Chapter 7: Risk management and Decision Making in Relation to Sustainable Development

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7.1 Executive summary

Land-climate change interactions affect the central issues in sustainable development: how and where people live and work, their access to essential resources like water, energy, and minerals, and their ability to feed themselves. Decisions about land management combined with anthropogenic climate change already contribute to soil degradation, desertification, flooding, extreme rain and heat wave events in cities, pests and disease in agriculture, browning of forests, and the loss of ecosystem services that support human well-being. Land-climate change interactions combine with population and political dynamics to generate risks of conflict, migration, displacement, and poverty. Evidence reveals policies that exacerbate these land-climate change challenges, as well as policies that dampen negative consequences and amplify co-benefits of mitigation, adaptation, and sustainable development.

Changes in land-climate interactions will result in the crossing of thresholds or tipping points for ecosystems and human welfare (*high agreement, limited evidence*). Risk is the potential for negative consequences where something of value is at stake and the outcome of events is uncertain, recognising that there is a diversity of values. Risks are dynamic and may change over time. Uncertainty exists in scientific findings due to definitional, observational, and modelling choices, and intrinsic complexity of human and natural systems. Disagreement in decision and policy making exists due to differing uptake of knowledge, diverse determinations of the problem and its consequences, leading to unpredictable decision making of actors at different levels. Risks arise from a combination of threats of desertification, land degradation and food insecurity in combination with climate and major non-climate stressors. Risks may arise in one domain and cascade through different domains such as human health, ecosystem services, livelihoods, or infrastructure with potential for adverse consequences at regional, national or global scales including multi food basket failures. (7.3)

Adaptive and flexible decision-making that can be revised as new information and data becomes available best responds to uncertainty. Scenarios can provide valuable information at all planning stages in relation to land, climate and food, but uncertainty in scenario planning requires that adaptive and flexible solution planning and pathway choices be made and reassessed in order to respond to new information and data as it becomes available. (7.5.4; 7.6.3)

Purposefully-designed packages of policy instruments to manage the risks of land-climate change interactions like drought, flood, fire, and food insecurity deliver co-benefits. It is not one single policy instrument that responds to risks of climate change-land impacts but a combination that prepares for, responds to and recovers from these events. A suite of policy instruments to improve resilience for floods, for example, will include flood zone mapping, building restrictions in flood zones, financial incentives to move out of flood prone areas, and appropriately calibrated insurance and disaster payments. Properly designed carbon tax can reduce GHG emissions but considerations of renewable energy and land use incentives and policies targeting specific climate mitigation measures and/or technologies also need to be considered. Policy instruments that can advance synergies of land, climate and food security include social protection, sustainability certification, technology transfer, land use standards and land tenure schemes integrated with early action and preparedness. (7.4.2; 7.4.3)

Land tenure is a key dimension in any discussion of land-climate interactions, and will influence the prospects for both rural adaptation and land-based mitigation. Both climate change and climate action will have possible impacts on land tenure and thus land security, especially of poor people (*limited evidence, high agreement*).

Local factors such as land tenure and the access food producers have to the food they grow, affect the degree to which policy instruments create opportunities to decrease poverty, food and livelihood insecurity. Evidence suggests that policies which pay attention to interactions of land and climate and system linkages are more likely to create co-benefits between mitigation, adaptation, and development. Local context, including land tenure and land rights, is an important consideration in relation to the selection and application of policy instruments. Sustainable Development Goals can be mutually reinforcing and there is *high agreement and medium evidence* that they need to be pursued in a manner that recognises their inherent linkages, synergies and trade-offs and co-benefits which are context specific depending on a variety of political, national and socio-economic factors. The gaps and omissions in Sustainable Development Goals (e.g. fresh water ecosystems and their ecosystem services) requires other frameworks to be considered as well. An adaptive management approach is increasingly being adopted to explore synergies and trade-offs between goals and targets, albeit depending on natural resource base, governance arrangements, available technologies and political ideas in a given location and context. A nexus approach to policies could also be adopted to develop comprehensive approaches to risk management. (7.4.3; 7.4.4)

Informal decision-making processes and institutions including traditional knowledge are important considerations in formal decision-making analysis (*high agreement, medium evidence*). If informal institutional interaction and decision-making are not considered, decisions and selection of policy instruments may be inappropriate. Traditional ecological knowledge is important for adaptation among farmers, pastoralists, and hunter-gatherers and can be congruent with climate mitigation measures. (7.5.1; 7.5.5; 7.5.6)

Including stakeholders and local populations in decision-making and policy formation related to land improves all levels of governance and may enhance social learning (*high agreement, medium evidence*). New ways of involving citizens in environmental decision-making, including combining citizen science, participatory modelling, and easily available technical tools to collect and disseminate information, have flourished in recent years and influenced decisions on land use and risk. (7.5.5; 7.5.6)

Social learning contributes to long term climate adaptation whereby individuals engage in multi-step social processes in managing different framings of issues surrounding climate risks and opportunities. Such processes facilitate social feedback and exploration of new policy options and institutionalise new rights and responsibilities. There is *high agreement and limited evidence* that such learning processes are important in engaging with uncertainty. Inclusive decision-making and good governance will build resilience to risk and enhance service delivery and food security by incorporating citizen obligations and responsibilities. (7.5.6)

Women play a dominant role in agriculture and face multiple barriers to adaptation. Land is an important determinant of women’s livelihoods; alienation of title, competing uses of land (such as biofuel)or impacts of climate change may increase vulnerability. Integrative approaches focused on gender and building on the collective action and agency of women increase resilience (Gender cross chapter box)

Measuring performance is important in decision-making and governance in order to create common understanding and advance policy effectiveness (*high agreement, limited evidence*). Measurable indicators are useful for climate policy development and decision-making and include the Sustainable Development Goals, targets established in the Paris Agreement, carbon stock measurement, measurement and monitoring for REDD and metrics for measuring biodiversity and ecosystem services. Institutional dimensions of adaptive governance include indicators of performance in institutional systems at multiple levels that enhance adaptive capacity of a system. (7.5.7)

The complex spatial and temporal dynamics of risk and uncertainty in relation to land and climate interactions and food security, may require an adaptive, iterative approach to assessing and revising risks and the accompanying decisions and policy instruments. Dynamic adaptation pathways are emerging as a mechanism to make decisions recognising that equilibrium should not be privileged and allowing socially disruptive threats and opportunities associated with the risks of tipping points and regime shifts to be identified and prioritised. Windows of opportunity, including during and after crises and extreme events, are important learning moments when ecosystem feedbacks in a degraded system are recognised and significant changes may be made. There is h*igh agreement and medium evidence* that acting early will generate returns on investments. (7.3; 7.5.9; 7.3.4)

7.2 Introduction and Relation to Other Chapters

This chapter focuses on policy responses and decision-making surrounding risks that arise due to the relationship between climate change, land and humans. The literature surrounding governance, institutions and decision making in respect of risks related to land-climate interactions is assessed. Land is integral to providing for human habitation, livelihoods, food, and resources and also serves as a source of identity and cultural meaning. However, the combined impacts of climate change, desertification, land degradation and food insecurity pose obstacles to climate resilient development and the achievement of the Sustainable Development Goals. This chapter shows that consideration of these inter-linkages, utilising a deep understanding of risk, improves decision-making, builds resilient institutions and adaptive governance, ultimately lessening the socio-economic impacts of climate change and advancing sustainable land management.

This chapter will complement and build on the identification of policies, decision making and governance issues in respect of land-climate interactions covered in chapters 3 to 6. It will specifically address trade-offs and synergies between policies identified in these chapters.

7.2.1 Findings of Previous IPCC Assessments and Reports and Gaps

Box 7.1 Relevant Findings of Recent IPCC Reports

Climate change and sustainable development pathways

Climate change poses a moderate threat to current sustainable development and a severe threat to future sustainable development (Fleurbaey et al. 2014; Denton et al. 2015).

Significant transformations may be required for climate-resilient pathways (Denton et al. 2015; Jones et al. 2014).

There is a wide diversity and flexibility in the choice of adaptation and mitigation pathways and approaches with many synergies and trade-offs in reducing impacts of climate change, ensuring effective risk management, and sustainable development (O' Brien et al. 2012; Denton et al. 2015; Smith et al. 2014a).

Prospects for climate-resilient pathways are related fundamentally to what the world accomplishes with climate change mitigation, but adaptation is also essential at all scales (Denton et al. 2015).

