the need to actively encourage and elicit support from institutions that are in the position to financially support adaptation and, in turn, to illuminate the ways in which they themselves can benefit.

3.4. Non-Governmental Organizations (NGOs)

Non-governmental organizations take a range of responsibilities for securing the use of adaptation technologies. They are involved in the research of appropriate technologies, the implementation, monitoring and evaluation of technologies and the financing of all of these activities. In taking a community based approach to researching adaptation technologies, NGO practitioners seek to identify indigenous technologies that have the potential for scaling-up to aid adaptation within different communities. Similarly, the implementation, monitoring and evaluation of technologies is often in a local and small-scale context, and led by individuals from within the community in association with community groups. Primary technology transfer is often in the form of knowledge dispersal for adaptation. This can be in the form of disaster preparedness activities, capacity building and provision of information about hard adaptation technologies. In taking these responsibilities, NGOs serve to bridge gaps between different innovators at varying scales, identifying where and how useful technologies can be applied to assist with climate change adaptation. Due to the local-level interaction of many NGOs, they are well positioned to aid understanding of the local context and evaluate both the scaling up of existing technologies and the adoption of new ones. As such, their input to the endeavours of other stakeholders could prove very beneficial.

Community Forests International (CFI) is an INGO who operate at the local level. In assisting communities to adapt to climate change, they share knowledge and information about specific technologies and activities, and encourage the community to adapt the technologies to fit their needs. Examples of this work come from their eco-village sites in Pemba Island, Tanzania. Here, they seek to enhance climate change adaptation through agricultural and livelihood diversification, including and in addition to the use of new technologies to assist with this (CFI, 2012). CFI report much success from this project. Their community-based afforestation and reforestation initiatives have achieved income generation leading to increased self-sufficiency of the community, their agroforestry approaches have strengthened food security and enhanced livelihood diversification, and their kitchen gardens have provided a range of benefits including food and health provisions, opportunities for community experimentation and education (CFI, 2012). Whilst these approaches have so far yielded benefits, long-term results require careful monitoring, particularly in cases where traditional methods are replaced, which could lead to difficulty in ensuring sustainability.

The NGO International Development Enterprises (IDE) have addressed this sustainability issue in their water technology projects. In implementing their Multiple Use Water System (MUS), they have utilised and built upon existing infrastructure (Mikhial and Yoder, 2008). This approach has minimised the cost of implementing MUSs, reduced disagreements over access to water resources and enhanced efficiency of resource use. By eliminating these barriers, sustainability can be further guaranteed. However, in taking this approach it should be ensured that existing infrastructural systems are operating effectively before they are used as a foundation for the installation of new technology.

Not all NGO involvement is at the local level and, more recently, there is increased focus in policy advocacy and stakeholder collaboration among the larger NGOs. Practical Action are an international NGO who prioritise the application of technology in their development endeavours. In addressing climate change adaptation, they advocate for and provide improved knowledge dispersal for adaptation technology at both the government and the local level (Practical Action, n.d.)

3.5. Community Experience

Communities under pressure to adapt to climate change develop their own technological knowledge to support this. Traditional adaptive practices can be scaled up for use by others. Simultaneously, these indigenous mechanisms can be supported through the adaptation and adoption of external technologies. The introduction of technologies can be problematic when the specific ecological, political, social and economic context that recipient communities inhabit is not accounted for. For example, in introducing hybrid seeds as a response to seed and food insecurity in Zimbabwe, it was found that the high cost, unavailability and unsustainability of hybrid seeds hindered their adoption (Progressio, 2009). Moreover, investigation within these communities also found that legal policies and frameworks can hinder necessary technology transfer, instead focussing on corporate rather than community desires. As such, experiences indicate that the community should play an integral role in technology adoption in order that effective, sustainable and socially acceptable adaptation is achieved.

In recognition of these challenges, a community-based adaptation (CBA) approach has been adopted by many of the organisations that seek to support communities to adapt to climate change. CBA approaches aim to identify traditional adaptive practices that can be scaled up for use by others. As such, they encourage communities to play an integral role in technology adoption in order that effective, sustainable and socially acceptable adaptation is achieved. It is often the case that traditional technologies are the most successful and sustainable. These technologies are developed within the context of their application, in contrast to externally produced technologies that can be too abstract from the context of their use. For example, effective technological adaptation options employed by small-scale farmers in Africa include the traditional technologies of Stone Lines in the Sahel and Fanya Juu terraces in Kenya (IIED 2011). As such, a more effective approach to development of technologies for adaptation may be to start within the community supporting various existing techniques, rather than applying technological solutions en masse. Refer to the agriculture section (4.1) for some case studies of farmer-led endogenous technologies for adaptation in agriculture, including floating gardens in Bangladesh and farmer-managed natural regeneration in the Sahel.

Community experiences have also shown the importance of accounting for long-term climatic changes and technological impacts. In Argentina, technological climate change knowledge was used in an attempt to aid early and successful adaptation. However, in the Plata Basin, the defenses built to protect against flood were unsuccessful when the area flooded in 1998. Instead, these defenses actually obstructed evacuation efforts (Barros 2006). By basing adaptation measures on short-term variability, likely long-term impacts or irregular events can be dismissed and hence, not accounted for in protective and adaptive approaches. It is the community within which the technology is applied that suffers the results of such oversights. In this example, the integration of community knowledge for climatic trends and evacuation procedures may have benefitted the project design, rather than leading to destruction within the community it intended to support. Crucially, whilst each stakeholder has an important role to play in the provision of adaptation technologies, collaboration with recipient communities is vital to maximize sustainability through experience sharing, policy support and contextual awareness.

3.6. Conclusions

There are a range of stakeholders involved in developing and implementing technologies for adaptation, including research, private sector, financial institutions, NGOs and communities.

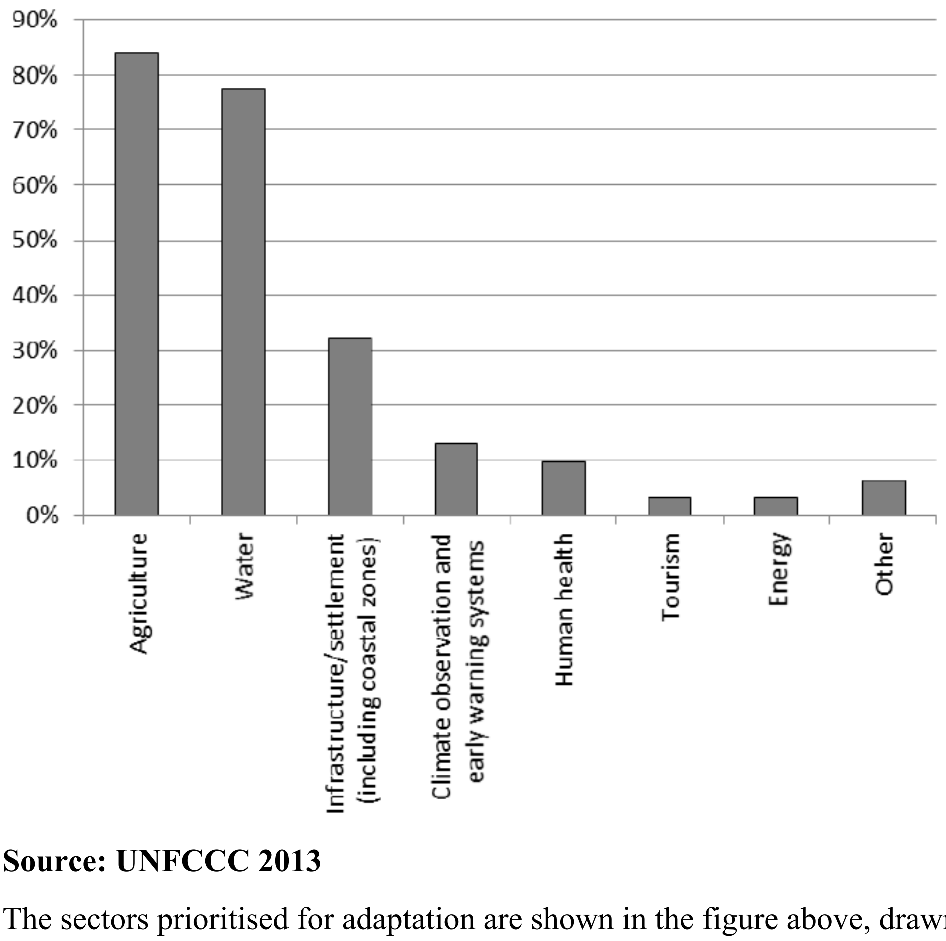
- Research institutes play an important role in developing technologies for adaptation, and research is particularly important in the R&D stage of the innovation chain.
- In agriculture, farmer-managed demonstrations have been found to be an effective way to try adaptation measures, e.g. climate-resilient seed varieties.
- R&D partnerships are necessary to ensure innovations are moved along the technology cycle
- In the private sector, there is a need for greater awareness of the risks posed by climate change in order to build private-sector capacity to respond.
- Public-private partnerships (PPPs) have high potential in strengthening climate resilience, for example, use of mobile phone networks for early warning systems.
- Much like private sector engagement, financial investment requires the potential to earn a return, for example, securing loans for more resilient urban infrastructure.
- Providing financial services to the poor, for example micro-insurance, is another venue through which financial organisations can support climate adaptation.
- Due to the local-level interaction of many NGOs, they are well positioned to aid understanding of the local context, as well as advocating for improved policies.
- Communities should play an integral role in technology adoption in order that effective, sustainable and socially acceptable adaptation is achieved.
- A community-based adaptation (CBA) approach has been adopted by many organisations. Scaling up traditional endogenous technologies may be more effective and sustainable than introducing externally produced technologies.

4. Lessons learnt from success and failures

This section provides an overview and a synthesis on experiences and lessons learned from success and failure stories for the development and implementation of various technologies for adaptation in the three selected sectors. As noted previously and shown in the figure below, agriculture, water and infrastructure and settlements (including coastal zones) were the three most commonly prioritized sectors identified by Parties in the third synthesis of TNAs (UNFCCC, 2013).

Building on previous work related to this theme (UNFCCC, 2006) the section reviews the application of different technologies for adaptation in these three sectors, considering experiences and lessons learned from successes (good practices) as well as from failures stories. The examples included should not be considered as recommended technologies and are not a comprehensive list of adaptation technologies, but are given as illustrative examples for lessons for successes and failures. The section also considers the application of endogenous technology in relevant sectors.

Prioritised sectors for adaptation as reported in Parties' technology needs assessments



Source: UNFCCC 2013

The sectors prioritised for adaptation are shown in the figure above, drawn from the third synthesis report on technology needs identified by Parties not included in Annex I to the Convention (UNFCCC, 2013).

4.1. Agriculture

Agriculture is the single most important sector in the economies of many low-income countries, and around 75 per cent of the world's population is engaged in agriculture directly or indirectly (UNFCCC, 2006). Responding to changing environmental or market conditions and societal demands is an intrinsic part of agricultural development. Technology and innovation have always been key in increasing and stabilizing production levels, and in reducing environmental impacts of agriculture. Climate change is an additional stressor to the agricultural production system in two ways. First the impacts will influence the effectiveness of current management, second low carbon development will require changes in energy efficiency of production systems. This paper will address only the responses to climate change impacts.

The IPCC 4th Assessment Report highlighted that agriculture is vulnerable to the effects of climate change, as many scenarios show negative yield impacts on major crops (IPCC, 2007). Furthermore, projected changes in the frequency and severity of droughts, floods and other extreme weather events have significant consequences for food security (IPCC, 2007) with implications for crops, livestock, forestry, aquaculture and fisheries. The impacts of climate change may benefit some areas or production systems and adversely affect other areas or production systems. In areas where the impacts of climate change are compounded by other stresses climate change has the potential to push many into a life of hunger and poverty.

Commonly adopted technologies for adaptation in agriculture include irrigation, high-yielding crop varieties, diversification of crops, as well as early warning systems and seasonal forecasts (UNFCCC, 2006). In the 'Third synthesis report on technology needs identified by Parties not included in Annex I to the Convention', agriculture was the most commonly prioritised sector, being prioritised by 84 per cent of the Parties (UNFCCC, 2013). Within this sector, the majority of the technologies prioritised were related to crop management. The most prioritised technologies were biotechnologies including new crop varieties (such as drought-resistant and short-maturing varieties) which were prioritised by more than 50 per cent of the Parties (UNFCCC, 2013). Irrigation was also highlighted by almost 40 per cent of Parties (UNFCCC, 2013).

Where adaptation has always been a part of agricultural development the distinction between adaptation to climate change and adaptation to other change is somewhat irrelevant. Acknowledging the fact that adaptation to climate change is not done in isolation but is part of overall agricultural development we limit the scope of this paper to those technologies and innovations that are related to climate stimuli and focus on arable farming. Hence this section primarily focuses on crop and land management technologies as well as irrigation. Agricultural adaptation technologies relating to livestock and forestry are not covered here, but are included elsewhere (Clements et al., 2011). Not all technologies are readily available some require landscape level interventions (e.g. construction of dams for irrigation) and require several years to implement, others require time and technology assessment before they are ready to be used (e.g. crop breeding, genetic modification).

In the UNEP guidebook to assist stakeholders in conducting the TNAs, Clements *et al* (2011) defines technology in a broad sense, including hard technologies, soft technologies, and organisational technologies. The experience of the TNAs has shown that the prioritisation and selection of technologies for adaptation are biased towards 'hard' technologies (Christiansen *et al*., 2011). But the successful implementation and dissemination of such technologies is dependent upon awareness-raising and engagement with stakeholders. Clements *et al* (2011) focus on smallholder farmers and showcase technologies based primarily on agro-ecological principles, recognising that technologies that allow for, and promote diversity are more likely to provide a strategy which strengthens agricultural production in the face of uncertain climate scenarios. Uncertainty is an important consideration because the level of warming is highly dependent on future socio-economic and emission scenarios. This section also focuses on smallholder farmers and draws on various examples based on the technologies featured by Clements *et al* (2011).

4.1.1. Seasonal forecasts and insurance

Technologies for data collection and information are pre-requisites for adaptation, particularly to identify the appropriate adaptation options in a changing environment, and to make adaptation decisions (UNFCCC, 2006). In agriculture, relevant weather and climate information can help farmers in planning decisions with regards to what and when to plant, and when to harvest. Forecasts and information are also an important pre-requisite for an effective early warning system. For example, long-range forecasts of El Niño/Southern Oscillation (ENSO) are important in determining weather conditions. Global climate models (GCMs) are widely used tools for climate prediction, but the resolution of these models do not allow for accurate downscaling to the local scale, as the output is long-term information, on the scale of hundreds of kilometres (UNFCCC, 2006). Seasonal forecasts may be more appropriate for local decisions, which are forecasts provided by meteorological services. Accurate weather data is extremely valuable for agriculture, and the more accurately weather can be forecasted, the better decisions can be taken (Clements *et al*., 2011).

At the national and regional level, a **climate change monitoring system** integrates satellite observations, ground-based data and forecast models to monitor and forecasts changes in the weather and climate (Clements *et al*., 2011). Historical data enables statistical analysis and identification of mean values, trends and variations, and more accurate information allows future conditions to be more accurately predicted. The World Meteorological Organisation (WMO) plays a vital role, forming the global network of national meteorological services which feed into a central database that is accessible to all. Effective adaptation planning will require improved observations at the local, regional, national and global levels, as well as greater collaboration between providers and users of climate information *(ibid*).

Seasonal to inter-annual prediction allows for a forecast of weather conditions for a period of 3-6 months ahead, based on existing climate data such as sea surface temperatures (Clements *et al*., 2011). ENSO forecasting is the main example of seasonal forecasting prediction, and there are continuous improvements in the techniques involved. However, availability of a seasonal forecast does not mean that farmers will respond to it. For example, in Burkina Faso, farmers did not feel that seasonal forecasts could reduce drought risk, as they did not believe they would be accurate, and also felt constrained by lack of capital to adapt to predictions (Barbier *et al*, 2009).