The design of climate policy is influenced by: (1) differing ways that individuals and organisations perceive risks and uncertainties; (2) the consideration of a diverse array of risks and uncertainties as well as human and social responses which may be difficult to measure, are of low probability but which would have a significant impact if they occurred (Kunreuther et al. 2014; Fleurbaey et al. 2014; Kolstad et al. 2014).

Building climate resilient pathways requires iterative, continually evolving and complementary processes at all levels of government (Kunreuther et al. 2014; Kolstad et al. 2014; Somanthan et al. 2014; Lavell et al. 2012; Denton et al. 2015).

Important aspects of climate resilient policies include local level institutions, decentralisation, participatory governance, iterative learning, integration of local knowledge, and reduction of inequality (Dasgupta et al. 2014; Lavell et al. 2012; Cutter et al. 2012; O' Brien et al. 2012; Roy, J., Tschakert, P., Waisman).

Land and rural livelihoods

Policies and institutions relating to land, including land tenure, can contribute to the vulnerability of rural people, and constrain adaptation. Climate policies, such as encouraging cultivation of biofuels, or payments REDD+, will have significant secondary impacts, both positive and negative, in some rural areas (Dasgupta et al. 2014).

Sustainable land management is an effective disaster risk reduction tool (Cutter et al. 2012).

Risk and risk management

Risk results from the interaction of vulnerability, exposure and hazard (Oppenheimer et al. 2015).

A variety of emergent risks not previously assessed or recognised, can be identified by taking into account: a) the interactions of climate change impacts on one sector with changes in exposure and vulnerability, as well as adaptation and mitigation actions, and; b) indirect, trans-boundary, and long-distance impacts of climate change including price spikes, migration, conflict and the unforeseen impacts of mitigation measures (Oppenheimer et al. 2015).

Under any plausible scenario for mitigation and adaptation, some degree of risk from residual damages is unavoidable (Oppenheimer et al. 2015)

Decision-making

Risk management provides a useful framework for most climate change decision-making. Iterative risk management is most suitable in situations characterised by large uncertainties, long time frames, the potential for learning over time, and the influence of both climate as well as other socioeconomic and biophysical changes (Jones et al. 2014).

Decision support is situated at the intersection of data provision, expert knowledge, and human decision making at a range of scales from the individual to the organisation and institution (Jones et al. 2014).

Scenarios are a key tool for addressing uncertainty, either through problem exploration or solution exploration (Jones et al. 2014).

Adaptation

Adaptation is a complex social process. There is no single approach to adaptation planning and both top-down and bottom-up approaches are widely recognised. Institutional dimensions in adaptation governance play a key role in promoting the transition from planning to implementation of adaptation (Mimura et al. 2014).

7.2.2 Emergent, Emerging, and Key Risks

Oppenheimer et al. (2015) define *risk* as "the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values" and cite the formula "Risk = (Probability of Events or Trends) x Consequences". Here we regard risk as having important dynamic, spatial and temporal characteristics, constituted partly by uncertainty and determined by factors including vulnerability, sensitivity, exposure, and adaptive capacity with tolerance and thresholds determined by anthropogenic and natural conditions (see 7.3.2). (Oppenheimer et al. 2015) define *key risks* as "those relevant to the definition and elaboration of dangerous anthropogenic interference with the climate system" in the terminology of UNFCCC (United Nations Framework Convention on Climate Change) Article 2, but more generally as "potentially severe adverse consequences for humans and socio-ecological systems resulting from the interaction of climate-related hazards with vulnerabilities of societies and systems exposed". Severity in this context can be associated with high hazard or high vulnerability, or both.

An *emergent risk* is "a risk that arises from the interaction of phenomena in a complex system" with the example of "feedback processes between climatic change, human interventions involving mitigation and adaptation, and processes in natural systems" (Oppenheimer et al. 2015: 1052).

The risks discussed in this chapter are all risks associated with land-climate change interactions. Within that category, given that several key risks are discussed in Chapters 3, 4 and 5, we have limited our discussion of risks here to:

- Risks arising from a combination of two or more of the processes or threats of desertification, land degradation and food insecurity, in combination with climate change, or;
- Risks arising from one or more of those processes or threats, in combination with climate change and major non-climate stressors (for example macro-economic, governance-related or demographic), or;
- Risks arising from one or more of those processes or threats, in combination with climate change, that cascade through different domains, such as human health, livelihoods and infrastructure, or;
- The potential for adverse consequences at regional, national or global scales where one or more Sustainable Development Goals (SDGs) and biodiversity and ecosystem services are at stake due to uncertain land-climate-society interactions under diversity of values and level of agreement on priorities (Griggs et al. 2013a; Nilsson et al. 2016c).

In this chapter we also define and consider both risk and opportunity arising from land-climate-society interactions in terms of trade-offs between SDGs, ecosystem services and biodiversity.

Box 7.2 Tipping points to illustrate complex problems, deep uncertainties, unknown unknowns

The complex interactions of land, climate change and society bring new challenges for risk management, particularly where the decisions made today for mitigation and adaptation can have long-term implications. A major challenge is that projections of future land-climate-society interactions are **deeply uncertain** because of long time-scales, non-linearities and feedback mechanisms. Furthermore, along with deep uncertainty, **tipping points** – where coupled biophysical and social systems or socio-ecological systems shift radically and potentially irreversibly into a different state or regime under climate and global change, offering both challenges and opportunities for mitigation and adaptation. These deep uncertainties and potential tipping points pose severe challenges for decision making frameworks which are already complicated due to diversity of norms, priorities and stakeholders. We will explore the role of scenarios, projections and early warning systems in planning for adaptation and mitigation under deep uncertainty and potential tipping points.

(Brook et al. 2013; Scheffer 2010; Kandlikar et al. 2005)

7.3 Characterising Risk

This section describes and characterises risk. It discusses the uncertainties that exist in the scientific understanding of risk within the context of this report (7.3.1), explores dimensions of risk across time and space (7.3.2), and describes emergent and substantive risks (7.3.3).

7.3.1 Describing Risk and Drivers

The specific dimensions of risk considered in this chapter relate to consequences of GHG fluxes, climate change, and impacts of climate change (drought, flood, fire etc.), which may lead to soil degradation, desertification, food insecurity and unsustainable land management. These impacts and consequences of climate change may be worsened by the existence of drivers or human or natural induced circumstances that cause change in ecosystems, either directly or indirectly; drivers may be due to biological, physical, demographic, economic, socio-political, cultural, religious, or technical factors (Nelson et al. 2006). The combination of the impacts of climate change with drivers creates a severe problem: a social system problem where the exact nature of the issue is ill formulated; information is confusing; many people have conflicting values that impact decision making differently; every problem has sub-problems and is linked to other probslems, and; confusing ramifications to the whole system exists (Waddock 2013; Grundmann 2016). Because of this, uncertainty and risk is not linear or simplistic, but complex requiring complex conceptual frameworks (Kunreuther et al. 2014). As an example, the risk assessment of a hydroelectric dam that provides renewable energy as well as irrigation water for food has not only climate change risk surrounding variations in stream flow that differ across and within regions (Hamududu and Killingtveit 2012), but also uncertainty in relation to the complex interplay of drivers including demographic shifts, human development needs, energy and food security, investment and trade patterns (Grumbine et al. 2012).

7.3.1.1 Uncertainty of Science

IPCC AR5 relied on two metrics for communicating the degree of certainty in key findings: Qualitative expressions of confidence in the validity of a finding based on the amount and level of agreement in the evidence available; and Quantitative expressions of likelihood or probability of specific events or outcomes. Uncertainty in climate science and its subsequent use has been assessed and reviewed many times (IPCC Reports) along with the well described cascade of uncertainty (see (Viner 2002)). However, the way in which scientific findings are used is less certain, in terms of planning for and assessing risk in land management and climate and land interactions. For instance, in the planning context, uncertainty in science exists when the exact nature of current and future environmental trends and negative ecological impacts are not known, or the consequences of possible interventions, their impact, what will occur if the interventions are not implemented or deferred (Janicke and Jorgens 2000). As outlined in Chapter 1, uncertainties exist in scientific observations surrounding land use and cover (Klein Goldewijk and Verburg 2013) and their associated agricultural or forest management practices (Erb et al. 2017). Furthermore, there are large uncertainties in future land projections due to differences in modelling approaches in current land use models which are at least as great as the differences attributed to climate scenario variations (Alexander et al. 2017; Popp et al. 2017). Finally, how land use and land management choices affect various ecosystem services (7.3.3) and translate into biogeochemical and biogeophysical impacts on climate (Chapter 2) is also uncertain. The uncertainty level is particularly acute for new technological solutions such as bioenergy plantations and BECCS which are put forward to counteract climate change, but have not been tested at large scales so far (Boysen et al. 2017a,b; Robledo-Abad et al. 2017; Vaughan and Gough 2016).