Box: Communication of Seasonal Forecasts in Lesotho **(Source: Ziervogel, 2004)**
In Lesotho, the Lesotho Meteorological Services (LMS) receives Lesotho's forecast from the Southern African Regional Climate Outlooks Forum (SARCOF) and then presents this at national annual workshop in October. In theory the chain of information dissemination is supposed to reach the end-users (farmers). However, it was found the October workshop is only attended by a handful of private farmers and only mentioned on a radio on a few occasions, limiting the extent to which the forecast could be used by farmers. Few agricultural extension officers seemed to hear about the forecast and therefore limited information filters down to the farmers. A participatory role-play undertaken with CARE Lesotho in 2001 found out that farmers had many ideas about how they would use a seasonal forecast, once they learnt about what it would involve. In particular it is important for farmers to understand the forecast is probabilistic, as this can determine how much trust is placed in it. In Lesotho, it was found farmers prefer interactive dissemination methods, and receipt of the forecast from Extension Agents was one of the most popular options for receiving the forecast.

Box: Making seasonal forecasts usable in Ghana & Kenya with Participatory Scenario Planning
The Adaptation Learning Programme (ALP) for Africa implemented by CARE International was launched in 2010. Participatory Scenario Planning (PSP) is an approach being used in Kenya and Ghana by ALP to facilitate communities and local governments to access and interpret seasonal climate forecasts for decision-making as part of a community based adaptation (CBA) approach. During PSP workshops, probabilistic forecasts are presented by officers from the national meteorological departments (Kenya Meteorological Service, and Ghana Meteorological Agency), and local seasonal predictions are presented by community members. Consensus between forecasts is established collectively by reviewing past trends and the status of the local environment, and the information is interpreted into scenarios in order to develop a plan of action for each livelihood group and sector.

These locally-relevant 'seasonal climate advisories' give advice on options on livelihood strategies to enable communities to address climate risks or opportunities; and aim to meet the information needs of different groups (e.g. crop farmers, livestock-keepers, pastoralists). The forecasts are disseminated to farmers through seminars, chiefs' meetings, local radio, churches and mosques, government and NGO extension services, and early warning systems. Farmers are benefiting from using the forecasts at different stages in the production to market cycle. Communities have been able to take advantage of opportunities, such as planting in the receding floodwaters or harvesting water for use in dry periods, and finding out how to avoid risks, for instance livestock keepers were able to relocate herds away from possible flood areas and vaccinate them against disease. PSP enables meteorologists and local government departments to provide relevant information and services. In turn, the increased community capacity to benefit from climate information builds their demand. The process underscores the fact that change is continuous; and adaptation means a constant process. The multi-stakeholder dialogue also raises the need to place PSP into a larger climate communication system. In Kenya, the devolution process has been an enabling factor in scaling-up the approach as there is a county-level meteorological service representative in each county. Kenya's Meteorological Service has organised a nation-wide training of county officials in climate communications and the PSP approach, and there are plans to scale-up and institutionalise the approach to all counties so that a workshop takes place after the seasonal forecast comes out. In Ghana, barriers to PSP include weak capacity of the meteorological services in generation and timely release of the seasonal forecast, adequate capacity and skills to facilitate PSP processes. The PSP model is scalable as there is general interest and demand for credible climate information by rural farmers in climate vulnerable regions and the fact PSP combines indigenous and conventional knowledge makes it more acceptable.

In addition, PSP allows for the identification of adaptation issues and priorities which need to be addressed at a higher level, for example longer term development needs. It was found that the advice must not be presented as 'instructions' to be followed, but rather as options for users to weigh up to make their own decisions to enhance their agency and ensure the information meets locally-specific needs. However, there were challenges around language and literacy, so symbols were used to ensure less literate people could be involved. It was found that it is important to ensure representation from all ethnic groups to that information can reach the most vulnerable. Initially, there were issues around trust between the communities and the scientific community. It was important to build an environment where both types of knowledge are valued and both have respect for others' way of looking at things. It was found the process works best as a co-creation of knowledge between different stakeholders.
(Source: www.careclimatechange.org/adaptation-initiatives/alp; Ward, N., Pers. Comm., 2014)

Climate insurance products are common in developed countries where farmers insure against crop loss due to extreme weather events (Clements *et al*., 2011). Climate information is a prerequisite for index-based insurance products. There are various types of climate insurance, for example, 'named risk insurance' is insurance against a specific event, while 'multiple risk insurance' insures against yield loss below expected yields (*ibid*). Index-based insurance provides a pay-out if certain climate triggers are passed, which has the advantage of allowing a large number of small holdings to be aggregated, and does not require a site inspection (Clements *et al*., 2011). Insurance can contribute to buffering farmers against extreme events. However, index-based insurance requires sophisticated meteorological monitoring including an extensive network of weather stations, necessitating the improvement of infrastructure and quality of weather data (Hazell *et al.,* 2010). There is potential for developing public-private partnerships in this area. Insurance products can also be flexibly adapted to farmers' particular needs, for example, linking to credit or irrigation provision. There is evidence climate insurance is more scalable and sustainable if offered as part of a wider package of services (Hazell *et al.,* 2011). Livestock insurance products also exist, for example in Kenya (livestockinsurance.wordpress.com). Challenges include the need to educate farmers and increase client awareness, as it has been found in pilots in Africa that there is a lack of understanding about general insurance concepts (Patt *et al.,* 2010). Successful pilots have grafted insurance onto existing, efficient delivery channels (Hazell *et al.,* 2010). Another challenge relates to the need for local climate insurance providers to be reinsured (*ibid*). Future climate change could also lead to rise in the numbers of homes or businesses considered uninsurable by the private market, demonstrating the importance of publicly funded safety nets (Herweijer et al., 2009).

Box: Crop micro-insurance in Ethiopia
Since 2009, the Horn of Africa Risk Transfer for Adaptation (HARITA) project has been implemented by Oxfam America, Swiss Re and partners in the drought-prone northern state of Tigray, Ethiopia. The integrated risk management scheme involves a combination of improved resource management (risk reduction), insurance (risk transfer) and microcredit (prudent risk taking) (Oxfam, 2011). In the face of slow-inset changes to temperature, farmers can select more tolerant crops, but in

the face of extreme weather conditions a combination of risk reduction and risk transfer is essential (*ibid*). After conversations with farmers, the farmers themselves suggested a solution – paying for insurance with their labor. The innovative 'insurance-for-work' scheme works on top of the government's "food and cash-for-work" Productive Safety Net Programme. The risk reduction activities included gully reclamation and spate irrigation with bunds. After piloting the scheme with 200 households in 2009, it has now been successfully scaled up to more than 13,000 households in Ethiopia in 2011, and the scheme is now being scaled-up in Senegal under the R4 Rural Resilience Initiative (Oxfam, 2011). Major accomplishments include a payout of over $17,000 dollars to 1810 farmers in 2011 when there was a drought (*ibid*). However one of the major challenges limiting the use of insurance in Ethiopia is lack of awareness and understanding amongst farmers about what insurance is, which results in a low willingness to pay for it (Patt *et al.,* 2010). Experiments suggest participatory simulation games like those tested in Ethiopia might be useful tools for improving understanding of basic insurance concepts (*ibid*). There is also evidence from Ethiopia that demand among farmers was increased when the training encouraged the sharing of insurance within groups, because group risk-sharing and index insurance can be complementary (Dercon *et al.,* 2014).

4.1.2. Water-saving irrigation

The projected changes in the hydrological cycle are among the most important direct impacts of climate change on agriculture. Coping with droughts and highly variable rainfall patterns has been especially relevant in arid and semi-arid regions. A large number of examples of water-related climate change adaptation technologies exist, ranging from crop selection and breeding to irrigation and water harvesting. Irrigation has often been recognised as an important technology to reduce vulnerability to climate change as farmers are no longer reliant on rain-fed agriculture. Irrigation is an example of a 'hard' technology. However, irrigation relies on existence of adequate water resources and attention to replenishment of water resources, as well as to relevant downstream or regional effects. The importance of adopting efficient water-saving irrigation has therefore been recognised, as this can save water and pumping costs while improving yields. For example, application of water-saving irrigation (WSI) in China in 2009 is estimated to have saved around 30Gm3 of water per year which accounted to 5-10% of national water consumption; enough water to increase the grain yield by 22Gt (Zou *et al.,* 2012).

Introduction of irrigation can be particularly transformative in areas which current rely on rain-fed agriculture, such as Southern Africa. Drip irrigation technologies in Africa can help to foster diversification towards irrigated high-value horticultural crops (Karlberg *et al.,* 2007; Woltering *et al.,* 2011). Irrigation has been vital in transforming agricultural production, improving food security and reducing reliance on timely rainfall. However, well-known failure stories of over-irrigation have highlighted the vital importance of managing water resources and using efficient technologies (see box below).

In drylands (arid and semi-arid lands), where irrigation is often introduced as means to 'stabilise variable rainfall' there are additional factors to consider. The soil type is critical (e.g. if salty it can lead to salinization and thus degradation of land); and size and governance of the intervention is also important (most large-scale top-down government schemes have failed in Sudan, Ethiopia, Kenya, Mali). Also important, but rarely looked at, are the opportunity costs of irrigation in drylands as these frequently displace existing land use systems which are often more suited to the environmental conditions than irrigated agriculture (e.g. pastoralism) (Behnke and Kerven, 2013). In the Sahel, it has been found that many irrigation schemes have exacerbated land tenure issues, thus it is important to pay attention to the distribution of irrigated land after the scheme as well as to gender issues, accompanied by appropriate safeguards to avoid elite capture (Cotula, 2006).

Box: Decline and restoration of the Aral Sea

The Aral Sea has been recognised as one of the worst environmental disasters of the 20th-century, and has lessons for adaptation technologies as the tragedy was primarily caused by over-irrigation. From the 1960's, under Soviet control, cotton production was expanded as a cash crop and a huge amount of water was diverted from major rivers for irrigation (Glantz *et al.,* 1993). Water resources were mismanaged, with huge diversions, poor irrigation construction and maintenance, and a bureaucracy which ignored potential consequences (*ibid*). Between 1960 and 2006, the area of the Aral Sea declined by 74% and the volume was reduced by 90% (Micklin, 2007). This had devastating economic, health and ecological impacts, including declining groundwater levels, intensifying desertification and 'salt pans' where nothing will grow (*ibid*). The reduction in spawning grounds destroyed the commercial fishing industry and led to extinction of the Aral salmon (*Salmo trutto aralensis*). Pollution of the remaining water bodies from irrigation run-off poisoned local people and wildlife (Glantz *et al.,* 1993). Salinity lowered crop yields, while strong winds blew sand, salt and dust onto surrounding lands, affecting the health of humans, plants and animals (Micklin, 2007). The surrounding 'ecological disaster zone' suffers from acute health problems including cancer, congenital deformities, intestinal disorders, and contaminated drinking water, combined with the lack of medical facilities (Glantz *et al.,* 1993; Micklin, 2007). In 1987-89 the Aral Sea separated into two water bodies; a smaller sea in the north, and a larger sea in the south.

Efforts to restore the Aral Sea have been introduced by the World Bank, UNDP, and NATO, amongst others. Irrigation in the Aral Sea Basin is hugely inefficient so there are opportunities to reduce water use by switching to less water-intensive crops (Micklin, 2007). The Aral's water balance improved during the 1990s due to more precipitation and a 12% reduction in water requirements for irrigation between 1980 -1995 (*ibid*). Yet climate change adds a new element and poses a threat to restoration efforts, as long, hotter summers may increase crop water irrigation needs and reduce inflow to the Aral Sea (*ibid*). Climate change poses a threat to ecosystems and resources that have already been eroded by anthropogenic activity. Lessons from this case study include the need to avoid over-irrigation and manage resources with an understanding of ecosystems. The Aral Sea is a reminder of the need to avoid over-reliance on hard technology and the need to avoid "groupthink" (whereby rational decision-making is undetermined by conformity within a group). When the disaster came to light, the Ministry of Water Resources Construction was charged with wasting large sums of money trying to restore the Aral by "proposing the same method that had caused the problem, namely canal construction" (Glantz *et al.,* 1993). The disaster is also a stark reminder of the need for caution in interpreting cost-benefit analyses. Cost-benefit assessments in the 1960's and 70's claimed diverting water for irrigation would be beneficial; these were based on inappropriate economic considerations and failed to consider ecological or social factors (*ibid*) .

4.1.3. Diversification and Resilient Crop Varieties

Farmers have introduced new and improved crop species over many centuries in response to environmental stress conditions, and agricultural researchers and extension workers can help farmers identify new varieties that may be better adapted to changing conditions (Clements *et al*., 2011). Breeding improved crops enhances the resistance of plants to a variety of stresses such as water stress, heat stress, salinity and new pests. IPCC (2000) highlights the importance of genetic improvements for climate change adaptation, since improvements in crop varieties have accounted for over 45 per cent of recent agricultural output growth. Switching to a more resilient crop can enable farmers to produce a crop that is more adapted to particular conditions. For example, in many places in Africa, farmers grow millet as it is resistant to drought. Biotechnology also gives us the prospect of making more rapid changes to crops than was possible with conventional breeding, although these technologies are new and there are concerns regarding long-term impacts (Clements *et al*., 2011). In relation to biotechnology, there is need for technology assessment because arguably whenever a technology involves purposeful "engineering" of a natural product or process, there must be a thorough evaluation of potential unintended consequences. For example, increasing drought tolerance of a crop might reduce nutrition or adversely impact the growth of another important crop. In addition, studies also show that particularly in this area, private companies use patents to restrict access to technologies relevant to R&D efforts for resilient crop varieties (Mba et al., 2012).

Crop diversification is a useful adaptation strategy that enables poor farmers to avoid the risk of dependence on a single crop and increase the chances of dealing with climate variability. Off-farm diversification can also manage price risk. However, it is important to note that many farmers in high and medium-income countries are specialists focusing on a very limited number of crops. According to Clements *et al* (2011) introduction of new crop species needs to consider a range of factors, such as: the availability and quality of resources; access to technologies (seed, fertiliser, marketing and storage); household-related factors (labour, cooking time) and investment capacity; price and market-related factors; and institutional and infrastructure factors. Lessons learnt from crop diversification in Zimbabwe were that strong local institutions are a critical success factor for adaptation, bottom-up processes are crucial for strong ownerships, and farmer-managed demonstrations are an effective way of trying adaptation measures (*ibid*).

Box: Drought tolerant maize in Africa (DTMA)

Launched in 2006, the Drought Tolerant Maize for Africa (DTMA) project is run by the International Maize and Wheat Improvement Center (CIMMYT) and the International Institute for Tropical Agriculture (IITA) in 13 countries of eastern, southern and West Africa. The project belongs to and is supported by the Consultative Group on International Agricultural Research (CGIAR), with initial funding from the Bill & Melinda Gates Foundation, USAID and DFID. The vision of the project is to generate drought tolerant maize that provides a 1 ton/hectare yield increase under drought stress conditions, to increase productivity by 20-30%% on adopting farms and reach 30-40 million people in sub-Saharan Africa (La Rovere *et al.*, 2010). Maize is one of sub-Saharan Africa’s most important food crops but the average yields are far below the crop’s genetic potential (DTMA, 2013) and drought poses a severe risk to rain-fed production. Since 2006, participants have marketed or otherwise made available 60 drought tolerant hybrids and 57 open pollinated varieties to smallholder farmers, which exceed the yields of widely sown seeds, and yield 20-30% more under drought (*ibid*). The new varieties also possess traits like resistance to common diseases, and superior cooking quality. The drought-tolerant maize varieties are the product of conventional breeding. Project results show that almost 29,000 tons of seed were produced in 2011/12, enough to sow more than 1.1 million hectares and benefit about 20 million people (DTMA, 2013). Engagement with governments has been key to the technology's success. Engaging officials in policy dialogue has helped fast-track the release of varieties and improved seed markets to enable access to quality, affordable seeds (*ibid*). To help disseminate the technology, DTMA has also coordinated various capacity-building events and activities for maize breeders, seed producers, extensions workers, NGOs and farmer groups (*ibid*).

At likely rates of adoption, it is estimated that drought tolerant maize can generate $530 million in benefits from increased maize harvests per hectare over 2007-2016 (La Rovere *et al.,* 2010). More optimistic scenarios for the yield estimate 10-34% improvement in yield, which would give benefits of $880 million (*ibid*). This would help more than 4 million people to escape from poverty, with the most striking benefits in Nigeria, Kenya and Malawi as these countries grow large amounts of maize. The numbers of people escaping poverty depends on the total benefits, the size of agricultural GDP as well as the poverty reduction elasticity with respect to agricultural GDP growth and the total number of poor (La Rovere *et al.,* 2010). However, poverty effects should be interpreted with caution since the poverty line at country level does not differentiate between households and does not necessarily represent rural households *(ibid*). Benefits are likely to accrue to both maize producers and maize consumers. Importantly, long-term benefits will continue after 2016 if farmers continue to use the varieties, and may even increase if farmers take up newer, more productive DTMA-project derived varieties (La Rovere *et al.,* 2010). Another important policy and management factor that affects the project results is fertiliser usage. It is possible that due to the reduced risk, farmers may intensify production by using more fertiliser, which would increase yield and income gains (*ibid*). The area upon which maize is grown could also be expanded.

4.1.4. Farmer-led Innovation for Sustainable Agriculture

Many farmers are already adapting to climate variability, building on indigenous knowledge as well as innovating new practices. It is widely recognised that indigenous knowledge is a powerful resource in its own right and is complementary to scientific knowledge (Clements *et al*., 2011). Experience has shown that inexpensive technologies requiring locally available resources have high potential for adoption (*ibid*). Acceptance and local applicability are crucial for uptake of technologies by farmers. IPCC (2007) highlights the importance of 'autonomous' adaptation which refers to the ongoing implementation of existing knowledge and technology in response to experienced changes in climate. Successful farmer-led innovations may have greater potential to be replicated autonomously elsewhere. There are opportunities for policy-makers to facilitate adaptation by encouraging diffusion of technologies from those that already exposed to certain conditions, to those becoming more exposed. Similarly, community-based adaptation programs with bottom-up and participatory processes can help to ensure ownership of technologies through on-farm piloting and testing of technologies and practices. Some farmer-led innovations for sustainable farming systems are explored below, including challenges and lessons learnt. Various field and farm level adaptation measures are available and if implemented properly would yield results within a few growing seasons. However in many cases financial, cultural, natural, institutional barriers or lack of information hamper the adoption of new and innovative approaches. Moreover, climate change will also influence the effectiveness and efficiency of implemented actions.

Box: Re-greening of the Sahel in Niger and Burkina Faso

The Sahelian rural population is highly vulnerable to drought and food crises. In the past three decades, there has been a 're-greening- of the Sahel' in large parts of Burkina Faso and Niger which has improved food security for about 3 million people (Reij *et al.,* 2009). This began when local farmers' practices were rediscovered by innovative farmers and NGOs and then diffused by a coalition of actors (*ibid*). The total area rehabilitated over past three decades is estimated at between 200,000 to 300,000 hectares (Reij *et al.,* 2009). In Northern Burkina Faso, a study in 2004 and 2006 found 49% of farmers use the *Zaï technique* to improve soil fertility and humidity, which consists of hoeing small holes in the soil, into which farmers put small amounts of manure and plant sorghum and millet (Barbier *et al.,* 2009). These planting pits concentrate water and nutrients precisely to where they are needed, and retain water for a long period (Reij *et al.,* 2009). 60% of farmers in the Burkina Faso study also build stone bunds around fields to capture runoff and reduce soil erosion (Barbier *et al.,* 2009). These practices are low-cost and highly effective in rehabilitating degraded land. Composting is widespread, with 56% of farmers adopting it, and a large number of farmers do some kind of *corralling*, while other adaptation strategies to cope with drought included off-farm migration and selling livestock (Barbier *et al.,* 2009).

Another practice that has led to increasing greenness is *farmer-managed natural regeneration* (FMNR) - protection and pruning of tree stumps to encourage the protection of trees, which provide fodder, firewood and fruit (Reij *et al.,* 2009). The practice was formalised by an NGO in the 1980's, which initiated a 'food-for-work' program based on this (Sendzimur *et al.,* 2011). The practice requires no expenditure beyond the farmer's own labour (Haglund *et al.,* 2011). Satellite images estimate FMNR now covers nearly 5 million hectares of the Sahel and supports the livelihood of 4.5 million people (Reij *et al.,* 2009). In Niger, FMNR raises annual gross income by 17- 21 million USD, contributing around 1 million extra trees (Haglund *et al.,* 2011). Although there is no discernable effect on food security, adoption of FMNR increases household income and crop diversity, and may make farmers better prepared to cope a changing climate (Haglund *et al.,* 2011). There are also synergies with mitigation of climate change, due to increased tree cover.

However, these innovations are only partially effective in addressing food crises. It has been found the 2004/2005 food crisis was one of inadequate buying power rather than physical shortage, because farmers could not buy grain when prices rocketed (Barbier *et al.,* 2009). Subsistence farming has been replaced by a semi-commercialised system, meaning farmers are vulnerable to market forces. Policy changes, beyond farmers' control, can exacerbate vulnerability. Credit programs, which were popular among farmers, were cancelled under 'structural adjustment' during the 1980s (Barbier *et al.*, 2009). Yet the power vacuum in the late 1980's reduced the state's capacity to interfere, enabling communities to realise that potential themselves (Sendzimur *et al.,* 2011). Systems analysis shows there was no single silver bullet, but social capital was enhanced by emergence of local oversight organisations *(ibid*). One must not assume climate variability is the main driver of adaptation, as farmers often assign economic and social factors as reasons for change rather than climate factors (Mertz *et al.*, 2009). In focus groups, farmers said most changes were caused by land shortage, as if population growth is a more decisive factor than rainfall variability (Barbier *et al.*, 2009). Yet the case of the re-greening of the Sahel shows that innovation by local people is as important as cutting-edge research (Reij *et al.,* 2009). The case shows even resource-poor societies can climb out of crisis (Sendzimur *et al.,* 2011). Locally-successful innovations are often simple and low-cost improvements that are already readily available. Furthermore, spreading local innovations requires coordination and collaboration between many different stakeholders, including governments, farmer groups and NGOs, as well as charismatic local leaders who become role models for others (Reij *et al.,* 2009).

Although confined to limited areas, flooding can destroy not only crops but also infrastructure and change entire landscapes. One traditional technology for dealing with coastal and riverine floods is the example of floating agriculture in Bangladesh (below) or floating greenhouses in the Netherlands.

Box: Floating Agriculture in Bangladesh **(Source: Various; Irfanullah, H., Pers. Comm., 2013)**
Floating agriculture has attracted attention as a traditional technology in Bangladesh, but there are concerns it is being promoted without adequate research (Irfanullah, 2013). Floating agriculture ('baira') is an age-old practice of cultivation in the southern floodplains of Bangladesh (Irfanullah *et al.*, 2011). In this system, aquatic plants are used to construct a floating platform on which vegetables and other crops are grown and seedlings are raised. The residue is recycled as fertiliser to prepare the soil for winter crop cultivation. Water hyacinth (*Eichhornia crassipes*) is the most common construction material for floating platforms. Although prevalent in the South, the technology was introduced to North-east Bangladesh by NGOs in a pilot program in 2005-6 which found floating gardening provides various benefits (Ifranullah *et al.*, 2008; Irfanullah *et al.*, 2011). Firstly, it can provide land for poor people that lack access to land, as many wetlands are submerged under flood for 7-8 months per year. Socio-economic benefits include enhanced nutritional security, increased income, and employment benefits. Agricultural benefits include early production of seedlings for winter vegetables, while ecological benefits include controlling water hyacinth which is otherwise a notorious weed, and moreover, chemical fertilisers are not required. Some farmers protected their platforms from waves using bamboo sticks or by inserting a bamboo pole as an anchor (Irfanullah *et al.*, 2011). Although the technique cannot withstand devastating floods, it can be useful during normal floods or to rebuild lives after disastrous flooding (*ibid*). Some nuances of the technology were 'lost in transfer' because piloted platforms were not used to grow seedlings, as they had been in the south. Arguably, engagement of the agricultural extension system is essential to promote the technique at wider scale, including engagement of local government to ensure access to common water bodies (Irfanullah *et al*., 2011). Shared water bodies are supposed to be accessible to landless communities, but are often captured by local elites.

The scarcity of studies on long-term impacts suggests the technology may have been given too much attention without undertaking sufficient research (Irfanullah, 2013). There are concerns about the health impacts of crops grown on floating beds, since water hyacinth absorbs heavy metals. Moreover, the floating beds may not be resilient under future climate impacts, as water hyacinth cannot survive in salty water, and the beds are weather-dependent, affected by floods or rainless spells (Pers Comm, 2013). There is a need for further assessments of long-term adoption. It is not a good option for everywhere with waterlogging, because it will not survive wave action. Despite the lack of research on resilience of the technology, the technique was listed in the Bangladesh NAPA. The Government of Bangladesh has now launched a $1.6m project for 12,000 households under the Bangladesh Climate Change Trust Fund. Yet the health and ecological concerns illustrate the need for systematic research in an evaluation phase before wider promotion of technologies, something which is yet to be done. There are various other technologies that may offer promise for the extreme poor on floodplains in Bangladesh, such as small-scale silage-making, and it has been suggested that promoting innovation among the extreme poor needs to be done with a sensitive, steady and motivational approach, rather than in a quick abrupt introduction (Khan et al., 2013).

Water hyacinth is known as an invasive weed that clogs waterways in more than 50 tropical and sub-tropical countries around the world. It costs around $700m (0.3% of GDP) to control in South Africa alone, and is expected to grow in response to climate change (UNEP, 2013). So it is possible the floating agriculture technology could be replicable elsewhere to make use of water hyacinth, if proper research is done. Health risks are posed by using polluted waterways, since water hyacinth absorbs heavy metals (UNEP, 2013). The case of floating platforms demonstrates the need for research to avoid potential maladaptation.

4.1.5. Key Lessons

From these illustrative examples of technologies for adaptation in agriculture, various key lessons can be drawn, inter alia:

- There is a need for communication of climate information and seasonal forecasts, including combining indigenous and conventional knowledge to ensure information meets locally-specific needs.
- Scaling up climate insurance will involve raising awareness of farmers, e.g. in Ethiopia, and insurance can be complementary to group risk-sharing.
- There is a need to manage agricultural water resources with an understanding of ecosystems and other local factors to avoid over-irrigation. The case of the Aral Sea shows there is a need to avoid 'groupthink' in decision-making.
- Overall, there is a need for policies to strengthen and preserve agro-biodiversity as well as diversification to strengthen agricultural production.
- In developing drought-tolerant maize in Africa, engagement with governments has been key to technology success.
- Furthermore, there is a need to recognise local knowledge, as farmer-led innovations have great potential to be replicated. Recognition of these innovations by policy-makers and implementation of supportive policies may enhance upscaling.
- Farmer-managed demonstrations are an effective way of trying adaptation measures.
- The case of floating gardens shows that research and technology assessment are needed to avoid potential maladaptation.
- Bottom-up and participatory processes can help to ensure ownership.
- The re-greening of the Sahel shows that strong local institutions are a critical success factor for adaptation.
- Spreading local innovations requires coordination and collaboration between many different stakeholders to ensure ownership, as seen in the case of the re-greening of the Sahel.

4.2. Water

People will feel the impact of a changing climate most strongly through shifts in the distribution of water across the world (UN Water, 2007). In addition to these shifts there will be a seasonal and annual variability of water distribution. Water is essential for good health, sanitation and a resource for maintaining life across the world and is therefore crucial for sustainable growth and development. Climate change, however, will alter patterns of water availability and the frequency of droughts and floods will increase over many years, as will the shrinking availability of water in certain regions of the world (Stern, 2006; Altieri and Koohafkan, 2008). There will be more rain in high latitudes and less rain in the dry subtropics. Furthermore, hotter land surface temperatures trigger more powerful evaporation and thus more intense rainfall, thereby increasing the risk of flash flooding. Already existing differences in water availability between different geographical regions will become even more pronounced in the future; areas that are already comparatively dry, such as the Mediterranean, the Middle East and parts of Southern Africa and South America are likely to experience further shortages in water supply. Figures in the Stern Review indicate a decrease of up to 30% in annual runoff in the above-mentioned regions for a 2°C, and 40-50% for a 4°C global temperature rise (*ibid*).

Approximately one-third (2.2 billion) of the global population live in countries experiencing moderate to high water stress and 1.1 billion people lack access to safe water (UN Water, 2007). Water stress is a good indicator, yet not necessarily reliable in reflecting access to safe water (potable water). According to Stern (2006), even without climate change, population growth itself, in addition to economic development, could result in billions of people without or with very limited water availability. Figures estimate that with a temperature rise of 2°C approximately 1-4 billion people will experience growing water shortages, in Africa, the Middle East, Southern Europe and South and Central America. These regions are already dependent on good water management for growth and development and additional water stress could set back the efforts made during the past decades. At the same time, other regions like South and East Asia may receive more water. This additional water could give rise to more serious flooding during the wet seasons.

Examples of adaptation strategies in the water sector are provided in the IPCC Summary for Policy Makers and include: expanded rainwater harvesting; water storage and conservation techniques; water re-use; desalination; efficiency in water-use; and efficiency in irrigation. Adaptation in the water sector provides many opportunities for what are known as 'no regrets' actions. Adaptation interventions that address issues like resilience to extreme weather events, contamination of drinking water supplies, and water resource diversification and conservation will yield social, economic and health benefits under almost any climate scenario. This section focuses in particular on technologies employed to adapt to a shrinking availability of water, including rainwater harvesting, desalination, boreholes and tubewells for domestic water supply during drought, and water management. These approaches will be discussed and case study examples are used to highlight successes and failures. Technologies to deal with flooding or water quality degradation are not discussed here but are discussed elsewhere (Elliot *et al*., 2011).

4.2.1. Boreholes and tube wells

In light of a shrinking availability of water in many countries and regions of the world, increasing household water supply (both, potable and non-potable) during drought is becoming a priority for many rural households and farmers.

Deeper tube wells and "relief boreholes" will increase resilience to drought, providing a more reliable source of water than for example springs (Elliot *et al*., 2011). Drought relief programs in rural areas therefore usually involve drilling or deepening tube wells and boreholes. Tube wells consist of a narrow screened tube driven into a water-bearing area of the subsurface. In many projects and in the literature, "tube well" is synonymously used with "borehole"; however, boreholes are more specifically defined as tube wells that penetrate bedrock with the casing not extending below the interface of unconsolidated soil and bedrock. Boreholes require a drilling with an external power source; the choice of technologies thereby depends on the cost, resources and groundwater level as well as desired water yield. A hand-powered or also automated pump can then be used to draw the water to the surface; in other cases if an aquifer has been hit, pressure may bring water to the surface (Elliot *et al*., 2011). There are usually three strategies employed to increase borehole water supply during drought – 1) drilling new or deepening existing boreholes, 2) repairing damaged boreholes and 3) development of "relief boreholes" with use restricted to drought periods.

Tube wells and boreholes are particularly important in the context of drought. Drought is defined as "a temporary aberration" in a climate pattern and is driven by variability in precipitation and evapotranspiration (Elliot *et al*., 2011). This is in contrast to aridity, which describes the climatic condition and water stress/scarcity for a given area, which reflects renewable water resources per capita. The costs of drilling new boreholes can vary widely depending on many factors; it is therefore difficult to estimate average costs globally. However, the average cost in much of Africa ranges between US$10,000-15,000; in contrast, the average cost in India is less than one-tenth of the costs in Africa.

However, inappropriate borehole development in the drylands of Africa can be responsible for damage to livelihoods and environment, while contributing to insecurity and conflict. There are several issues: (i) Differentiating between water for livestock or wildlife and water for people; most emergency water development in times of drought or famine focuses on people only, leading to the proliferation of bore holes relatively close together (for domestic purposes) but this can be catastrophic for livestock (often the dominant economy), and for the environment as it concentrates livestock and reduces mobility (leading to over-grazing, loss of livestock productivity, declining diet) (Hesse and Cotula, 2006). (ii) Discharge levels of water – motorised bore holes can pump thousands of cubic metres of water in 24 hours – suitable for people, but not for livestock as there is no relationship between the amount of water available and the amount of pasture available. A lot of water attracts many animals, but in areas characterised by seasonal (and variable) growth of pasture, there often not enough grass so animals die. (iii) Governance of water – the drylands may look empty to the outsider, but to local people every hill, plain and gully has a priority user. When new water is put it an area it immediately makes that place economically attractive so it is critical to understanding the complex land tenure dynamics and socio-political relations between different groups to ensure peaceful management of the water resources (Cotula, 2006; ACF, 2007).