Previous IPCC assessments have examined and used scenarios in a wide range of different ways and from a very wide variety of sources, but questions still exist on how best to develop and use scenarios (Lempert 2013). Scenarios have less confidence than do predictions, projections, and forecasts, but they can provide valuable information at all planning stages depending on the competence of the stakeholders. Using a broad range of scenarios can provide a comprehensive assessment but increase complexity and cost (Lawrence et al. 2013). Uncertainty exists in relation to pathways to achieve the ambition of keeping global-temperature change below 1.5°C; current Nationally Determined Contributions (NDCs) maintain this uncertainty as they are far off the most realistic scenarios to meet this target (Rogelj et al. 2016) as well as in relation to early warning systems, model structures, parameterisations and inputs, and unknown futures as indicated in Chapter 1. A further challenge exists surrounding uncertainty of anthropogenic climate change attribution as distinguished from natural climate variability (Trenberth et al. 2015). Information on attribution plays an important role in informing policy response (Garcia-Menendez et al. 2017). In order to address, understand and ultimately cope with uncertainties in scenarios there is a requirement for policy makers to understand that there is not one optimal and most likely future. Solutions and actions therefore need to be adaptive and flexible to respond to new information and data that becomes available (Hallegatte and Rentschler 2015).

7.3.1.2 Uncertainty (Disagreement) of Norms, Values, Priorities

The proactive actions of people adapting and mitigating climate change is based on how they construct the risk of climate change and its impacts or judge its magnitude, and this is both an individual and a political act (Fischhoff et al. 1984). While making a scientific realist assessment of risk and objectively quantifying outcomes, the likelihood of a certain event is determined (likely to rare) and the magnitude of its consequences (insignificant, minor, moderate, major, or catastrophic) (Wisner et al. 2003). While engaged in this activity, people are fallible learners acting with often incomplete information, based on perceptions of benefits, costs and reciprocity of relationships (Ostrom 1998, 2010). Opposing the realist risk perspective is the perspective that risk is constructed as experiences, emotions, attitudes, and knowledge, calibrating a 'risk' using a set of socially ascribed decisions and calculative practices (Renn 2011; Zinn 2008; Kasperson et al. 1988).

These differing perspectives produce and underwrite uncertainty that can be: (1) substantive – where there are gaps and conflicting understanding in the knowledge base such that there is no agreed and clear understanding of the problem; (2) strategic – where many actors are involved having different preferences such that their interaction and ultimate decision is unpredictable, and; (3) institutional – where the processes of reaching decisions is messy and uncoordinated as the relevant actors are attached to a variety of organisational locations, networks, and regulatory regimes (Koppenjan and Klijn 2004). How risk is determined or constructed informs actors' decisions and policy choices (Hoppe 2011; Hisschemoller and Gupta 1999).

A problem may be structured, where there is agreement on norms, values and priorities and the science is clear, or unstructured where there is little agreement on the norms, values and priorities and the science is not clear. It is here with the unknown unknowns, chaotic (where cause and effect is not discernible) and complex (where cause and effect may be determined after the event), that problems reside (French 2015). Because of the uncertainty inherent in these problems, they are not often holistically and consistently addressed by policy on the national, regional and local scales (Hurlbert and Gupta 2016).

7.3.2 Exploring Risk

7.3.2.1 Across Spatial Scales

The characteristics of risk, including vulnerability, exposure and hazards, vary along spatial scales in relation to both human and natural systems. For instance, global temperature increases are predicted to impact specific species composition in a given location according to the impact on species interactions at the local scale and dispersal between habitat patches at the regional scale (Grainger and Gilbert 2017). Each of these local interactions may react to changes in climate in different ways and positive local effects on one species' intersections may have limited effect on habitat patches elsewhere, due to a higher risk to a species of traversing a corridor to reach a neighboring patch (Grainger and Gilbert 2017). As a result, single-scale analyses might misestimate the impacts of anthropogenic modifications on species or the environment (Cohen et al. 2016). In relation to human systems resilience at the household level, variations are not only by household (idiosyncratic shocks such as illness of the breadwinner or loss of a job) (Holzmann and Jørgensen 2000), but also in relation to agro-ecological setting (such as lowland, midland, and highland experiencing different levels of vulnerability) (Tesfamariam and Hurlbert 2017).

7.3.2.2 Time Frames of Risk – Current and Future

Risk is a dynamic phenomenon that varies across time and includes short-term, or acute shocks (e.g. extreme events of storm, fire or flood), and slow onset, or chronic events that occur over a long period of time including drought. These events have differing levels of predictability at differing timescales. For instance, current weather (0-14 days) at specific locations and specific times has a degree of predictability, but as the timescale increases to monthly, seasonal, multi-annual or decadal, etc. predictability changes in relation to the source of predictability (large scale weather patterns, sea-surface temperatures, sub-surface oceanic conditions) and the scale of predictability (specific locations, geographical scales (sub-continental, tropics etc.) (Jones and Morse 2012).

People and fauna are impacted by these natural events, but also experience vulnerability over time, or at specific points in their life cycle. In a plant lifecycle, regeneration and recruitment are key phases related to adaptation, distribution and survival of species (for example of trees in Nepal germinating at higher temperatures but failing to establish, and insects altering behaviours at key points see (Marzluff and Neatherlin 2006)). There is *medium agreement but limited evidence* of the interactions of rapid and slow onset events and their impact on physiological and behaviour plasticity, genetic differentiation, and phenotypic plasticity of species. The inherent dynamics of socio-economic changes in vulnerability and resilience over time and space must also be considered such as urbanisation or infrastructure construction; a gap in the literature exists as often only biophysical dynamics of change are taken into account (Jurgilevich et al. 2017). Climate change risk across a range of time scales from current weather induced risks to longer term changes is complex due to multiple causal pathways of transmission through interconnected systems such as agriculture, trade and food security; for example, climate change may give the UK a comparative advantage causing domestic food production to become unsustainable (Challinor et al. 2017).

7.3.2.3 Pace of Risk: Dynamics of risk

The dynamics of risk (vulnerability, hazard and exposure) change over time both as a result of human and natural process. Biological processes, genomic regions, and specific genes, for example, can influence the vulnerability of individuals, populations and species. Adaptive phenotypic plasticity (such as altered breeding times) and genetic evolution (such as increased metabolism) can mediate the effects of environmental or climate shifts (Chevin and Lande 2010). An initially maladapted population may become less vulnerable over time as plasticity benefits accrue over time. However, species or individuals that lack such responses, or are unable to respond at the same rate, may have heightened vulnerability. Genomic regions and specific genes are involved in climate change adaptation in yellow warblers (Fitzpatrick and Edelsparre 2018). Longer lived species must evolve faster per generation to adapt to a given rate of environmental change (Chevin et al. 2010). A recent study shows that sea bird populations have been unable to adjust their breeding seasons over time in response to changes in sea surface temperature; their vulnerability will increase if they are unable to adapt to their prey (which is being changed by sea surface temperature change) (Keogan et al. 2018).

7.3.2.4 Augmentation and Reduction of Risk

Risks may become augmented through stresses with long fuses or triggering events because of linked nature of climates across different regions of the world (e.g. ENSO climatic impacts that result in large-scale droughts with multiple impacts in different countries and regions) (See Box 7.3), through socio-economic factors such as real or perceived resource limitation (e.g. when food systems fail to deliver food security or food price volatility as an aggregate perceived risk) (Challinor et al. 2017), and maladaption (see 7.5.8). Collective responses can further augment risks, especially if sudden onset, affecting a large number of people and having significant short-term impacts (Homer-Dixon et al. 2015). Risks may be reduced through adaptation, mitigation and policy measures (see 7.4, 7.5).