Box: Boreholes in Somalia **(Source: UNICEF, 2011)**

As drought has affected communities in Somalia following the failure of the (October-December) "deyr" rains in 2011, UNICEF and other agencies installed a new borehole to provide emergency relief to the villagers. Saddex Higlo, with an estimated population of 950 families, is in north-eastern Somalia. For years the villagers have relied on water trucking from boreholes 80 -100 kilometres away to meet their household and animal needs.

To ensure that the drought–response is cost-effective and sustainable, UNICEF has been working with local and international partners in affected areas to rehabilitate and repair strategic water sources (e.g. wells and boreholes) instead of providing water trucking. For example, a borehole in *Saddex Higlo, South Mudug,* is providing almost 1,000 families with water. Previously, the village used to rely heavily on water trucking and needed 10 tankers of water daily at a cost of US$1,400. Now the people of the village will no longer have to spend lots of time and money to get water.

There is a vast range of examples, where the attempted drilling of new boreholes and tube wells has failed, for instance in this example from Machakos County in Kenya:

Box: Boreholes in Machakos County, Kenya **(Source: University of Nairobi, 2013)**
Machakos County, Eastern Kenya, has a population of approximately 1 million. Demand for water is very high and exceeds water resources available. The county experiences harsh climatic conditions and has very little vegetation. This has led to a decrease in volume of surface water availability and residents depend heavily on (under)-groundwater abstraction. Government and NGOs have helped in construction of boreholes in the area. However, borehole failure is a widespread problem in Machakos County. Some of the boreholes fail to produce water, or the water they produce is not potable. The county has 69 boreholes and a borehole failure rate of around 20%.
Borehole failure is caused by several factors:
Geology: The dominant lithologies in Machakos are metamorphic and igneous rocks, which are known to be compact and very dense and therefore do not make good aquifers.
Over-abstraction: Over-abstraction results in drops in the water table. The water table can drop to depths exceeding the depths of the boreholes in the area.
Precipitation of minerals in the aquifer: This can cause blockages and lead to borehole failure. The conditions for precipitation of these minerals are optimum when the borehole is being pumped. Therefore to solve this problem, the time for pumping water in the borehole has to be reduced.
Climate: Prolonged droughts are common in Machakos, leading to an overall fall in the water table.

4.2.2. Rainwater harvesting (RWH)

The collection of rainwater, from rooftop catchments, is an increasingly promoted technical option for supplementing household and institutional water supply, whilst RWH is used in different forms in agriculture as well. In developing countries RWH is usually used for collecting water for potable and other household uses; in more developed settings with safe and reliable piped supplies, RWH is mainly used for collecting water for non-potable uses. RWH for climate change adaptation has a two-fold function: it can be used for the diversification of the household water supplies and it can be used for increasing the resilience to water quality degradation. The storage of rainwater can provide short-term security against periods of low rainfall and the failure or degradation of other water supplies. In 2006, more than 60 million people worldwide were using RWH as their main source of drinking water; this is projected to rise to more than 75 million by 2020 (Elliot *et al*., 2011).

Box: Rainwater harvesting in conservation agriculture, Zambia (**Source: UNEP, 2011)**
Zambia's southern province has some of the most fertile soils in the country and is a key agricultural area for the country's maize belt. It accounts for over 70% of the country's cattle population in smallholder farming systems. Annual rainfall, which ranges from 400mm to 800mm, falls within four to five months. However, from the early 1980s, agricultural production has steadily declined because of drought, land degradation and other factors. By the 1990s extreme poverty, hunger and malnutrition reached unprecedented levels. The Zambian Ministry of Agriculture's Extension and Technical Services Departments, in cooperation with various other project partners, subsequently initiated training programs as well as introduced new technologies into the farming practices of Zambian farmers; this has included rainwater harvesting. Reduced tillage was the entry point. A key feature of these new planting stations/furrows was their depth - which ensured the plough pan (a

compacted layer below ploughed soil created by plowing) was "broken". With crop residue largely left on the surface, the fields had become excellent in-situ rainwater harvesting traps. During the 2002/2003 season, over 12% of the farm households were estimated to have adopted conservation agriculture. This has been estimated to involve at least 50,000 hectares.

From the farmers' point of view, some key issues underlying adoption were:
• The ability of the conservation agriculture fields to produce a crop even in years with poor rainfall;
• Elimination of stress during the first year when labour demand appears intensive; and
• The restoration of the dignity of the community through the ability to provide their own food.
Crop yields have on the minimum doubled. Maize yield rose from under 0.5 t/ha to above 2 t/ha and cotton from 1.5 t/ha to 3 t/ha with conservation agriculture compared to conventional agriculture. This has been attributed to improved rainwater harvesting, which was made possible by the planting stations and surface cover. Most farmers were able to also diversify their cropping system to include crops such as maize, beans and sunflower.

***Box: Rainwater harvesting for supplementary irrigation, Kenya (*Source: UNEP, 2011)**
Mwala Division of Machakos District, Kenya, lies within a semi-arid area and is characterized by a topography of undulating hills and seasonal streams. Despite the fact rainfall amounts and distribution rarely meet crop water requirements, rainfed agriculture constitutes 70% of rural employment and economic activities. The greatest challenge to sustainable crop production remains how to cope with recurrent droughts and prolonged dry spells. Moreover, the problem of water scarcity in Mwala is exacerbated by salinity of ground water, distant location and contamination of surface sources.

Interventions on rainwater harvesting in Mwala are based on runoff catchment schemes and the water is channeled into small underground reservoirs, either communally or individually owned. The success of the scheme relied on the fact the community is organized in groups which contributed to the resources for construction of the tanks. The catchment area could either be homesteads or terraces and often the land would belong to neighbours upslope, as well as runoff diversion from existing paths and roads. Mitre drains then direct runoff into the underground tanks, with silt traps and trenches to reduce sediment inflows just ahead of the pipe, which finally leads the water into the storage tank. The underground tanks have various designs to suit site and economic conditions. They include spherical, sausage, plastic-lined tanks, with capacities ranging 30-70 m3. Water either gravitates or is pumped to the fields. Harvesting runoff water for supplemental irrigation is a risk-averting strategy, pre-empting situations where crops have to depend on rainfall whose variability is high both in distribution and amounts. By using underground sausage or spherical tanks in cascades having a combined capacity of 60 m3, seasonal water for supplemental irrigation for an area about 400 m2 is guaranteed. Supplementary irrigation increased crop yields by 20%. With rainwater harvesting, farmers have diversified to include horticultural cash crops and the keeping of dairy animals. For instance US$ 735 (per ha) compared to US$ 146 normally earned from rainfed maize. This has contributed to food security, better nutrition and family income.

4.2.3. Desalination

Over 97% of the water on earth is unsuitable for human consumption due to its salinity. The vast majority (approximately 99%) of this is seawater, with most of the remainder consisting of saline groundwater (Elliot *et al*., 2011). Purification/desalination of these water resources could provide coastal areas and countries with an unlimited supply of water resources. Desalination is the removal of sodium chloride and other dissolved constituents from seawater, brackish waters, wastewater, or contaminated freshwater. More than half of the world's desalination capacity lies within the Middle East and North Africa. Desalination can result in two "streams" of water: pure water and waste stream or brine to be used in households, agriculture, tourism and industry. Approximately 75 million people worldwide rely on desalination and that number is expected to grow as freshwater resources are stressed by population growth and millions more move to cities with inadequate freshwater resources. Although technological advancements continue to decrease the economic and environmental costs, desalination is expensive, energy-intensive and often leads to negative side effects on local ecosystems. Moreover, where fossil fuel resources are used as an energy source, the energy consumption of desalination technologies can contradict mitigation objectives.

***Box: Desalination Plant in Torrevieja, Spain* (Source: Palomar and Losada, 2010; Cala, 2013)**

The award-winning €300m ($438m) desalination plant at Torrevieja on Spain's arid south-east coast is Europe's largest facility for converting seawater into freshwater, and the second biggest in the world. However, neither the pipes to the sea nor the power transmission lines have been approved or built. Even if it does begin to process seawater, the product may be so expensive nobody will be able to afford it.

Co-finance by Spain and €55m of European Union regional development funds, the Torrevieja plant has been challenged on environmental and financial grounds repeatedly. The plant has fallen victim to intense political rivalry between the Spanish Socialist party, which runs the national government in Madrid, and the rightwing Popular party, which controls the Valencia autonomous region and Torrevieja's town council.

4.2.4. Water management fora

Historically and at the time of writing, heavy agricultural subsidies, extremely low water tariffs and import restrictions in many countries provide little incentive to use water more efficiently and to switch to more sustainable agricultural activities, *i.e.* to abstain from growing water-intense fruits such as bananas and strawberries, usage of different crops and lower quality water, *i.e.* grey water (Starr, 1991). Over-use of water will have to be eliminated by stopping illegal underground water drilling and reducing production and export of water-intensive agricultural products. However as shown in the case study of Jordan, below, forums that bring together water users, policy makers and experts can enable feasible options and alternatives to be discussed. Moreover, participation and stakeholder engagement can enable comprehensive action plans to be developed.

***Box: Highland Water Forum in Jordan (GIZ)* (Source: Haddadin et al., 2006; Glatzel, 2013)**

The 'Highland Water Forum', which was initiated in 2010 by GIZ and the MWI, aims at bringing together policy makers, private sector companies, farmers, international organisations, academics and customers to discuss feasible options and alternatives to make agriculture and domestic water usage more sustainable. Twenty prominent farmers of the Azraq region were identified and asked to nominate their most influential peers to participate. One of the main aims of the Forum is to draft a comprehensive action plan including measures to limit unaccounted for water and to reduce illegal abstractions from aquifers. Farmers indicated a readiness to abandon cultivation of crops that consume large amounts of water and initiate projects to preserve aquifers from depletion while generating more income. However, farmers lack the technical and financial resources to shift from water-intensive cultivation and inefficient irrigation systems to environmentally sustainable and economically feasible investments.

Although awareness of water scarcity appears high, willingness to reduce water consumption remains low. This is due partially to societal factors, including a lack of education in remote, rural areas and fear of lack of alternatives. Many farmers in Jordan have traditionally grown water-intense fruits and vegetables and appear reluctant to change to less water-intense crops; according to GIZ this is mainly due to the concern that switching production will yield less revenue and hence decrease welfare. GIZ, however, found that if there were adequate alternatives and support from Government, farmers would be willing to switch. Poor and antiquated technologies result in inefficient usage of water in irrigation, but one-off payments for new technologies can often not be afforded by small farmers. Initiative's such as JOHUD's and GIZ's 'Water Wise Women' aimed at educating women in rural and remote areas to use water more consciously and efficiently and to incentivise behavioural change. According to JOHUD, the project was received well by local communities; but challenges such as water theft, which is common with some tribal groups, remains a problem that has yet to be dealt with and so is poverty. Taking Jordan's economic situation into consideration, public funding will not be available for such projects and it was highlighted in several interviews in Jordan that heavy reliance on development aid from "friendly countries" is not acceptable over the long-term. Thus, the private sector in this context was seen, by many interviewees, as to provide the necessary technologies and investments – in the form of PPPs or individual company investment – for this shift to become feasible and to close the funding gap in climate change adaptation technologies.

4.2.5. Key Lessons

From these examples of technologies for adaptation in the water sector, various key lessons can be drawn, including:

- Rehabilitating and repairing strategic water sources (e.g. wells and boreholes) instead of providing water trucking has proven more cost-effective and sustainable, as well as more time-saving and affordable for farmers.
- In the context of surface water scarcity boreholes offer an alternative to facilitate groundwater abstraction. However, borehole failure is common and factors including the geology, precipitation of minerals, climatic conditions and over-abstraction have to be considered.
- In drylands, over-grazing around boreholes can be an issue; thus it is important to understand water requirements for livestock, wildlife, and humans, as well as considering governance and land tenure dynamics. There is a need to consider abstraction, distribution and utilisation issues.
- Rainwater harvesting allows farmers to diversify to include horticultural cash crops and the keeping of dairy animals.
- In the case in Spain, desalination was not a cost-effective solution to provide freshwater to individual consumers and farmers.
- Bringing together all stakeholders involved in the development of water policies and strategies provides policy makers with more legitimacy, as stakeholders feel they are involved in decision-making and are able to raise concerns or make suggestions.

4.3. Infrastructure and Settlements including Coastal Zones

Infrastructural adaptation technologies are utilized to provide large-scale and wide-reaching responses to climatic impacts. There is a particular focus upon coastal technologies, in reaction to the immediate threats faced by communities residing in these areas, resulting from sea level rise (SLR), storms and tsunamis (Gedan *et al.*, 2011). These climatic impacts cause increased shoreline erosion and higher rates and intensity of flooding, the effects of which are likely to be heightened by intensifying human activity (IPCC, 2007; Zhu *et al*., 2010). Whilst the impacts are variable in different coastal areas, the interrelation of ecological events also means that transformation in one area can have secondary impacts in another. Hence, vulnerability in coastal areas can be increased through a variety of climatic pathways. Coastal zones are also the target of much adaptation and development activity due to the wide array of livelihood resources that they encompass (Marfai, 2011). However, the installation of hard structures in coastal areas is not always effective and can prevent patterns of natural coastal change such as inland migration (Zhu *et al.* 2010).

The 2010 UNEP TNA Guidebook for coastal adaptation technologies details various technological approaches to adaptation (Zhu *et al.,* 2010). Here, the technologies are grouped under three separate adaptation approaches, including protection approaches (e.g. beach nourishment, seawalls and storm surge barriers), accommodation approaches (e.g. wetland restoration, flood hazards mapping and flood warnings) and retreat approaches (e.g. managed realignment and coastal setback. Furthermore, informational adaptation for coastal zones is assisted by various information technologies and tools such as geographic information systems, integrated modelling and flood simulations (IPCC, 2007). GIS is an example of a tool that can contribute to all four steps of the adaptation process (information, planning, implementation and monitoring) (Klein et al., 2001). Under the IPCC (2007) and the UNFCCC (2013), the most prioritized of these coastal technological adaptation strategies are found in wetland restoration, seawalls, community-based early warning systems and beach reclamation. Such technologies require supportive policies that reflect consideration for climate change (IPCC, 2007). Their use and adoption is primarily hindered by financial and technological constraints, whilst they can also provide opportunities through harmonizing with development goals and integrating appropriate policy with the management of such infrastructure (IPCC, 2007). Examples of these technologies are found around the world, some with more success than others, dependent on the ecological, social and economic context of their installation and maintenance.

4.3.1. Wetland restoration

The predictions for coastal wetland destruction in the face of climatic change are significant (Gedan *et al.*, 2011). However, the vegetation of such areas provide natural protection for coastal zones through direct and indirect mechanisms. As such, their conservation and restoration creates a buffer against coastal climatic impacts such as sea-level rise, flooding and storm surges (IPCC, 2007). Moreover, stimulative activity enhances biodiversity, regenerates ecosystem services and provides benefits for poor local communities (Fistrek, 2010). In increasing coastal sedimentation, providing a buffer zone and enhancing existing resources, this natural technology offers a more viable economic option in comparison to manmade infrastructure (Gedan *et al.*, 2011; McIvor *et al.*, 2013; Russi *et al.*, 2013). Wetland restoration arguably constitutes a 'no regrets' measure with benefits regardless of climate change (Zhu et al., 2010). However, it should be noted that protection in the case of extreme events cannot be achieved in isolation by these natural buffer zones (Gedan *et al.*, 2011). As such, their integration with additional coastal protection measures is sometimes considered. Examples of this are found in the pairing of wetland restoration projects with large infrastructure, such as seawalls and breakwaters, and smaller infrastructure that is designed to reduce the impact of incoming waves, such as oyster domes and reef balls. These can provide a successful and sustainable protective solution, though more evaluation research is required to assess their potential (Gedan *et al.*, 2011).

A prominent example of wetland infrastructure is found in mangrove development. Siltation build-up resulting from mangroves causes coastal surface elevation matching that of sea-level rise. Hence, alongside contributing to carbon sequestration, mangrove forests offer sea defenses that protect coastal zones from climatic impacts (Persaud, 2011). Whilst purposeful generation and restoration of mangrove forests can provide a viable technological adaptation option, it should also be ensured that existing forests are protected from anthropogenic damage (McIvor et al., 2013).

Box: Mangrove Restoration in Guyana **(Saywack, M., Pers. Comm., 2014)**

In 2009, the Government of Guyana (GoG) introduced a new Sea Defence Policy to restore the coastal belt. This recognized the need for alternative protection methods to use in combination with the existing seawall. The mangrove forests along the coast of Guyana provide significant defence against the increasing impacts of climate change, found in heightened tidal impacts and significant sea-level rise (Ackroyd, 2010). Over the past 50 years, the once heavy coverage of mangrove species has been critically diminished through both natural and anthropogenic activity. As such, efforts are being made to restore the forests, in order to maximize ecological and protective benefits. The Guyana Mangrove Restoration Project was initiated in 2010. It sought to provide a low-cost, low-regret solution to provide coastal protection. In doing so it has provided some steps towards coastal adaptation, yet due to the expected impacts of climate change expected, this solution is only viable for the next 10-20 years. The pilot project focused on 12km of the coast, and more than this is now protected through a combination of hard and soft technologies. The project has sought to aid coastal adaptation through trapping sediments to strengthen the shoreline and raise the land above the sea level. Moreover, mangrove development on the coastal side of the seawall was perceived to provide the benefit of reducing wave impact on the seawall itself.

Though these primary objectives have largely been successful, challenges have been experienced with regards to community involvement, legislation and its enforcement and, in some parts of the coast, environmental suitability. Communities were consulted from the inception of the project through women groups who were involved in the planning and management of the mangrove area. In addition, incentives for involvement were offered, such as restoration of community services (e.g. play areas) when mangrove conservation activities (e.g. awareness raising) were conducted. Yet, some community groups have already lost interest in this, and their long-term involvement is doubted, particularly due to the lack of funding available after completion of the project in 2014. Moreover, indigenous communities exploit mangrove resources for small-scale livelihood activities such as bark harvesting for leather tannin. Though alternative livelihood options are offered, they are not economically competitive and so local-level stakeholders are not interested and mangrove conservation is hindered.

Legislative gaps further hinder the protection of mangroves. No specific legislation to protect mangroves exists. The amended Forest Act of 2009 recognizes the protection of the mangrove species itself, but not of the system within which they are developed. Though this has been noted by many, no moves have been made to change related policy. The legal framework in existence to aid mangrove protection is not enforced due to a lack of political will to follow pit through on the ground.

Though the destruction of mangroves has been made illegal, no one has yet been charged for such activity and economic exploitation continues.

The major lesson learnt from the project was with regards to suitability for the environmental context. It was quickly established that planting in areas where the mud elevation was unsuitable led to the washing away of mangrove seedlings. Since most of the sites were subject to erosion, the need to establish the right mud elevation prior to planting was a major challenge. To address this, several techniques were tested. They include planting coastal grasses, such as Spartina, to facilitate the stabilization of sediments and natural entrapment of mangrove seedlings; installing fences to stop animals grazing on the mangroves and supportive vegetation, and; establishment of coastal engineering structures, such as geo-textile breakwaters and low cost brushwood dams, to reduce wave energy and facilitate accretion of sediment. These approaches have shown significant success in encouraging natural mangrove growth. However, in applying this technological method to other areas, knowledge about the level of high tide and height of the land should be gained, and costs should allow for raising the land where needed.

In the context of coastal Guyana, it has been recognized that this hard and soft combinative approach to coastal protection is not the best long-term option. The high SLR expected mean that the mangroves will need to migrate inland. Yet this natural migration is blocked by the presence of the seawall. As mangroves cannot survive in saline water, the sustainability of the mangroves, and subsequently the seawall also, is questioned.

Careful planning is crucial to achieving success in mangrove regeneration. A complex relationship between different mangrove species, the surrounding environment and adjacent infrastructure exists (Ackroyd, 2010). As such, sustainable rehabilitation of mangroves relies upon an intricate understanding of the specific ecological context within which development is occurring. As in the initial assessment process in Guyana (above), natural and manmade technologies can be combined to ensure adequate planning and monitoring of mangrove development. In addition, planning requires collaboration between all stakeholders involved, with a particular emphasis on the community within which the project is being implemented. Hence, restoration endeavours must account for the social, as well as the ecological and economical context of the project (Fistrek, 2010). Such acknowledgement should start from the planning phase of the project.

4.3.2. Seawalls and Storm Surge Barriers

The construction of storm surge barriers can serve to provide a strong coastal flood barrier, providing physical protection for both land and buildings. Such hard technologies include seawalls, sea dikes, revetments, armour units and breakwaters (Zhu *et al.,* 2010). However, whilst they provide a logical and tangible defence, these installations require much consideration for the context within which they are built. They reduce the recreational attributes of coastal areas by dominating beach areas and reducing the natural dynamics. Furthermore, in disrupting natural erosion patterns, they present an environmental threat. In response to some of these problems, a combination of technologies could be used to gain the benefits provided by storm surge barriers whilst also reducing the negative impacts (Zhu *et al.,* 2010). An example of such an approach includes the combination of beach nourishment with seawalls. This would reduce the impact of recreational and environmental side effects (although beach nourishment incurs its own environmental impacts, as is discussed below).

Moreover, unintended 'indirect effects' of adaptation are possible; for example embankments may protect one community but increase vulnerability for another community (Atteridge and Remling, 2013). For example, in the Mississippi River in the US, levies were intentionally breached in one area during the record-breaking flooding in 2011 in order to save a more populated area from flooding. Some kinds of adaptation technologies, like sea walls, when deployed in one location might exacerbate adaptation in other areas, in essence shifting the vulnerability from one place to another (more likely from richer to poorer), which can be described as spatial spill-overs or 'vulnerability redistribution'. Adaptation technologies and policies must take account of these wider effects on other groups and places, if they are to avoid undermining the goals of sustainable development (ibid).

Alongside environmental and social barriers, storm surge barriers are economically demanding, both in the immediate installation period and in the upkeep required for long-term sustainability (Zhu *et al.,* 2010). Whilst seawalls and other barriers provide protection against storm surges, planning needs to account for the possibility of extreme events in order to ensure protection at times of disaster. The unavoidable costs can lead to corners being cut in construction of seawalls resulting in inadequate protection against extreme events. This situation was exemplified in Japan in 2011. Here, a well-constructed and wide reaching seawall failed to provide protection when a tsunami struck (see below). The high costs associated with planning for irregular but extreme events meant the seawall provided inadequate protection for much of the coastal area. Assessment since this event has indicated that in addition to a lack of planning for such events, the structures needed improvement and upkeep following their initial construction (Kato et al., 2012; Mikami et al., 2012; Ogasawara et al., 2012). Though such failures should provide the opportunity to learn from experience, in Japan, isolated focus on the physical structure in tandem with a disregard for the social and environmental context indicates the new seawall could lead to further catastrophe.

Box: Rebuilding the Japanese Seawall **(Seino, S., Pers. Comm., 2014)**

The first seawall in Japan was built in the 1970-80's after a huge typhoon in the 1960's caused widespread destruction, alerting attention to the need for protection. It was built following a government scheme and covered half the coastline, destroying the ecological balance and recreational merits of these locations. Though damaged through wave impact in the years after its construction, this seawall provided protection against small-scale coastal events.

However, when the Eastern Japan Great Earthquake Disaster occurred in 2011, a Tsunami 40m in height was incurred, against which the seawall could provide very little. Damages were incurred not only from the strength of the wave itself, but from the huge water mass that was brought inland. Following the loss of lives, families, houses and other property a huge increase in poverty has occurred amongst coastal communities. In an attempt to boost the economic circumstances of communities, local governments began to buy up the coastal zone belt. As such, local communities have been forced to move elsewhere. There are no policies to support this shift in land ownership and decrease in community land tenure and as such, huge social disruption has inadvertently resulted.

In the year after the disaster, a new sea wall was planned, construction of which began in 2013. A complicated management system has been used, wherein responsibilities are divided between the national government, local governments and private representatives. No citizen groups were involved in reflection of their lack of ownership of coastal land. The national government created a basic scheme for construction, producing guidelines on which local governments acted upon to restore the sections of the seawall under their geographical scope.

Many problems with regards to this new infrastructure have already surfaced. Though knowledgeable in their field, the engineers employed by the local governments to construct the seawall, lacked details of the local-level site geology, wave action, historical culture and specific context of the beach upon which they were building. Environmental destruction has been heightened due to the lack of an ecological element to the disaster scheme. The large scale of the seawall has disrupted the ecological habitat and made fresh water wetlands that have been exploited for 400 years for growing rice unusable. In addition, ancestral lands have been lost. The approach taken also means that the new seawall is not sustainable. Though the new sea wall was primarily built for disaster reduction, it was also built in the same location in an attempt to sustain the existing shore line. It is a hard structure built on sand and therefore much groundwater passes through the foundations of the seawall causing much weakening of the seawall. Hence, it is a hard structure only, which offers no compatibility with the environmental and social context within which it is built.

The disaster event in 2011 alerted the attention of a wider range of experts to the need for effective and sustainable coastal adaptation plans, providing incentives for collaboration across sectors. Yet as this heightened awareness is not reflected in the planning approach taken, problems are unavoidable. Moreover, there is no public rescue system for the people who remain inhabiting the shoreline. It is expected that if another disaster such as a tsunami or earthquake effects Japan, much suffering will be incurred despite the seawall. Hence, communities require alternative adaptation options. Most effectively, this would be the migration of communities to mountain areas. In the absence of this option, however, it has been suggested that a buffer zone along the coast is required, alongside a setting back of human territories.

4.3.3. Community-Based Early Warning Systems

Early warning systems seek to combine and disseminate climate and response knowledge to provide communities and individuals with the necessary information to respond to the threat and the occurrence of climatic hazards (DKKV, 2010). They demand the capacity of both the informers and the audience to quickly digest and respond to the information provided in order to reduce the extent of harm to lives and livelihoods. The use of early warning systems is particularly prominent in the case of extreme coastal climatic events such as storm surges, tsunamis and cyclones. Experiences gained from a fairly substantial history of use around the globe, in Europe, Australasia, Africa and Asia, can highlight shared lessons (UNISDR, 2010).

Firstly, for early warning systems to function adequately, they must be community-based. An initial assessment of community needs should direct the approach taken in initiating and updating early warning system (UNISDR, 2010). This people centred approach can also ensure sustainability and effectiveness. Systems tend to be reliant upon volunteers residing within affected communities to assist in gathering and disseminating relevant information. This demands a wide comprehension of their significance and purpose throughout the community within which they operate in order that not only individuals implementing warning and response measures, but also the intended audience, comprehends warning implications and, as such, responds appropriately (Tompkins *et al.,* 2005). Using simple technologies that are easily adopted by those likely to be affected enables both effective information sharing and effective action. As such, a combination of training exercises, education and awareness raising better prepares communities and reduces their vulnerability to natural hazards (UNISDR, 2010). Language barriers between different parties must be addressed according to each specific context *(ibid*). Whilst visual aids have proven to provide much success, consistency is needed to avoid ambiguity. Integrated and ongoing training processes can also enhance community motivation for involvement and increase capacity for improving and updating systems. Hence, community participation is crucial in all aspects of early warning systems, from the planning and management stages to the response at times of climatic emergency (UNISDR, 2010).

In addition to this community focus, collaboration between national and local government bodies and individuals, relevant experts and the user community must be established. Supportive technical measures such as satellite weather forecasting should be addressed and strengthened through an ongoing, collaborative process with appropriate stakeholders (UNISDR, 2010). Additionally, government bodies, urban planners and coastal management officers can help to ensure that the climatic events publicized through early warning systems can be responded to with early actions (IFRC, 2002; DKKV, 2010).

Such early actions include both preparations for these events in the form of preventative and protective activities, as well as speedy and effectively assessed responses at the time of warning. Associated preparative measures can include mitigation activities, designed to reduce the effects of such events, and infrastructural installations, such as roads and cyclone shelters. In the case of the latter, infrastructure must be adequate to allow access and use for all of those within the catchment area. As such, the 'early' element of early warning systems fits into a broad multi-stakeholder preparation and response mechanism, which must be combined with widespread capacity building and knowledge raising activities amongst all involved parties that focuses not only on the short term-response but the longer-term use and significance of systems. Investment in these improvements is critical, and significantly, it is widely indicated that the costs of pre-disaster mitigation and preparation much outweigh the costs of recovery and rehabilitation, and as such, should be ensured (UNISDR, 2010).

Though much progress has been made with regards to the initiation and application of community-based early warning technologies, strengthening remains a requirement in the most vulnerable areas. The national adaptation programmes of action (NAPAs) that have been initiated in many of the LDCs reflect that this is a pressing issue for most vulnerable regions (DKKV, 2010). Analysis of the use of early warning systems in the urban contexts of Padang and Semarang in Indonesia have revealed the need for vulnerability monitoring including assurance of comprehensive dissemination of the risks and appropriate responses, appropriate infrastructure to allow such adequate responses, integration of a range of actors including those involved in emergency preparedness and response alongside those focussing on the long-term needs to allow such a response (DKKV, 2010). Such insights indicated that early warning systems should be used for fast and slow onset climatic events, accounting for multiple hazards rather than focussing on the singular. Hence co-ordination between and within sectors is crucial.

***Box: Bangladesh's Cyclone Preparedness Program* (Source: Khan, A.L., Pers. Comm., 2013)**

Bangladesh exemplifies much success in employing a community based early warning system as an effective adaptation technology. The Cyclone Preparedness Program (CPP) instigated by the Government of Bangladesh (GoB) and the Bangladesh Red Crescent Society (BDRCS) was officially established in 1971. The government provided administrative and operational costs while BDRCS provided equipment and technical support. Initially the program sought to use radios to warn of disasters. However, the provision of radios for the masses was not a feasible option as the ability to repair the radios and source batteries was limited. Moreover, it was found that there was increased confidence in information when it came from a known member of the community rather than an unknown source in a centralized location. Therefore, a system based on community volunteers that disseminated disaster warnings via megaphones and flag signals was adopted as a more sustainable option. This system is the basis of the CPP that is in operation today.

Community-level enthusiasm was immediate due to the huge personal losses incurred by frequent exposure to extreme climatic events in coastal Bangladesh. Therefore, community involvement is widespread and includes 65,000 early warning volunteers, who are divided into three specialized groups, consisting of first aid, search and rescue, and evacuation. The volunteers receive information from the GoB's Comprehensive Disaster Management Programme (CDMP) and organize meetings and simulations to ensure widespread involvement, understanding and preparedness within the community. The origin of the volunteers from within the community maintains confidence in the system, and heightens comprehension through dissemination of information through local dialects and communication strategies.

Despite much success, some social constraints to this approach remain, in terms of both evolving attitudes and traditional customs. New attitudes towards offering voluntary services have resulted in less enthusiasm to commit time for prioritizing livelihood activities. CDMP are addressing this obstacle by providing both livelihood and early warning training for volunteers, simultaneously. An increase in female volunteers reflects a change in social attitudes and progression in development goals. However, traditionally women move to their in-laws home when they are married, meaning that communities with female volunteers are likely to have to find replacements. This requires further selection and training processes, delays in which can leave communities without volunteer services for some time. These problems inherent to ensuring a steady volunteer service point towards the issue of sustainability, which was highlighted as the most important lesson learnt from the CPP. This year 60% of the volunteers had to be replaced for various reasons. In reaction to this, it has been suggested that a volunteer badge be awarded to scouts who attend and pass training and examinations. These young community members can then become active volunteers within their communities.

Though the long history of the early warning system brings with it many advantages, including widespread use, effective stakeholder collaboration and adequate policy support, it also leads to problems related to renewing and updating outdated elements. Problems in amending the signal system are experienced. For example, in the city of Chittagong, the original signals were centered on protecting the port and as such, are related to the direction in which the storm is approaching the port rather than the strength of the storm itself. In recognition of this, the system is being currently being changed so that it is the same throughout the country. However, as original systems are ingrained into community behavior, times of transition can pose danger due to misunderstood signals. Hence necessary updates to the system require detailed planning and supported implementation.