PLACE HOLDER - figure illustrating risk and uncertainty in relation to GHG fluxes, land (degradation, desertification), climate, and food security

Box 7.3: El Nino Southern Oscillation (ENSO)

The El Nino Southern Oscillation (ENSO) which occurs quasi-periodically influences climate, ecosystems and societies across the world and is one of the most important sources of variability in the global carbon cycle, especially for tropical forests. ENSO's relationship with regional climate such as the Monsoon has been non-linear and non-stationary. The El Nino of 2015/2016 was one of the strongest tropical climate events in the last hundred years, 20 years after the very strong 1997-98 event, and draws our attention to the future of this phenomena under climate change and the role it is likely to play in influencing the success or failure of mitigation and adaptation at diverse temporal and spatial scales. This box will illustrate the scenarios of emerging and cascading risks and possible policy responses at global scales, locally and regionally across diverse socio-ecological systems from changes in the intensity of ENSO (El Nino/La Nina) under future climate and land scenarios.

(Betts et al. 2016; Cai et al. 2015; Cane 2005; Paz and Semenza 2016; Wolter and Timlin 1998)

7.3.3 Emergent Risks and Substantive Risks

An analysis of risk as a factor of probability and impact does not work well for non-linear or 'tipping point' occurrences (such as the collapse of the West Antarctic Ice Sheet). There is *high agreement and limited evidence* that highly uncertain, low probability but high impact events that include crossing thresholds or tipping points are increasingly important for policy makers to address (Trisos et al. 2018) document that rapid Solar Radiation Management (SRM) termination would result in rapid climate change significantly increasing the threats to global biodiversity and ecosystems, especially in the tropics. SRM geoengineering is cited as a feasible and affordable technology to cool specific areas of the earth and reduce some climate risks for biodiversity, but there may be agricultural impacts and further research is needed (Caldeira et al. 2013; Kosugi 2013).

Table 7.1 Characterising land-climate risk and indicative policy responses

Table 7.1 shows hazards from land-climate-society interactions identified in other chapters or in IPCC reports; the regions that are exposed or will be exposed to these hazards; components of the land-climate systems and societies that are vulnerable to the hazard; the risk associated with these impacts and the available policy responses. The last column shows representative supporting literature.

Land-Climate-Society interaction Hazard	Exposure	Vulnerability	Risk	Policy Response (Indicative)	References
Forest dieback	Widespread across biomes and regions	Marginalised Population with insecure land tenure	• Loss of forest-based livelihoods • Loss of identity	• Land rights • Community based conservation • Enhanced political enfranchisement	(Allen et al. 2010; Sunderlin et al. 2005; Belcher et al. 2005; Soizic Le Saout and Michael Hoffmann,Yichuan Shi, Adrian Hughes,Cyril Bernard,Thomas M. Brooks,Bastian Bertzky,Stuart H.M. Butchart,Simon N. Stuart,Tim Badman 2013)
		Endangered species and ecosystems	• Extinction • Loss of ecosystem services • Cultural loss	• Effective enforcement of protected areas and curbs on illegal trade • Ecosystem Restoration • Protection of indigenous people	(Bailis et al. 2015; Cameron et al. 2016)
Fluvial flooding in urban areas	Widespread across regions	Across socio-economic strata but socially differentiated	• Loss of property • Loss of life and livelihood • Public Health impairment	• Regulation of urban land use • Pervious green spaces • LID (Low Impact Development) • Improved drainage • Upstream measure, i.e. upland restoration (peat uplands) • Sacrificial agricultural areas • Floodplain restoration	(Ashley et al. 2005; Wilby 2007; Pelling 2012; Douglas et al. 2008; Tyler and Moench 2012)
Extreme events in	Global	• Food importing countries	• Conflict	• Insurance	(Fraser et al. 2005;

Land-Climate-Society interaction Hazard	Exposure	Vulnerability	Risk	Policy Response (Indicative)	References
multiple (biophysical and management) agricultural regimes **Multi-bread basket failure**		• Low income indebtedness • Net food buyer	• Migration • Food inflation • Loss of life • Disease, malnutrition • Farmer suicides	• Social Protection encouraging diversity of sources • Climate smart agriculture	Schmidhuber and Tubiello 2007; Lipper et al. 2014a)
Changes in river systems	1.5 billion people, Regional (e.g. South Asia, Australia) Aral sea and others	• Water intensive agriculture • Fresh-water, estuarine and near coastal ecosystems • Fishers • Endangered species and ecosystems	• Loss of livelihoods and identity • Migration • Indebtedness	• Assess performance of climate model in simulating historical regional climate • Build alternative scenarios • Experiment with Alternative crop and water management strategies • Redefine SDGs to include fresh-water ecosystems	(Craig 2010; Di Baldassarre et al. 2013; Verma et al. 2009; Ghosh et al. 2016; Higgins et al. 2018)
Exhaustion of ground-water	Wide-spread across biomes and regions	• Farmers, drinking water supply • Irrigation • See forest note above • Agricultural production • Urban sustainability (Phoenix, US)	• Food insecurity • Migration • Disease	• Adaptation strategies that reduce dependence on deep ground water	(Wada et al. 2010; Rodell et al. 2009; Taylor et al. 2013)
Climate change impacts on land and water including impacts of mitigation measures	Across various biomes	• Farmers and pastoralists • Endangered species and ecosystems	• Regional food insecurity • Downstream impacts on biodiversity, ecosystem services and marginalised communities	• Avoidance • Mitigation of impacts	(Zomer et al. 2008; Nyong et al. 2007a; Pielke et al. 2002; Schmidhuber and Tubiello 2007; Jumani et al. 2017a; Eldridge et al. 2011)
Ecosystem shifts: e.g. Bush and woody encroachment in grasslands and pasture lands	Wide-spread across grass/semi-arid biomes	• Farmers and pastoralists • Biodiversity	• Downstream impacts on food security, biodiversity, ecosystem services and marginalised communities	• Adaptive management of fire, livestock and wild herbivores	(Eldridge et al. 2011; Asner et al. 2004; Moleele et al. 2002)
Competition for land e.g. Plastic substitution	Peri-urban and rural areas in developing	• Rural landscapes; farmers; charcoal suppliers; small	• Land degradation; loss of ecosystem services; GHG	• Sustainability certification; producer permits; subsidies	(Woollen et al. 2016; Kiruki

Land-Climate-Society interaction Hazard	Exposure	Vulnerability	Risk	Policy Response (Indicative)	References
by cellulose, Charcoal production	countries	businesses	emissions; lower adaptive capacity	for efficient kilns	et al. 2017)
Overharvesting of biomass and/or dependence on traditional cookstoves	Mainly poor rural areas in developing countries	• Rural landscapes; poor households; women and children	• GHG emissions, indoor air pollution, short-lived climate forcers	• Subsidies for cleaner fuels and stoves; promotion of managed woodlots	(Woollen et al. 2016; Bailis et al. 2015)
Land degradation and desertification	Arid, Semi-arid and sub-humid regions	• Farmers • Pastoralists • Biodiversity	• Food insecurity • Migration • Loss of agro and wild biodiversity	• Restoration of ecosystems • Climate smart agriculture and livestock management • Managing economic impacts of global and local drivers	(Fleskens, Luuk, Stringer 2014; Lambin et al. 2001)
Loss of snow and glaciers	Boreal, Mountain regions and downstream river basins	• Riparian Ecosystems • Mountain villages and towns	• Summer flows of rivers • Loss of biodiversity	• Climate change mitigation • Prioritize remaining high elevation and latitude biodiversity hotspots to reduce non-climatic stressors • Maintain ecological flows	(Barnett et al. 2005a)
Coastal inundation	Islands, coasts and deltas	• Cities, towns, delta farmers, fishing communities, • Estuaries, mangroves, Beach and dune ecosystems	• Loss of infrastructure, livelihoods and migration	• Adaptation to transforming ecosystems • Planned migration	(Tribbia and Moser 2008a)
Loss of carbon sinks	Wide-spread across biomes and regions	• Tropical forests • Boreal soils	• Feed-back to global and regional climate change	• Conservation prioritisation of tropical forests • Afforestation	(Barnett et al. 2005b; Tribbia and Moser 2008b)
Permafrost destabilisation	Arctic and Sub-Arctic regions	• Soils • Indigenous communities • Biodiversity	• Enhanced GHG emissions	• Enhanced carbon uptake from novel ecosystem after thaw • Adapt to emerging wetlands	(Schuur et al. 2015)

7.3.3.1 Extreme Events

The length or number of warm spells or heat waves has increased in many areas of the world and many are experiencing more intense, frequent, and longer droughts. At the same time, and often in the same place that drought is being experienced, torrential rains and flooding is occurring (Modarres et al. 2016; Mann et al. 2017). Other extreme events resulting from climate change and documented in chapter 6 are anticipated to have impacts on human systems and livelihoods, socio-economic factors, and food security as detailed in Table 7.1.