In addition to updating current practices, the system is also being strengthened through the application of complimentary mobile phone technology. New activities will allow access to weather forecasts and immediate signal updates via SMS. However, limitations in the length and languages of messages sent are currently hindering the potential of such activities. In reaction to this, a system of symbols is being trialed in Cox's Bazaar area, and an effective service is to be launched in June 2014. In order to ensure storm signals reach fishermen who are outside of the network area, CDMP, in collaboration with the GoB, Bangladesh Meteorological Department and the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia, are developing a satellite system that can broaden the reach of these technologies. The positive experiences gained from the CPP are being employed to inform a Flood Preparedness Program. This seeks to address both slow and fast onset climatic events through training community groups in both cyclone and flood preparedness. As such, the community based early warning system in Bangladesh has potential to be scaled up within Bangladesh, and lessons learnt can help strengthen the resilience of coastal communities worldwide.

4.3.4. Beach reclamation

Beach reclamation involves the enrichment, nourishment and replacement of existing beaches from alternative sediment sources in order to reinforce natural protection attributes. The most common method is found in offshore dredging, though land-collection is also used (Zhu *et al.,* 2010). This technology offers an effective solution to coastal vulnerability, with the advantages of being flexible and reversible. Integration of this technique with harder technologies, such as storm surge barriers, can enhance its protective effectiveness, yet such combinations will nullify the flexibility offered by using beach reclamation in isolation (*ibid*).

Though beach reclamation is popular with advocates of conservation and eco-tourism, the approach can include destructive processes, which are often not immediately apparent or visible (Widayati *et al.,* 2007). A critical problem lies in the source of the sediment being used for nourishment. The imbalance created by removing sediment through unnatural processes from one location may cause problems in the location from which the sediment is derived. Hence, planning must account for the specific ecological contexts within which such activity is occurring and specialist contractors and equipment employed alongside localized knowledge and public awareness (Zhu *et al.*, 2010).

Any beach reclamation approach must address the root cause of coastal erosion, which can be both natural and anthropogenic, if it is to achieve long-term success (Kim *et al.,* 2008). Continuation of erosion processes, particularly natural ones that cannot be hindered or controlled, dictate that for beach reclamation to be successful, ongoing and regular monitoring, maintenance and engineering should be conducted. Moreover, the long-term continuation of beach reclamation activities should be flexible to the changing ecology of the site concerned. This extra necessity comes with extra cost, and can therefore provide a critical barrier to both the implementation and the sustainability of such projects.

Box: Beach Reclamation at Songdo Beach, South Korea

Songdo beach in South Korea provides an example of a long-term beach nourishment project. The First Coast Repair Project was established in 2000 in acknowledgement of the detrimental effects of wave action on the recreational use of the beach (Lee *et al.* 2013). Within this project, the impact of incoming waves on beach erosion was reduced through the installation of two submerged breakwaters. These also served to trap beach sand that had been eroded and would otherwise have been carried away by the current. In addition, protection was heightened through the construction of an artificial reef (Widayati *et al.,* 2007).

Monitoring of the process has provided critical lessons that can inform beach nourishment activities around the world. It has been found that a stable reclamation program at Songdo beach is not appropriate, due to the changeability of erosion processes. Instead, long-term effectiveness of a re-nourishment program must be flexible to the strength and frequency of incoming storms. The differentiated impacts of different storms incur irregular erosion, meaning that a standardised method of nourishment will not be adequate (Lee *et al*., 2013; Widayati *et al.,* 2007). Monitoring and investigation have indicated that any beach re-nourishment project must fit into a larger coastal management plan (Widayati *et al.,* 2007). Hence, sites in which such adaptation technology is being implemented cannot be treated in isolation, but must be considered as part of a wider picture of adaptation, resilience and development.

This holistic approach is advocated elsewhere as an advantageous direction for coastal adaptation. Integrated Coastal Zone Management (ICZM) is an approach aiming to utilise a range of interdisciplinary knowledge and awareness in achieving adaptation in coastal areas (Zhu *et al.,* 2010). ICZM is an adaptive management process that is flexible and informed by iterative learning. The approach involves collaboration between multiple stakeholders who govern, research and use coastal areas, to prevent unsustainable action by accounting for both the economic and environmental aspects of management strategies. ICZM should be considered from the start of the planning stages and it is recommended that technology implementation should take place in this framework (*ibid*), so that the use of coastal zones is maximised in the face of both climatic and non-climatic impacts.

4.3.5. Key Lessons

From these examples of adaptation technologies for infrastructure and settlements including coastal zones, various key lessons can be drawn:

- The case of wetland restoration shows that conservation and restoration of natural vegetation can provide a low-cost, no-regret buffer against coastal climate impacts.
- Seawalls and other hard structures can have unintended negative side effects, like shifting vulnerability from one place to another. Moreover seawalls need regular maintenance and can fail, thus requiring consideration of the social and ecological context in which they are built.
- Sustainability of technologies relies on local level and community enthusiasm and involvement alongside an in-depth understanding of the historical, environmental, political and social context. As an example, collaboration between all stakeholders and community engagement has been integral to the success and sustainability of the cyclone early warning system in Bangladesh.
- Coastal zones represent changeability and flux in their ecological character and the technologies used for adaptation must be reflective of this by themselves being flexible to the changing environment.
- Future environmental impacts induced by climate change may be greater than previously experienced and therefore the design of technologies cannot be based purely on historical patterns but must instead incorporate consideration of the more extreme predictions for future climate change impacts.
- Coastal adaptation technologies should fit into a wider coastal management plan, as for the case of beach reclamation at Songdo, whilst also incorporating the above lessons from the initial design phases in order to ensure feasibility.

5. Enablers and Barriers for Successful Implementation of Technologies

This section identifies enablers and barriers for the successful implementation of adaptation technologies, taking into account that the respective nature and attendant characteristics of enablers and barriers may very well differ depending on the applicable level at which the technology is adopted, and the contextual differences between adopting entities at the same level. The section takes into account the findings from the 'Third synthesis report on technology needs identified by Parties not included in Annex I to the Convention' (UNFCCC, 2013). Barriers and enabling factors are identified for technologies for adaptation that have been noted by Parties, drawing out any commonalities or unique barriers. There have been progress and challenges at different stages of the technology cycle, right from the stage of R&D, to commercialisation and diffusion. Finally, the section considers the importance of an enabling environment for the application of technologies for adaptation in agriculture, water or coastal zones.

In assessing barriers to adaptation technologies, it is important to recognise there are limits to adaptation technologies. For example, there are physiological or bio-physical limits to adaptation, such as upper temperature limits for heat tolerance of plants or animals. Barriers can be defined as "mutable obstacles" whereas existing limits can be defined as "absolute obstacles" (Kolikow et al, 2012). Moser and Ekstrom (2010) argue that barriers to adaptation are different from limits in that they are obstacles that can be overcome with, for example, concerted effort, creative management or changing thinking. Barriers are also dynamic, as possible adaptation options change due to technological innovation or changing socio-economic circumstances. Hence, an absolute obstacle can become a mutable obstacle over time, for example, due to innovation of crop varieties. There are human and informational resource-based limits relating to knowledge, technological and economical restrictions, as well as normative and cognitive barriers (Jones, 2010). Psycho-social barriers to adoption of adaptation technologies also exist, for example, a farmer will not adopt a strategy if they perceive the marginal cost of adoption exceeds the marginal benefit (Kolikow et al., 2012). In summary, adaptation and technologies co-develop in a dynamic field in which socio-economic conditions change in response to technology; and adoption of technology depends on a range of factors (social, biophysical, economic, legal, etc.).

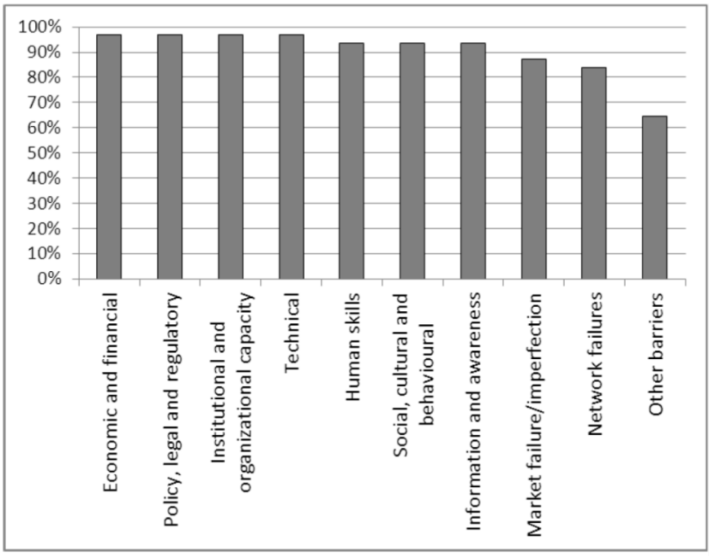
In identifying barriers, UNEP (2012) subdivides technologies into the categories of market goods (consumer goods and capital goods) and non-market goods (publicly-provided goods and other non-market goods). According to UNFCCC (2013) many technologies for adaptation fall into the categories of consumer or public goods. Consumer goods include seed varieties, which face barriers at all steps in the supply chain (UNEP, 2012), while public goods include sea walls or early warning systems. However these categories are bias towards 'hard' technologies in market economies, since many 'soft' technologies, such as farming practices for soil and water conservation, do not easily fall into these categories as they are not traded products but are rather practices that are learnt and adopted.

5.1. Barriers and constraints to successful implementation

More than 70 non-Annex I Parties have completed their Technology Needs Assessments (TNAs) and there have been three synthesis reports on technology needs identified by non-Annex I Parties. The third synthesis report found that many of the Parties identified barriers and enablers using tools such as logical problem analysis, problem trees and market mapping (UNFCCC, 2013). When assessing the barriers to prioritised technologies within the prioritised sectors, most Parties followed the guidelines from the guidebook on ‘Overcoming barriers to the transfer and diffusion of climate technologies’, including classifying barriers according to Annex A (UNEP, 2012). UNEP (2012) notes that it is important to identify which barriers are only symptoms of problems, and which are real problems. For this purpose, it was recommended to use a root cause analysis or Logical Problem Analysis.

In the third TNAs synthesis report it was noted that almost all Parties (97 per cent) identified economic and financial; policy, legal and regulatory barriers; institutional and organizational capacity related; and technical barriers to the development and transfer of prioritised technologies for adaptation (UNFCCC, 2013). Within the category of economic and financial barriers, most Parties (90 per cent) identified lack of or inadequate access to financial resources as the main barrier (UNFCCC, 2013). Of policy, legal and regulatory barriers, the most common barrier was an insufficient legal and regulatory framework (85 per cent) (UNFCCC, 2013). In the category of institutional and organizational barriers, the most commonly-reported barrier was limited institutional capacity (90 per cent), while in the category of technical barriers the most commonly cited barrier was system constraints (68 per cent) (*ibid*). Some TNAs referred to issues relating to intellectual property rights (IPRs), mainly in relation to economic and financial barriers, such as the cost implications of obtaining access to certain technologies (UNFCCC, 2013). IPRs were also raised in relation to policy, legal and regulatory barriers and some also identified a lack of experts in negotiating IPR contracts as a barrier to transfer and diffusion of prioritised technologies.

An overview of the barriers to technology for adaptation identified in Parties’ technology needs assessments (TNAs) (Source: UNFCCC, 2013)

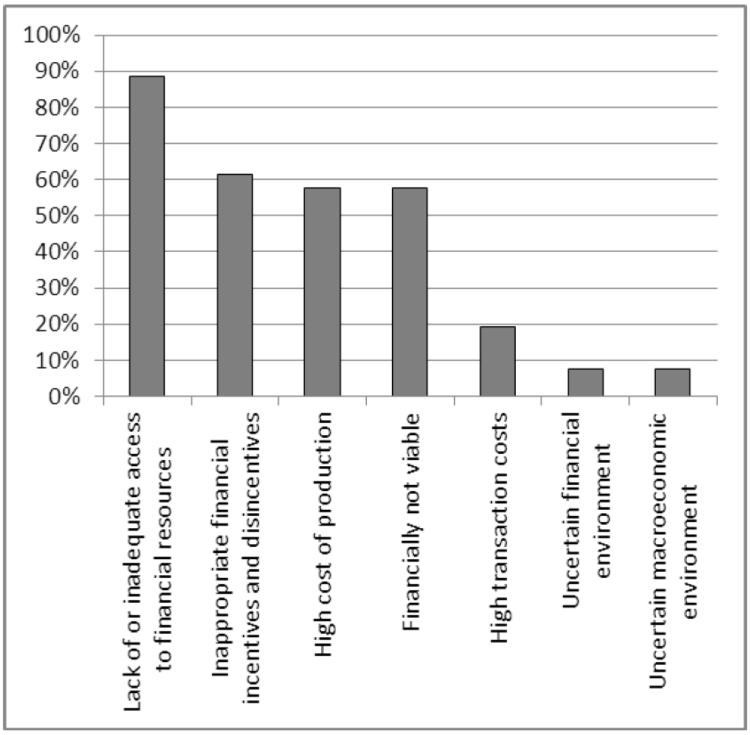


Similarly, analysis from the 'Second synthesis report on technology needs identified by Parties' (UNFCCC, 2009) also found that economic and market barriers were the most widely-cited barriers to technology transfer. However once these economic barriers to implementation have been overcome, these seems to be a range of other barriers.

5.1.1. Barriers on a sectoral basis: Agriculture, water and coastal zones

Barriers and constraints can also be differentiated on a sectoral basis. In the agriculture sector, commonly identified barriers in the third TNAs synthesis report of the TNAs included lack of or inadequate access to financial resources; and an insufficient legal and regulatory framework (UNFCCC, 2013).

Economic and financial barriers to development and transfer of adaptation technologies within the agriculture sector identified in the TNAs (Source: UNFCCC, 2013)



Agriculture

Drawing on the previous section on lessons learnt in success and failures stories in agriculture (section 4.1) we can identify a range of barriers that constrained these agricultural technologies:

- Understanding and awareness (including lack of trust) can be a barrier to adoption of responses to seasonal forecasts or to micro-insurance (e.g. in Ethiopia).
- In Ghana and Kenya (ALP programme) it was found that language and literacy can also be barriers to distribution of climate information to farmers (demonstrating the need for an effective and locally appropriate communication strategy).
- Both credible seasonal forecasts and insurance schemes are constrained by the capacity and resources of meteorological services.
- Use of irrigation is constrained by available water resources for agriculture, people, wildlife and livestock.

- In the Sahel, market related factors, such as food prices, are non-climatic barriers to improving food security under climate change.
- Land tenure issues were a barrier to accessing water bodies for floating agriculture in Bangladesh. Furthermore, there were physical limits to adaptation, as floating gardens were susceptible to wave action. Success therefore depends on the extent of climate change.
- Often, financial constraints can be an initial barrier, but when these constraints are overcome there are a range of other barriers to implementation and up-scaling.

The IPCC 3rd Assessment Report also argues that key constraints to adaptation in the agricultural sector include “technological and financial constraints, access to new varieties, markets” (IPCC, 2007). Other literature identifies that there is a lack of Research and Development (R&D) investment in the agricultural sector in developing countries. For example, McIntyre et al (2009) found only 6% of global agricultural R&D investments were spent in the 80 low-income countries with a combined population of 600 million people. Clements et al (2011) identify various financial, informational and communication barriers to specific agricultural adaptation technologies, for example, sprinkler irrigation is limited by lack of finance, skills and available components, as well as low public awareness of benefits.

Water

Drawing from the section on lessons learnt from success and failures stories in the water sector (4.2) it is possible to identify a range of barriers:

- For boreholes and tubewells, barriers to successful implementation in drylands include inadequate consideration of the multiple users of water (humans and animals), over-abstraction, and failure to consider governance issue.
- Technical barriers to implementation of boreholes and tubewells included compact and dense rocks, minerals causing blockages, and borehole failure.
- In implement rainwater harvesting, barriers include technical knowledge and resources.
- Barriers to implementation of desalination include cost, energy intensity, environmental implications and political opposition.
- In terms of forming successful water management bodies and organisations, in the case of Jordan the barriers included poverty, deeply-rooted cultural traditions, and lack of technical and financial resources to access technology.

IPCC (2007) identifies key constraints in the water sector include “financial, human resources and physical barriers”. The long list of potential barriers to adaptation in the water sector include lack of access to finance, lack of cultural acceptance of change, gender bias, lack of acknowledgement and use of traditional knowledge, lack of cooperation between authorities and top-down or outsider interventions without local anchoring (Wilk and Wittgren, 2009). Elliot *et al* (2011) observe there are a range of barriers to specific water technologies; for example the barriers to water safety plans include limited data availability, unplanned developed and limited human resources.

Box: Legal barriers to rainwater reservoirs cited in Indonesia's Technology Action Plan
Indonesia's Technology Action Plan (2012) identifies various barriers to diffusion of rainwater reservoir technology including regulatory, economic and financial, institutional, and social and cultural barriers. In the category of regulatory barriers, there is a lack of laws regulating installation of rainwater reservoirs. Regulations on utilisation of water resources are already set up but are still not sufficiently understood by the public, making them difficult to implement. Lack of specific regulations on management of water resources can trigger conflicts of interest amongst members of society. Relevant laws and regulations which could be used for guidance or references include: Law No. 7/ 2004 regarding water resources, Government Regulations No. 42/ 200 regarding water resources management, No. 43/2008 regarding ground water, No. 37 regarding Dam, and No. 38/2011 regarding rivers.

Infrastructure and settlements including coastal zones
From the section on lessons learnt from infrastructure and settlements, including coastal zones (4.3) we can identify a range of barriers:

- Hard coastal technologies are often on a large scale and require continuous upkeep and upgrading (e.g. for seawalls), therefore a crucial barrier is represented by the ongoing financial costs needed to support this.
- Land tenure is a significant issue for consideration in the introduction of coastal adaptation technologies and must be approached in a manner that protects local community rights.
- Legislative gaps represent a barrier to technology implementation, for example in the case of wetland restoration in Guyana, and as such support for technologies must be reflected in national policies.
- The case of the successful cyclone early warning system in Bangladesh illustrates the need to overcome language and communication barriers in disseminating early warnings.

The IPCC identified that in coastal areas, key constraints include "financial and technological barriers; availability of relocation space" (IPCC, 2007). Different technologies for accommodation, protection or retreat from coastal zones each have their own barriers. For instance, sea walls, dikes and storm surge barriers can be high cost or require space; while flood early warning systems come up against barriers such as lack of trust and fatalism (Zhu *et al.,* 2010).

5.1.2. Barriers on a regional basis and across scales

There may also be common barriers on a regional (or context-specific) basis. The table below shows commonly reported barriers in the TNAs on a regional basis.

Commonly reported barriers to the development and transfer of adaptation technologies by region (Source: UNFCCC, 2013)

Africa	*Asia-Pacific*
• Lack of or inadequate access to financial resources • Poor market infrastructure • Restricted access to technology • Limited institutional capacity • Inadequate information	• Lack of or inadequate access to financial resources • Limited institutional capacity • Inadequate information
Eastern Europe	*Latin America and Caribbean*
• High cost of production • Financially not viable • Restricted access to technology • Insufficient legal and regulatory framework • Inadequate information	• Lack of or inadequate access to financial resources • Insufficient legal and regulatory framework • Traditions and habits • Inadequate information

The barriers to implementing an adaptation technology may well differ depending upon which scale is being analysed, or the scale at which it is being introduced. Consumer goods (at the household level) may well meet a different set of barriers to those which are being implemented as public or non-market goods (e.g. national early warning systems).

Barriers can be context-specific, which demonstrates the need to tailor policies to local needs (UNEP, 2012). However, other barriers to adaptation technologies are global or cross-cutting, such as trade regulations or IPRs.

Vulnerability and adaptive capacity are both determined at multiple scales (Smit and Wandel, 2006). As Adger (2006) points out, it is also important to consider vulnerability at the whole-system level, where the influence of governance and institutions might be more relevant than it is at the individual or household level. Since governments can only act on national barriers, the evidence of global barriers to adaptation technologies demonstrates the need for greater international collaboration in this area.

Illustrative examples of barriers at different scales

Scale	**Examples of barriers to transfer and implementation of technologies for adaptation**
Local	• Lack of or inadequate access to financial resources • Poor infrastructure • Limited capacity of local government • Limited awareness and trust • Literacy barriers • Caste or class inequalities
National	• Lack of or inadequate access to financial resources • National macroeconomic conditions • Lack of specialised government agencies • Poor infrastructure • Insufficient legal and regulatory framework • Limited institutional capacity
Global	• WTO regulations, e.g. pertaining to IPRs • Distorting or perverse subsidies

	• Lack of supportive international agreements • Insufficient regional or international cooperation • Lack of progress in related areas e.g. development goals or mitigation

Sources: UNFCCC, 2013; Jones, 2010; Lybbert and Sumner, 2010; UNEP, 2012

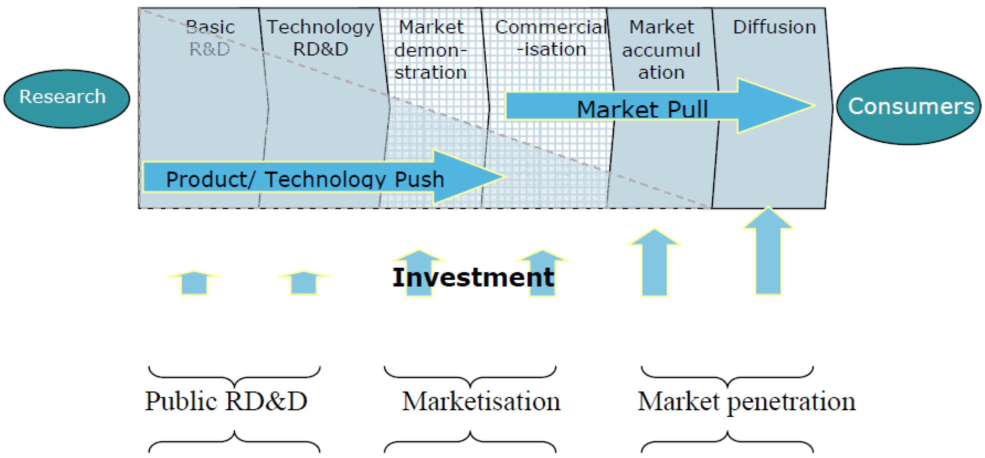
5.2. Enablers and opportunities for successful implementation

In the third synthesis report on TNAs, the most commonly mentioned enabler was the measure to "increase the financial resources available", by introducing or increasing the allocation for the technology in the national budgets, or by identifying and creating financial schemes, funds, mechanisms or policies (UNFCCC, 2013). Another commonly mentioned measure was to "strengthen the relevant institutions, via increased human resources and facilities", in order to accelerate the research and development of the technology (*ibid*). Other cross-sectoral measures included provision of capacity-building and establishment of information and awareness programmes (UNFCCC, 2013).

Measures to overcome barriers can be specific to particular technologies. For market goods, for example drip irrigation or seed varieties, where diffusion is contingent on the market, 'market mapping' can be used to understand and approach market development (UNEP, 2012). UNEP (2012) suggests the participatory market chain approach (PCMA) can facilitate the collaboration that is needed to improve linkages within the market chain. This approach is particular to market goods.

Enabling measures may depend on the stage of technology development. The diagram below illustrates various stages of technology innovation for market-based technologies, from basic R&B to diffusion. Grubb (2004) argues there is often a 'valley of death' in the central stages of demonstration and commercialisation. At this stage, many emerging technologies fail to reach their potential, indicating a need for more policy interventions to enable viable technologies to move from the stage of piloting to widespread diffusion.

Main steps in the technology innovation chain (Source: Grubb, 2004)



Under the UNFCCC, the TNA process led to the development of 'Technology Action Plans' (TAPs) to overcome barriers relating to adaptation technologies. Further information and examples are found in the section on the work under the Convention (section 2). Another potentially relevant policy enabler for 'hard' adaptation technologies could be the development of Technology Roadmaps (TRMs).

5.2.1. Enablers on a sectoral basis: Agriculture, water and coastal zones

As for barriers, the enablers or opportunities for implementation can be unique to different sectors. The TNA Guidebook highlights that there is no 'pre-set' answer to technology diffusion and transfer, so policy actions need to be tailored to the specific contexts and interests (UNEP, 2012). There is a need to further consider cross-cutting policies to enable adaptation action across regions, sectors and scales. Thus, promotion of adaptation technology will require overcoming barriers at national and global scales, such as regulatory or trade barriers, or lack of infrastructure or services, as well as overcoming local barriers such as lack of awareness.

Agriculture

For example, opportunities identified by IPCC (2007) in the agriculture sector include longer growing seasons in higher altitudes and revenues for 'new' products, while opportunities for infrastructure and settlement include integrated management as well as synergies with sustainable development goals. In the agriculture sector, in the TNA process the majority of Parties suggested the need to create new financial products, a mechanism or architecture for the prioritised technology (UNFCCC, 2013). The measures put forward to overcome identified policy, legal and regulatory barriers were quite diverse; establishing quality control systems and agriculture crediting and certification systems (27 per cent of Parties), formulating detailed regulations and standards for the prioritized technology (27 per cent), creating policies to enforce land utilization and avoid conflicts between farmers (23 per cent) and reviewing the current regulatory framework to include an agricultural extension service (UNFCCC, 2013).

Box: Technology Action Plan (TAP) for the Agriculture Sector: The case of Mongolia
Some countries developed TAPs for adaptation technology on a sectoral basis. In 2013, Mongolia developed a TAP focusing on agriculture, including separate actions at the sectoral level for arable farming and for animal husbandry. Livestock is a particularly important sector for Mongolia. In arable farming, TAPs were developed for the System of Wheat Intensification (SWI), vegetable production and potato seed production. In the animal husbandry sector, actions plans were developed for seasonal prediction and livestock early warning systems, and sustainable pasture management.

In the agriculture sector, it has been recognised there is a need for diversity to strengthen agricultural production in the face of uncertainty (Clements *et al*., 2011). Uncertainty is an important consideration since future scenarios are highly dependent on emissions and socio-economic variables, and also because the use of information from weather forecasts is probabilistic. There is a need for policies to strengthen and preserve agro-biodiversity, for instance with seed banks. Research networks will provide a vital role in developing resilient seed varieties and such research will also require public investment to overcome barriers relating to IP protection.

There have been challenges in effectively using climate information in agriculture. Accurate climate information depends on strengthening meteorological services. The case of Lesotho demonstrates the need to improve communication of seasonal forecasts (Ziervogel, 2004).

Even when forecasts are available, farmers are constrained from adopting adaptation technologies due to lack of credit, demonstrating the general need to improve financial services for smallholders. Index-based insurance relies upon sophisticated meteorological monitoring including an extensive network of weather stations (Clements *et al*., 2011).

The Aral Sea case demonstrates the need to avoid maladaptation, and the need to manage resources with an understanding of ecosystems. In agriculture, various case studies also demonstrated the need to recognise local knowledge and promote endogenous technology. The case of floating gardens in Bangladesh demonstrates the vital need for research, piloting and evaluation, in scaling-up technologies. It must not be assumed technologies are applicable or replicable elsewhere without adaptation to the local context and piloting. The case study from the re-greening of the Sahel illustrates that there is no 'single silver bullet' (Sendzimur *et al.,* 2011). The Sahelian case also shows that transformative resilience can occur after a period of reduced resilience which leads to realignment and formation of new structures *(ibid*). Moreover, spreading local innovations requires coordination and collaboration between many different stakeholders, including governments, farmer groups and NGOs, as well as charismatic local leadership (Reij *et al.,* 2009).

Several case studies demonstrated the important role of extension services in disseminating agricultural technologies. Such services are part of the 'enabling environment' in which a technology is disseminated and scaled up. Local and regional networks, including communities, governments, research and private sector, provide a vital role in developing resilient farming systems and farming landscapes these networks will require public and private commitment and investments to overcome barriers. The Montpellier Panel (2012) also highlights the importance of building resilient markets and policies to reduce the risk of food price volatility.

Water

In the water sector, key opportunities identified for enabling adaptation include promotion of integrated water resources management (IWRM), promoting synergies with other sectors, and finding fresh and flexible funding that is additional to official development assistance (ODA) commitments (IPCC, 2007; Wilk and Wittgren, 2009). In the previous section on lessons learnt from success and failure stories, enabling factors in the case of boreholes in Kenya appeared to be availability of international aid and government support. In the case of Jordan, a key enabling action was the provision of training for water users.

Policy recommendations and actions that can be drawn from the literature and case studies include the need to rehabilitate and repair strategic water sources. In many countries, villages rely on water trucking from boreholes 80 -100km away to meet their household water demands and animal needs. Amidst a changing climate and in order to guarantee water supplies also during drought or shifting seasons, rehabilitating and repairing strategic water resources is key also for emergency relief. There is a need for risk-averting strategies to prevent situations where crops have to depend on rainfall whose variability is high both in distribution and amounts. Alternative and new technologies, such as underground "sausage" or spherical tanks in cascades, provide increased capacity of seasonal water for supplemental irrigation which can increase yields considerably. With rainwater harvesting, farmers have diversified to include horticultural cash crops and keeping of animals.

The private sector can play a role in provision of new irrigation technologies or less water-consuming and more drought-resistant crops as well as other technologies and machinery. Yet frequent changes in government and fluctuations in government strategies towards water render it difficult to develop plans for private sector companies to enter the market; there are too many uncertainties and risks, and policy-making appears arbitrary which in turn creates a barrier for companies to make investments or to get involved in co-financing. There is a need to ensure consistency and continuity in legislation that regulates the water sector. Regulation is necessary to addresses the problem of shrinking availability of water and the role of private households and private sector companies in regulating the demand and supply. In other areas, flooding poses a threat and there is a need for effective land use planning and reforestation to reduce run-off, as well implementation of early warning systems and flood-monitoring technologies. Furthermore, water management can have regional and cross-border implications, demonstrating the need for broad multi-national cooperation in various cases.

Infrastructure and settlements including coastal zones

For infrastructure and settlements including coastal zones, opportunities and enablers include complementarities between different adaptation technologies, and development of building regulations and land use policies, for example strategic shoreline management plans and ICZM (Zhu *et al.,* 2010). In the previous section on lessons learnt from success and failures stories, it was found that community involvement represents a critical enabler for ensuring widespread adoption and long term sustainability of coastal adaptation technologies whilst a well-informed approach here can also ensure socio-economic benefit for communities.

The central examples of coastal adaptation technologies highlight various point of interest for associated policy and promotion. Awareness building and cooperative involvement amongst government, experts, and private and community groups can promote the use of sustainable adaptation technologies (Marfai, 2011), whilst also encouraging the policies necessary for their appropriate adoption. These policies should stress the necessity of planning appropriately for the contexts within which technologies are to be introduced, and incorporate climate change projections to account for long-term changes and, thereby, ensure sustainability (DVVK, 2010). Whilst foregoing experiences can provide lessons for the scaling up of projects in alternative locations, direct technology transfer is rarely a viable option. Hence, in order to ensure the right approach is taken, intricate planning processes, alongside reciprocal experience sharing are crucial, and can help to avoid repetition of mistakes (Zhu *et al.* 2010). Moreover, as protection measures are achieved differently at different scales, the scale and context of technological interventions must be accounted for, with plans examined according to habitat (Erwin 2009).

Once a technological input is established, monitoring and evaluation processes are crucial to ensure continuous adaptation of the technology to its changing environment. More often than not, there is a perceived need to combine both natural and manmade, and hard and soft technologies, in order to make sustainable progress for climatic preparedness and protection.

However, evaluation appears to focus on certain technologies in isolation, rather than addressing them as part of a wider picture alongside supportive technologies as well as ecological, social and economic contexts. In the case of climate adaptation, technologies are being implemented in areas already subject to much change. While coastal infrastructure technologies can be protective, slow onset changes and fast onset events will continue to occur and the management of the technology must be flexible to this. As such technological installation should not be viewed as an isolated event, but as an ongoing process. Policies to support such management, e.g. coastal management plans, should be reflective of this.