7.3.3.2 Loss of biodiversity and ecosystem services

Climate change is a great risk to maintaining biodiversity and ecosystem services. According to the Millennium Ecosystem Assessment (Millennium Ecosystem Assestment 2005), climate change is likely to become one of the most significant drivers of biodiversity loss by the end of the century. Climate change is already having an impact on biodiversity, and is projected to become a progressively more significant threat in the coming decades; loss of Arctic sea ice threatens biodiversity across an entire biome and beyond; the related pressure of ocean acidification, resulting from higher concentrations of carbon dioxide in the atmosphere, is also already being observed (Secretariat of the Convention on Biological Diversity 2009). (Parry et al. 2007) suggest that approximately 10% of species assessed so far will be at an increasingly high risk of extinction for every 1°C rise in global mean temperature, within the range of future scenarios modelled in impacts assessments (typically <5°C global temperature rise). There is ample evidence that climate change affects biodiversity. Although there is relatively limited evidence of current extinctions caused by climate change, studies suggest that climate change could surpass habitat destruction as the greatest global threat to biodiversity over the next several decades (Pereira et al. 2010). However, the multiplicity of approaches and the resulting variability in projections make it difficult to get a clear picture of the future of biodiversity under different scenarios of global climatic change (Pereira et al. 2010).

7.3.3.3 Vulnerability of carbon sinks (e.g. BECCS)

Mitigation scenarios stabilising temperature change at or below 2°C relative to pre-industrial levels typically rely heavily on BECCS and/or afforestation (AR5 WGIII, Ch11; SR1.5, Ch2; this report Ch2; (Millar et al. 2017)). In essence, these strategies are transferring emitted carbon previously stored in geological reservoirs into the terrestrial biosphere (afforestation) or back to a geological layer or aquifer (BECCS) (Smith et al. 2015). The carbon sequestered in terrestrial ecosystems as in the case of afforestation is directly exposed to changing climate conditions, climate extremes, fires, insect outbreaks and other disturbances thus threatening the permanency of carbon storage and therefore the overall effectiveness of the approach. This represents an emergent risk that is currently not accounted for in future land use scenarios (Popp et al. 2017). E.g. forest mortality under climate change (McDowell and Allen 2015) and wildfire (Balshi et al. 2009). The level of risk will be directly affected by the magnitude and rate of future climate change. The AR5 WGII report highlighted that, in medium to high-emission scenarios, increased tree mortality and associated forest dieback is projected to occur in many regions over the 21st century, due to increased temperatures and drought (*medium confidence*). In contrast, this risk remains limited in low emission scenarios and therefore afforestation measures will be most effective when combined with a decarbonisation of the energy sector consistent with the Paris Agreement goal. In addition to the vulnerability of the carbon stored in the terrestrial biosphere, there is also the issue of the long-term stability of the carbon re-injected in geological reservoirs (specifically for the case of BECCS).

7.3.3.4 Migration

The First Assessment Report of the IPCC (1990) included mention of environmentally induced migration, and empirical studies have accelerated since this time (Warner 2010; Warner et al. 2010), recognising that people respond to weather change and climate related factors (in tandem with other variables) and people act as agents choosing their future about how and where to live (Hendrix and Salehyan 2012). Displacement may occur because of extreme events, whereby people return once conditions return to normal; weather dependent livelihood systems may deteriorate from slow onset events causing people to move in search of alternative livelihoods in the short to medium term; climate may interact with social conflict causing movement at larger scales (detailed below) and long term deterioration in habitability of regions could trigger spatial population shifts (Denton et al. 2015).

7.3.3.5 Urbanisation

There is *low agreement and limited evidence* that people don't always move away from environmental risks, but may move towards environmental risks, due to drivers of urbanisation (Geddes et al. 2012; Adger et al. 2015). Growing urban areas from rural population migration may lead to exposure to - and a state of being trapped in - serious risk due to health, poor building standards and mud slides etc. (Geddes et al. 2012; Adger et al. 2015)

7.3.3.6 Conflict over Resources

Climate change and climate change migration could be a factor leading to tensions over scarce strategic resources, exacerbating fragile States into socio-economic and political unrest (Carleton et al. 2016). Increasing conflict could be in relation to land when rainfall patterns change, thereby degrading land and vegetation and impacting productions systems, particularly where there is rain fed agriculture or subsistence farming (Papaioannou 2016; Wario, Adano, R., Fatuma 2012). There is *low agreement and limited evidence* on the extent that climate change versus politics link directly to violent conflict (Barnett and Adger 2007; Scheffran et al. 2012; Nordaas and Gleditsch 2015), but there is *medium agreement and medium evidence* that governance is key in magnifying or moderating climate change impact and conflict (Oshiek 2015).

Climate change and climate change induced development responses in countries and regions are likely to enhance conflicts over water and land its impact on agriculture, fisheries, livestock and drinking water downstream (Raleigh and Urdal 2007; Vörösmarty et al. 2000). Shared pastoral landscapes used by marginalised communities are particularly impacted by conflicts that are likely to become more severe under future climate change (Hendrix and Glaser 2007). Extreme events could considerably enhance these risks, in particular long-onset droughts (Wilhite and Pulwarty 2017).

Mitigation measures such as solar farms and hydro-electric projects could potentially impact livelihoods and resources for marginalised communities and reduce socio-ecological resilience and resistance to these could impact mitigation strategies (Turney and Fthenakis 2011; Chowdhury and Kipgen 2013). Land based mitigation measures could benefit from additional criteria of quality of soil for other potential competing uses under a changed climate such as food and livestock production.

Multi-national agreements on water sharing are currently inadequate in covering issues related to shared resources and ecosystem services (Lebel et al. 2005). Poff et al. (2003) identify four key elements for successful decision making to resolve conflicts: conduct ecosystem-scale experiments through controlled river flow manipulations with existing projects; more cooperative interactions among diverse stakeholders; experimental results be synthesised across studies to allow broader generalisation to other regions; and new, innovative funding partnerships at local and regional scales engage to broadly involve scientists, government, the private sector, and NGOs.

Adoption of wide scale BECCS and solar coupled with increasing demand for land from urban development and resources substitution such as plastics has the potential for increased conflict and displacement. This is an identified research gap.

7.3.3.7 Cascading Risk of Migration and Conflict

Biodiversity will be severely impacted by climate change induced land degradation and ecosystem transformation (Pecl et al. 2017). This may impact humans directly and indirectly through cascading impacts on ecosystem function and ecosystem services (Millennium Assessment 2005). Climate change induced human migration is likely to impact biodiversity in two ways: movement into areas that are suitable for biodiversity now and in the future, and; new areas that are suitable for migrating biodiversity under changed climate but may be occupied by migrating humans under climate and land degradation stress (Oglethorpe, J., Ericson, J., Bilsborrow, R.E. and Edmond 2007).

The policy and management approaches to conserving biodiversity in a changing climate include: population restoration: reintroduction and reinforcement, conservation introductions, assisted colonisation or migration, ecological replacements (Rebuilding ecosystems by removing invasive species and introducing ecological replacements) as well rewilding (McLachlan et al. 2007; Seddon et al. 2014). Interventions under the current scenarios of millions of people migrating across frontiers are already being tested successfully (Oglethorpe, J., Ericson, J., Bilsborrow, R.E. and Edmond 2007).

Limiting greenhouse gas emissions will allow more time for species to adapt. However, movement of biodiversity poleward or to higher elevations will be more complicated for aquatic biodiversity compared to terrestrial biodiversity because of the linear nature of river systems especially those that are east-west (Pereira et al. 2010). Combined with ongoing and future transformations of water systems for other development goals, loss of aquatic biodiversity is a cascading risk. Policy and decision support systems that go beyond narrow economic criteria to include socially valued ecosystem functions and services such as EEDS offer promise for stakeholder defined metrics under unknown climate states (Poff et al. 2016). Alien species and novel ecosystems that could replace native biodiversity and displace existing ecosystems pose both challenges and opportunities for adaptation and mitigation (Walther et al. 2009). Policy and management responses, such as assisted migration of biodiversity or introduction of non-native biodiversity in new regions under climate change or land sparing and land sharing approaches to conservation, are still being debated and are a big source of uncertainty, disagreement and concern. Uncertainty and disagreement about policy and management approaches can be reduced considerably by integrating social sciences in conservation planning and scenario building (Perrings et al. 2011; Dawson et al. 2011).