Finally, planning, establishment and monitoring of infrastructural adaptation technologies must be people-centred. Having a people-centred or community-based basis can help to ensure approaches are appropriate to context, enthuse the involvement of local citizens who will be interacting within the affected site, and strengthen sustainability of the technology in the long term.

5.2.2. Enabling environments and enablers across regions and scales

UNEP (2012) divides the elements of the enabling environment into national, macroeconomic conditions; human, organisational and institutional capacity; research and technological capacity; and social and cultural aspects. Each of these has associated relevant government policies. There are different and interacting levels of the enabling environment, at which different stakeholders work (e.g. regional/local networks) (UNFCCC, 2003). Enabling measures can be targeted at specific barriers, as described above, and can be analysed across all stages of the technology cycle, from R&D to diffusion. In the third synthesis report of TNAs it has been noted that the structured approach taken by countries to identify sectors, technologies and specific barriers has led to identification of very specific measures (UNFCCC, 2013). However, it is possible this approach leaves out important cross-cutting structural, international or regional measures to enable adaptation.

Better integration or mainstreaming into national programmes and policies could provide a means of wider diffusion of technologies, and provide an enabling environment for adaptation. For example, the International Labour Organisation (ILO) has suggested a means of implementation of adaptation technologies, such as ‘hard’ technologies for infrastructure, through labour and local-based methods that offer employment and income to disadvantaged local groups (Harsdorff *et al.,* 2011). There are a range of social protection programmes and employment-intensive disaster risk reduction efforts already ongoing around the world which can contribute to adaptation, for example, food for work programmes that have contributed to reducing vulnerability in Haiti (*ibid).* Although technological innovations can support poverty reduction, there are questions as to whether current trends of innovation have done justice in reaching the poor (Khan *et al.,* 2013). In order for technologies to be most effective in promotion adaptation, it has been suggested these technologies should be targeting the most vulnerable, for example through social safety net (SSN) programmes (Harsdorff *et al.,* 2011; Khan *et al.,* 2013).

Regional or international collaboration can enable adaptation. Development of successful adaptation technologies is often a collaborative effort requiring multi-stakeholder or cross-border cooperation. For example, development of meteorological services in African countries, a prerequisite for reliable early warning systems, is enabled by national and regional institutions. For example in Africa, the African Centre of Meteorological Applications for Development (ACMAD) provides seasonal climate outlooks for Africa. At the global scale, the World Meteorological Organisation (WMO) has facilitated the development of global and regional climate prediction infrastructure, and supported capacity-building in climate information. By the end of 2017, the Global Framework for Climate Services (GFCS) is expected to facilitate access to improved climate services globally in 4 priority sectors (agriculture, disaster risk reduction, health and water).

Potential areas for future regional or international cooperation to enable adaptation include collaborative joint R&D on adaptation that is publicly funded to ensure that the intellectual property is available in the public domain. Other enabling actions would be promotion of business-to-business platforms for capacity building within the developing-country private sector, and promoting financial incentives for FDI (foreign direct investment).

Enabling environments for transfer of adaptation technology include attention to trade regulations. In the guidebook for TNAs, UNEP (2012) describes changing WTO regulations as an example of a "non-starter" in terms of policy because this is a long-term challenge and the TNA process is focused at the national level. However, in the context of the long-term challenge posed by climate change, and considering the potential for collaboration at the international level, changing trade regulations to enable adaptation appears to be an important area for future work.

6. Conclusions

Overall, the background paper supports the conclusion that technology is not a panacea and technologies require mechanisms, expertise and other resources to make the technology useable and sustainable (Klein *et al,* 2005). The paper confirms the importance of the enabling environment in scaling up and enabling access to adaptation techniques and technologies. It is possible the structured approach to identify sectors, technologies and barriers under the Technology Needs Assessment (TNA) process leaves out important cross-cutting structural, international or regional measures to enable adaptation. Better integration into national programmes could provide a better enabling environment for adaptation technologies, for example, scaling-up adaptation technologies in ongoing disaster risk reduction or safety net programmes. Regional or international collaboration in the development of meteorological services to facilitate seasonal forecasting and early warning systems is another key suggested area for future work. Furthermore, renewed focus on trade regulations at the global level to facilitate trade in climate technologies could enable the scaling up and diffusion of relevant technologies, as well as enabling adaptation action.

Under the Convention, the NAPA process has showed not all project ideas get funded or implemented, demonstrating the importance of scaling-up finance for adaptation. In some areas, private investment can be mobilised. Under the TNA process, the participatory market chain approach (PCMA) was described as a tool to facilitate market technologies like resilient seed varieties. However, for other adaptation technologies that are public (non-market) goods such as wetland restoration or sea walls, regulation, public funding or investment (from national or international sources) and political will are required.

Analysis of processes under the Convention also suggests a need for further mainstreaming of these activities and coherence to avoid duplication, including integration of TNAs and NAPs. Mainstreaming the promotion of adaptation technologies in development processes would both have a wider impact in promoting adaptation technologies, and also, create an enabling environment for adaptation as a process. Integrating adaptation approaches and technologies into existing schemes, development or relevant services, while broadening the reach of those services, would contribute to reducing vulnerability and building adaptive capacity.

The background paper also illustrates that a range of stakeholders have been engaged in technologies for adaptation outside the Convention, spanning research, private sector, financial organizations, non-governmental organizations (NGOs) and local community groups. Various case studies, e.g. the case of the re-greening of the Sahel, demonstrate that spreading innovations requires coordination and collaboration between different stakeholders. A people-centered approach can contribute to adaptation as a social learning process (Collins and Ison, 2009) because adaptation is more a continual 'process' of learning than an outcome of the application of any particular technology. Collaborative learning can also draw strengths from different areas of expertise, including local knowledge, and may contribute to mobilizing private investment. Under the Convention, the Climate Technology Centre and Network provides a renewed opportunity for practical and successful engagement with stakeholders in order to scale-up adaptation technologies and approaches.

Having a people-centred or community-based basis can help to ensure approaches are appropriate to context and strengthen sustainability. The case studies demonstrate that much can be learnt from indigenous and endogenous technologies, and that adaptation technologies do not have to be 'new' but can be the application of age-old practices. There is a need to recognise the specificities of different ecosystems, economies and societies. For example, boreholes and irrigation in the drylands have often failed due to insufficient attention to the systemic nature of economics and livelihoods (e.g. borehole development without looking at pasture), lack of attention to governance issues, and a failure to manage interventions at scale. Successful technologies are notable in that they often stem from and strengthen what local people have already been doing (e.g. zai planting pits), where a systemic approach is taken, and where attention to socio-political relations are key. Recognition of indigenous technology by policy-makers in respective sectors may go a long way towards enhancing scaling-up and further development and transfer of technologies.

Another important conclusion relates to the need to avoid potential maladaptation. In highlighting lessons learnt from various case studies, it was found that failure cases are often poorly documented, demonstrating the need for further documentation of failures in order to learn lessons for policy making. Moreover, even where a technology is successful there are often synergies and trade-offs, for example trade-offs between yield increase and environmental impacts. What is successful for one stakeholder group can also have negative consequences for others. Once a technology is established or piloted, monitoring, evaluation and learning are crucial to ensure continuous adaptation of the technology to its changing environment. Technologies must be assessed against various criteria include equity, efficiency, effectiveness, and social, economic and environmental impacts. There is a crucial need for technology assessment to avoid maladaptation. The case of floating gardens demonstrates that it must not be assumed that technologies are applicable or replicable elsewhere without adaptation to the local context and piloting. Moreover, desalination technology demonstrates there can be conflicts between adaptation and mitigation objectives. There is a need to promote synergies between adaptation and low-carbon resilience in order to achieve multiple long-term policy objectives. Technological failures in the Aral Sea also demonstrate the need to avoid 'groupthink' or institutional momentum, which can be avoided by stakeholder engagement and integration of a wide range of perspectives. Assessment of technologies to avoid maladaptation may benefit from existing approaches such as Strategic Environmental Assessment (SEA). Due to the uncertainty in future climate change, an iterative, flexible approach to adaptive management has been suggested. Overall, there is a need for further guidance and tools on avoiding maladaptation.

In terms of enablers and barriers to the successful implementation of technologies, in the TNA process almost all Parties identified economic and financial; policy, legal and regulatory barriers; institutional and organizational capacity related; and technical barriers to technologies for adaptation (UNFCCC, 2013). The most common enabler mentioned by Parties under TNA process was to "increase the financial resources available" demonstrating need for scaling up adaptation finance, but finance is not the only barrier. Barriers and constraints can be differentiated on a sectoral basis or regional (context-specific) basis, while other barriers are global or cross-cutting.

In summary, the background paper illustrates the need to move beyond pilots into a mainstreamed approach that builds adaptive capacity and promotes the enabling environment for adaptation. The TNA process might have led to prioritisation of hardware over software or 'orgware' (Christiansen *et al*., 2011). There is a need for further exploring software or 'orgware' for adaptation as well as tools for promotion of adaptive management and learning. At various points in the paper, limits to adaptation have been described (financial, institutional, regulatory, technical etc.). The prevalence of such barriers and limits to adaptation, and the uncertainty associated with future climate change projections reiterates the importance of an integrated strategy that limits the worst impacts of climate change, both by scaling up adaptation action and increasing mitigation ambition, optimising synergies between the two and integrating with development.

7. Recommended policies and actions

This section recommends policies and actions to further promote technologies to enhance action on adaptation to climate change, taking into account the above analysis of the work of various bodies and the experiences of various stakeholder experiences. While technology is important in reducing vulnerability, its effectiveness often depends on the economic, institutional and socio-cultural context in which it is deployed (Christiansen *et al*., 2011). In the enablers and barriers sections, it was noted that the structured approach taken to identify sectors, technologies and specific barriers under the TNA process had led to identification of very specific measures. Furthermore, some measures were already in place at local levels but were still to be extended to the national level *(ibid*). However, the structured approach might have left out important enablers across regions, scales and sectors. This has demonstrated the importance of creating the enabling environment for a range of adaptation technologies and practices.

7.1. Cross-cutting policies and actions

Research, monitoring and evaluation

Potential areas for future work include strengthening collaborative joint R&D on adaptation. Research networks can provide a vital role in development new technologies, such as new seed varieties. The case studies demonstrate the need for technology assessment to avoid the risk of maladaptation. It is important to ensure technologies do not have negative side-effects or indirect 'spill-over' effects on the vulnerability of another community or area. It must not be assumed technologies are applicable or replicable elsewhere without piloting or adaptation to local contexts through collaborative research which includes a wide range of stakeholders, such as on-farm testing of technologies. Across all sectors, various case studies emphasised the importance of considering uncertainty about future scenarios and the limits to adaptation, which are important considerations to avoid maladaptation. Monitoring and evaluation (M&E) is crucial to ensure continuous adaptation of the technology in a changing environment. The evidence of barriers and limits to adaptation also reaffirms the need to increase mitigation ambition under a global climate agreement, which highlights the need to maximise synergies with mitigation.

Stakeholder engagement

Across the three sectors, the case studies reinforced the importance of M&E and sharing of experiences. Adaptation has been described by some as a process of "social learning" (Collins and Ison, 2009). Having a people-centred or community-based basis can help to ensure approaches are appropriate to context. There is often a need to build awareness and involvement through government, private and community cooperation. Stakeholder engagement is important right from the planning stage, for example in coastal management planning. In the water sector, it is critical to understand complex land tenure dynamics and socio-political relations between different groups.

Financing

Parties' cited financial factors as the key barrier to adaptation technologies, demonstrating the importance of scaling-up provision of climate finance for development and diffusion of adaptation technologies. Lack of political will and capacity barriers (including lack of information or skilled personnel) were important barriers, highlighting the need for further supportive actions in this regard. There is need for further support on financing implementation of TNAs and TAPs. For example, supportive actions could include promotion of business-to-business platforms within the developing-country private sector, or promoting financial incentives for FDI (foreign direct investment).

Policies and regulations

The operationalization of the UNFCCC and associated finance mechanisms might have led to prioritisation of hardware over software and orgware (Christiansen et al., 2011). In TNA's for adaptation, most of the prioritized technologies fall in the categories of consumer and public goods (UNFCCC, 2013). However, the literature and examples have illustrated the need to consider both 'hard' and 'soft' technologies for adaptation (Klein et al., 2005).

Furthermore, successful promotion of 'hard' technologies also requires 'soft' strategies to overcome identified barriers, such as changing laws, or implementing supportive policies. For example in agriculture, there is a need for policies to strengthen and preserve agro-biodiversity. Furthermore, policies are needed to reduce food price volatility. In the water sector, there is a need for consistency and continuity in policies to lower the risks of private investment. Enabling measures can be targeted at specific barriers, as described in section 5, and can be analysed across all stages of the technology cycle, from R&D to diffusion. Policy actions may depend on which stage of the innovation cycle the technology is at. For market-based technologies, UNEP (2012) recommends focusing on early adopters and possible niche markets as a means to kick-start diffusion.

Planning
Rather than adopting a technology-specific focus that centres on 'hard' technology, there is a growing awareness that adaptation is a process, not an outcome. This may require building 'adaptive management' processes at national level, for example, through Integrated Coastal Zone Management (ICZM), Integrated Water Resources Management (IWRM), or land-use planning.

Institutions and infrastructure
Institutions, including local institutions, are a vital part of the enabling environment for scaling-up technologies for adaptation. Use of climate information, including for early warning systems, seasonal forecasts or index insurance all depend on strengthening meteorological services and a network of weather stations. UNEP (2012) recognises that many adaptation technologies, like seed varieties, are market goods which encounter market barriers at various stages of the value chain. Lack of market access, land tenure and inadequate financial services are all barriers to access or adoption of adaptation technologies at the local scale which may need to be overcome through the development of market infrastructure or expanding financial services.

International or regional cooperation
Planning for technologies for adaptation at national level do not generally tackle international or regional issues relating to adaptation. There may be a further need to consider cross-cutting policies to overcome legal and trade barriers to diffusion and transfer of technologies, for example, import tariffs, subsidies, or restrictive patents. International cooperation is also required on cross-border issues relating to water management.

Mainstreaming and integration
Enabling actions at broader scales are cross-cutting across regions and scales. Recent literature has highlighted the importance of mainstreaming and integration of adaptation into development processes. Interconnecting the TNA process with other processes such as national development planning is likely to enable implementation to have a wider impact. In order for adaptation technologies to be most effective, it has also been suggested these technologies should be targeting the most vulnerable stakeholders. Potential means to scale-up adaptation technologies in this way would be through social safety net (SSN) programmes, disaster risk reduction efforts or government extension services.

7.2. Possible actions for the TEC

Arising from these issues, possible recommendations for actions for the TEC could include:-

- Further consideration of cross-cutting barriers and enablers for adaptation technologies, for example facilitation of a workshop on the issue of regulatory or trade barriers to transfer adaptation technologies in order to generate dialogue on this issue. This may require greater collaboration with stakeholders outside the UNFCCC including other international organisations and bodies.
- Promoting further action on cross-cutting areas to strengthen availability of technologies adaptation, in areas where international collaboration is necessary, for example strengthening meteorological services.
- Promoting further dialogue or development of guidance on 'soft' technologies for adaptation such as strengthening local institutions in order to build adaptive capacity, for example for early warning systems (EWS), or development of guidance on 'adaptive management' processes such as ICZM or IWRM.
- Following up with countries on the extent to which TNAs and TAPs have been implemented or integrated into National Adaptation Plans (NAPs). This could be combined with development of guidance and research on financing TNAs and TAPs.
- Producing guidance on mainstreaming of adaptation technologies and approaches into national development plans or programmes, for example social protection, disaster risk reduction efforts or agricultural extension services.
- Collaboration with the CTCN on activities to bring together stakeholders for shared learning on research, development and implementation of technologies for adaptation.
- Development of specific guidance and tools for technology assessment for technologies for adaptation including, for instance, maximising synergies with mitigation efforts, and avoiding the risk of maladaptation.
- Further consideration of endogenous adaptation, for example hosting a workshop in indigenous technologies for adaptation to climate change in order to raise awareness and contribute to learning on the potential of such technologies for adaptation.

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