7.3.3.8 Food, Health and Nutrition

There is little understanding of how food system shocks cascade through a modern interconnected economy (Benton et al. 2017; Centeno et al. 2015; Puma et al. 2015a; Maynard 2015). Further, reliance on global markets can carry a systemic risk and on-going globalisation of food trade networks exposes the world food system to new impacts that have not been seen in the past. The global food system is vulnerable to systemic disruptions and increasingly interconnected inter-country food dependencies and changes in frequency and severity of extreme weather events may complicate future responses (Puma et al. 2015a; Jones and Hiller 2017).

There is a complex interplay among different environmental changes, including land dynamics, climate change, and resource scarcity that increase human exposure to infectious diseases, access to food and water, protection from natural and other hazards, and impact negatively human health (Myers et al. 2013). In addition, there can be insulating factors or processes that protect populations from negative health outcomes, specifically, in the relationship between public health and climate change at global scales. (Watts et al. 2015) shows how the inclusion of demographic trends including ageing, migration and population growth, makes the affected population larger than expected in other global reports (Smith et al. 2014a). Little capacity to respond to food production shocks exists at global levels. Rather, most capacity exists at the national scale or lower and policy interventions are prioritised for national interests. This leads to poor coordination at regional and global scales. Coordinated responses at scale will require a holistic international framework (Jones and Hiller 2015, 2017). Responses in advance to address food production shocks could include investment in food buffer stocks and protection of agriculturally productive lands (Puma et al. 2015a). Global or regionally integrated food buffer stocks and emergency reserves need to be large enough to be of assistance (Jones and Hiller 2015). To better model, predict, respond to and prepare for concurrent agricultural failures, and gain a more systematic assessment of exposure to agricultural climate risk, large data gaps need to be filled, as well as gaps in empirical foundation and analytical capabilities (Janetos et al. 2017; Lunt et al. 2016). Data required include global historical datasets, many of which are unreliable, inaccessible, or just unavailable (Maynard 2015; Lunt et al. 2016). Assessment of socio-economic and spatial dynamics poses challenges (Jurgilevich et al. 2017). Challenges to scenario-guided adaptive action on food security under climate change include developing long-term shared capacity for strategic planning – both development of the capacity to produce anticipatory knowledge and also the capacity to use it (Vervoort et al. 2014).

There is a well-established relationship between extremely high temperatures and morbidity and mortality (Watts et al. 2015). Quantitative assessments and statistical modelling for all regions of the world show an increase in *additional deaths* attributable to climate change induced heat waves, in virtually all regions of the world (World Health Organization 2014); on average, 37,588 additional deaths for 2030 and 94,621 additional deaths for 2050 will occur due to climate change induced heat waves. Land cover and land use change is important to explain heat waves, specifically changes related to the increase of impervious surfaces like asphalt, cement, roofs in urban centres, which can produce 30°C to 40°C difference from surrounding air (Frumkin 2002) and increase 5°C to 11°C compared to surrounding rural areas (Aniello et al. 1995). This phenomenon converts cities to “heat islands,” which exacerbate the effect of extreme heat waves in cities (Li et al. 2015). On the other hand, very strong cooling effect in terms of surface temperature has been identified in regions where the proportion of vegetation cover was between 70% and almost 80% per square kilometre (Alavipanah et al. 2015).

It is also well documented how vectors of infectious diseases, including mosquitos, ticks, sandflies and others, and infectious agents, such as protozoa, bacteria, and viruses, are extremely dependent on the dynamics of ecological conditions, including climate and land cover change (Smith et al. 2014a). For example, for dengue and chikungunya, (Campbell et al. 2015) indicate complex global rearrangements of potential distributional areas for the two main vectors, which are likely to translate into actual distributional shifts across the globe.

Much attention has been put into the effects of climate and land change with regards to malaria. The WHO (World Health Organization 2014) estimates 60,091 additional deaths for climate change induced malaria for the year 2030 and 32,695 for 2050. There is an ongoing debate on the impacts of climate change in relation to malaria, especially in Africa, where new research shows how changes in temperature will change suitability areas for the transmission of malaria, and will shift very high-risk areas and temporal cycles to places that did not experience it before (Ryan et al. 2015; Terrazas et al. 2015; Kweka et al. 2016), but also ameliorate the impact in areas previously impacted (Yamana et al. 2016). In terms of the nexus between land cover change and malaria, there is also contrasting findings. In the Amazon for example, new research shows that deforestation will increases malaria, where vectors are expected to increase their home range (Alimi et al. 2015) but also shows how the association between forest status and malaria can be confounded with multiple factors such as water bodies, social-economic conditions and immunity (Tucker Lima et al. 2017). Moreover, not only net loss of forest is important, but also edge effects and fragmentation have been found to exacerbate malaria transmission (Barros and Honório 2015). In Asia and specifically in China, taking into consideration land use and urbanisation simultaneously, Ren et al. (2016) predict a substantial net increase in the population exposed to the four dominant malaria vectors in the years 2030 to 2050. Here, deforestation has been shown to enhance the survival and development of larvae major malaria vectors (Wang et al. 2016). New research has found key differences across regions and there still is considerable uncertainty related to the differences in data and climatic scenarios, spatial explicit methods in infections modelling, and how to capture local climatic effects in disease prediction.

7.3.4 Economic Costs – What is at stake?

Healthy functioning land and ecosystems are essential for human health, food and livelihood security. While many of the values are inestimable in an economic sense, others can be appraised, at least partially, and the numbers are substantial. One study estimated the value of ecosystem services in 2011 at 125 trillion USD per year, showing a loss from 2007 due to land use change of 4.3 – 20.2 trillion USD per year (Costanza et al. 2014; Rockström et al. 2009). A preliminary regional assessment suggested the economic value of ecosystems like coastal and freshwater wetlands in West Asia to approach 7.2 billion USD in 2007 USD (Eppink et al. 2014). Land-climate change interactions pose a significant threat to these values, and evidence about economic costs as a subset of these values illustrates how substantial climate impacts may become.

Understanding the full cost of what is at stake from climate change presents challenges because of inadequate accounting of how much climate change and land interactions impact society, and the value of those impacts for society (Santos et al. 2016). Concerns related to negative impacts from land-climate interactions pertain fundamentally to issues of valuation (Paracchini et al. 2016). Some values people assign to land are inalienable when it becomes degraded or lost and when symbolic value is high, such as ancestral ties to the land, or traditional and indigenous knowledge systems (Morrissey and Oliver-Smith 2013; Boillat and Berkes 2013). Such inestimable values of land are core to social cohesion—sense of community, social norms and institutions, and trust, which are linked to shared symbolic understandings related to land and space. Symbolic value, and the systems that maintain it, lie at the heart of social capital which is central to resilient societies (Adger 2009). The destruction of such symbolically valuable goods can therefore result in major losses in human well-being, which are not captured in economic terms.

There is a perception that acting on climate change involves a trade-off with economic growth. However, a range of studies have attempted to estimate the economic impacts of climate change, and while the values are not directly comparable (due to differences in modelling approaches, assumptions and time periods) they range from a global average reduction in GDP from 0% of GDP to 11.5% of GDP (Tol 2014). Another study estimated that global incomes would decline by 23% by 2100 with unmitigated warming (Burke et al. 2015). This range includes earlier appraisals (e.g. Nordhaus 2014) that have been criticised for the credibility of their damage functions (Stern 2016; Diaz and Moore 2017), and since then methods have been refined, resulting in higher magnitudes of costs. Most studies show increasing effects on GDP as global mean temperatures increase. There is compelling evidence (Schleussner et al. 2016; e.g. Pretis et al. 2018) that impacts in a 1.5˚C warmer world will fall within the range of natural variability, while 2˚C of warming may mean a shift in the climate regime (although some countries are identifying significant impacts at less than 1.5˚C (Li et al. 2018) .

Although current economic models do not yet fully capture the negative economic impacts of a world 1.5˚C above pre-industrial levels, evidence suggests substantial threats to coastal communities, fisheries and ecosystems related to coral reef tipping points within this range (Schleussner et al. 2016). Some of the places and systems most likely to be affected by this difference are those already vulnerable to certain impacts, such as the Mediterranean (including North Africa and the Levant) which is projected to become a hotspot for reductions in water availability and increases in dry spell periods between 1.5˚C and 2˚C (Schleussner et al. 2016). Extreme heat and crop yield reductions are expected to increase most in tropical regions in Africa and South-East Asia under 2˚C warming, which combined with the other stressors these regions already face, may be very difficult to adapt to. Beyond localised economic effects, a 2˚C warming scenario is likely to be associated with significantly lower projected economic growth for a large set of countries (Pretis et al. 2018) (*medium* *confidence, medium agreement*). The implications of this understanding are that limiting temperature increase to below 1.5˚C may avoid a number of impacts and implications that will be much harder to adapt to.

At higher levels of mean global temperature, economic damages caused as a result of climate change are estimated at between 7%-8% of global GDP for a 3˚C increase, and between 9%–10% when including catastrophic risks (Howard and Sterner 2017) (*medium confidence, medium agreement*). While most studies project greater reductions in lower income countries, studies show that economic activity in all regions is coupled to the global climate (Burke et al. 2015). However, warming is likely to amplify global inequalities (*high evidence, high agreement*) (Burke et al. 2015; Tol 2018).

[Placeholder on or referring to evidence on costs of land degradation, desertification, etc.]

7.3.4.1 The costs and timing of action

The costs of adapting to these impacts are also projected to be substantial (recognising also that the delineation between the cost of impacts and the cost of adaptation is blurred). The evidence for the costs of adaptation at a global level is limited, and summarised in (Chambwera et al. 2014a). These studies primarily identify the magnitude of adaptation finance needed and indicate huge values ranging from 9 to 166 billion USD per year at various scales and types of adaptation, from capacity building to specific projects. Other studies estimating residual costs suggest even higher values (Parry et al. 2009). However the value and accuracy of these aggregated costs is questionable, compared with more detailed sectoral level studies (Fankhauser 2017).

In the humanitarian sector, in areas such as food security, early action yields economic benefits greater than costs (*high agreement, high evidence*) (Fankhauser 2017; Wilkinson et al. 2018; Venton 2018; Venton et al. 2012). Studies show that for every dollar spent on disaster mitigation and risk reduction activities, between 4 and 11 USD in disaster-related economic losses can be prevented (Clarvis et al. 2015). In Kenya, Somalia and Ethiopia, early humanitarian response for drought would save an estimated 1.6 billion USD in aid costs over a 15-year period (Venton 2018). If avoided losses are also included in cost estimates, such early response could save 2.5 billion USD or an average of 163 million USD per year (Venton 2018). Modeling of household level data for 2.6 million people in the Zambezi Valley and Limpopo Basin suggests that early response to droughts and floods could save between 330 million and 2 billion USD over 20 years (Venton et al. 2013). Similar trends exist for health interventions. Prevention of diseases, including non-communicable diseases related to diet and consumption, offers a higher return on investment than disease control (Nugent et al. 2018). Benefit–cost ratios of non-communicable disease prevention vary by intervention but generate an average economic return of 5.6 and social returns of 10.9 (Bertram et al. 2018). Early action in other sectors can also result in win-win outcomes or co-benefits in the current climate (Fankhauser 2017), for example through ecosystem-based adaptation measures that can provide biodiversity, water and soil quality, carbon sequestration and recreation co-benefits (McVittie et al. 2018).

Despite this evidence, decision makers often discount future or geographically remote risks (Challinor et al. 2017; Clarke and Dercon 2016). Lack of investment in early action reflects the lack of incentives to allocate funds in advance of crisis (Clarvis et al. 2015; Clarke and Dercon 2016) A perceived risk in responding early is that funds will be released unnecessarily for situations that turn out not to be disasters. However, one study suggests that donors could mistakenly release funds six times in Mozambique before the cost is equivalent to the cost of humanitarian aid for one event (Venton et al. 2013).

Not only is timing important, but the type of intervention itself can influence returns (*high agreement, high evidence*). Policy packages that make people more resilient - expanding financial inclusion, disaster risk and health insurance, social protection and adaptive safety nets, contingent finance and reserve funds, and universal access to early warning systems – could save 100 billion USD a year, if implemented globally (Hallegatte et al. 2017). In Ethiopia, Kenya and Somalia, every 1 USD spent on safety net/resilience programming results in net benefits of between 2.3 and 3.3 USD (Venton 2018). Investing in resilience building activities, which increase household income by 365 to 450 USD per year in these countries, is more cost effective than providing ongoing humanitarian assistance.

There is a need to further examine returns on investment for land-based adaptation measures, both in the short and long term. Other outstanding questions include identifying specific triggers for early response. Food insecurity, for example, can occur due to a mixture of market and environmental factors (changes in food prices, animal or crop prices, rainfall patterns) (Venton 2018). The efficacy of different triggers, intervention times and modes of funding are currently being evaluated (see for example forecast based finance study (Alverson and Zommers 2018). To reduce losses and maximise returns on investments, this information can be used to develop: 1) coordinated, agreed plans for action both pre and post-event action; 2) a clear, evidence-based decision-making process, and; 3) financing models to ensure that the plans for early action can be implemented (Clarke, Daniel; Dercon 2016).

Early action on reducing emissions (mitigation) is also estimated to result in both lower temperature increases as well as lower costs than delayed action (Luderer et al. 2013). Continued inaction reduces the future policy option space, reduces economic growth and increases the challenges of mitigation (Moore and Diaz 2015; Luderer et al. 2013).

The cost of reducing emissions is generally estimated to be considerably less than the costs of the damages. A number of studies identify these costs on a global level (Klenk et al. 2015; Kainuma et al. 2013) or at a national, subnational, sectoral or project level (e.g. (Moran 2011; Sanchez 2016).

The residual impacts of climate change that we are not able to avoid through emissions reductions and that people have not been able to cope with or adapt to come under the category of ‘loss and damage’ (Warner and van der Geest 2013). While there is considerable overlap between all of these cost categories, the implications are clear: the more harm from climate change we fail to avoid through adaptation and mitigation, the more that will have to be addressed through contingency arrangements (Verchick 2018), some of which may involve changing values and objectives or accepting that it may no longer be possible to secure those objectives (Dow et al. 2013b; Kates et al. 2012). But while some damages can be valued in economic terms, such as crop failure, others are less able to be valued, or compensated for, such as irreversible land use change, species extinction, and loss of social cohesion and social disarticulation (Romero Manrique et al. 2018; Below et al. 2012; Tschakert 2014). Finding the right balance between these types of costs is a complex question, informed by local and global social, cultural, environmental and economic priorities.

Case Study – Indonesia (Mercy Corps Indonesia and EcoMetrix Solutions Group 2018)
(Placeholder)

7.3.5 Conceptualising key, substantive and emergent risks

Figure 7.1 embodies uncertainty and risk. It captures case studies and examples of key, substantive, emerging and cascading risks from land-climate-society interactions defined along three dimensions: The three axes are described as: x= scale (spatial and temporal), y= disagreement (norms, values, and priorities) and z= uncertainty in knowledge. The level of risk is indicated by a simple sum of three numbers. The level of uncertainty in respect of each case study is assessed from 1 (low uncertainty/disagreement/local scale) to 3 (high uncertainty/disagreement/distant scale). The size and the grey scale intensity shade of the bubble is proportional to the level risk (sum). The numbers inside the bubble indicate trade-offs with respect to some specific combination of the 17 SDGs and three additional goals related to including Life and Rivers, Ecosystem services, and Response to Land, Climate interactions which are shown in Figure 7.1. Within the bubbles a number appears; in the box below the figure these numbers appear with the associated references supporting the bubble.

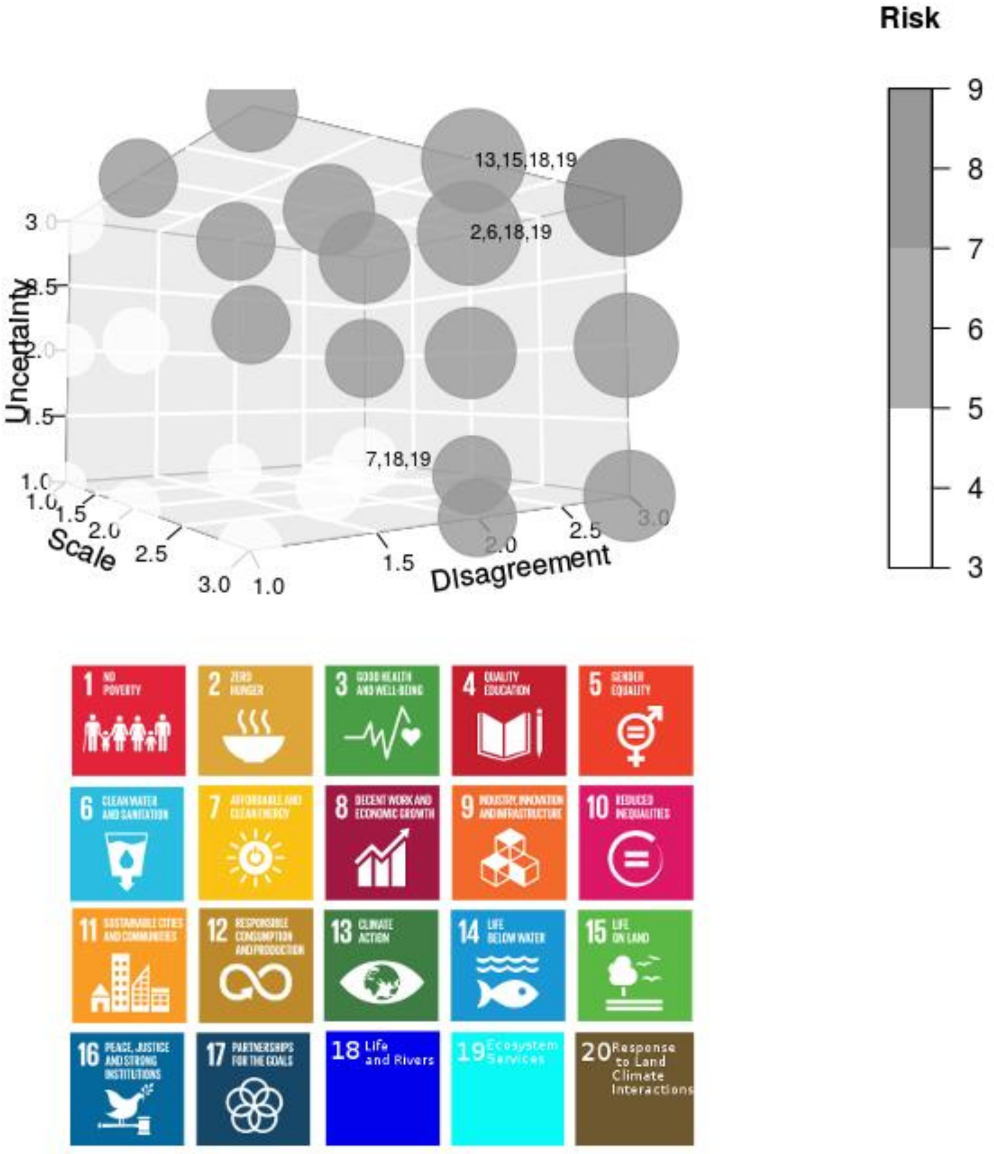

Figure 7.1 Characterising risk on dimensions of disagreement on norms and priorities, scale and uncertainty

7.4 Policy Response to Risk

This section outlines responses to risk. It describes limits and barriers to adaptation (7.4.1), policy instruments responding to risk (7.4.2), effectiveness of instruments (7.4.3), policy mix and suites of policy instruments (7.4.4) and multi-level response to risk (7.4.5).

7.4.1 Multi-level response to risk

Policy responses and planning in relation to land and climate interactions occur at and across multiple levels, involve multiple actors, and utilise multiple planning mechanisms (Urwin and Jordan 2008). Climate change is occurring on a global scale while the impacts of climate change vary from region to region. Therefore, in addressing local climate impacts, local governments and communities are key players since local areas have high vulnerabilities and great need for climate resilience. Advancing governance of *climate change* across all *levels* of government and relevant stakeholders is crucial to avoid policy gaps between local action *plans* and national policy frameworks (Corfee-Morlot et al. 2009).

The immediate challenge is incorporating ecological restoration and biodiversity concerns in top down NDC and SDG climate mitigation and adaptation targets, as well as bottom up and decentralised conservation. These could be combinations of land sharing, land sparing and ecosystem based adaptation approaches using economic and normative instruments across both state, community and private sectors (Busch and Mukherjee 2017; Agrawal et al. 2008; Colls et al. 2009). Although the role of biodiversity (both wild and managed) in underpinning ecosystem services and enhancing resilience of socio-ecological systems to perturbations, including extreme events and climate change is now well recognised amongst the scientific community, its influence on policy and decision makers is still limited (Elmqvist et al. 2003; Albert et al. 2014). One of the challenges is finding agreement on “desirable” future states of ecosystems and integrating this with economic and other policy instruments (Ring and Schröter-Schlaack 2011; Tallis et al. 2008). The incorporation of biodiversity and ecosystem services perspectives in management responses and development planning under climate change is a “wicked problem” in part due to disagreement on values, norms and priorities (Perry 2015).

One of the response options agreed at COP21 was the effective implementation of restoration projects and programmes which “helps to achieve many of the Aichi Targets under the CBD, but also ecosystem-based adaptation and climate change mitigation under the UNFCCC, striving towards land degradation neutrality and Zero Net Land Degradation under the UNCCD” (Aronson and Alexander 2013). Success of restoration approaches to conserving biodiversity and ecosystem services is often based on incremental knowledge from pilot projects and can progress only with bold experiments at various spatial scales across the globe (ibid.). Achieving a transformative 2012 United Nations Rio+20 Conference on Sustainable Development target of restoring 150 million ha of disturbed and degraded land globally by 2020 is severely constrained by knowledge and technology capacity (Menz et al. 2013). Many top down climate change mitigation initiatives are still largely carbon centric with limited opportunities for decentralised ecological restoration at local and regional scales (Vijge and Gupta 2014). The current IPBES initiative seeks to generate policy relevant knowledge for sustainable management of biodiversity and ecosystem services at all relevant spatial scales using a “co-constructive” approach that involves a diversity of stake-holders and may achieve the goal of agreement on desirable state of human-nature interactions (Díaz et al. 2015).

7.4.2 Policy instruments responding to risk

Policy instruments are used to influence behaviour and affect a response to do, not do, or continue to do certain things (Anderson 2010) and can be invoked at multiple levels (international, national, regional, and local) by multiple actors. For efficiency, equity and effectiveness considerations, the appropriate choice of instrument for the context is critical, and across the topics addressed in this report the instruments will vary considerably. A key consideration is whether the benefits of the action will generate private or public net benefits. (Pannell 2008) provides a widely-used framework for identifying the appropriate type of instrument depending on whether the benefits of the actions are private or public, and positive or negative. Positive incentives (such as financial or regulatory instruments) are appropriate where the public net benefits are highly positive and the private net benefits are close to zero. This is likely to be the case for many GHG mitigation measures. Extension (knowledge provision) is recommended for when public net benefits are highly positive and private net benefits slightly positive, again for some GHG mitigation measures, and many adaptation, food security and sustainable land management measures. Where the private net benefits are slightly positive but the public net benefits highly negative, negative incentives (such as regulations and prohibitions) are appropriate, for example over-application of fertiliser.

While this is a useful framework, policy-makers should be aware that it does not address considerations relating to the time-scale of actions and their consequences particularly in the long time-horizons involved under climate change: private benefits may accrue in the short term but become negative over time (Outka 2012) and some of the changes necessary will require transformation of existing systems ((Park et al. 2012; Hadarits et al. 2017) and see section 7.3.2.2) for which a more comprehensive suite of instruments would be necessary. Furthermore, the framework applies to private land ownership, so where land is in different ownership structures, different mechanisms will be required. Indeed, land tenure is recognised as a factor in barriers to decision-making (see 7-74). A thorough analysis of the implications of tools temporally, spatially and across other sectors and goals (e.g. climate v. development) is essential before implementation to avoid unintended consequences (7-57) and policy incoherence (7-69).

Climate change increases disaster risk from both extreme events and slow onset events. Thereby, climate change adaptation requires more comprehensive risk management. Comprehensive risk management encompasses risk assessment, reduction, transfer, retention, including social protection instruments such as insurance and transformational approaches to build resilience and to strengthen adaptive capacity._Climate related risk could be categorised by climate impacts like event type, such as flood, drought, cyclone etc. (Christenson et al. 2014). Table 7.2 outlines instruments relating to impacts responding to the risk of climate change. Categories of instruments include regulatory instruments (command and control measures), economic and market instruments (creating a market, sending price signals, or employing a market strategy), voluntary of persuasive instruments (persuading people to internalise behaviour), and managerial (arrangements including multiple actors in cooperatively administering a resource or overseeing an issue) (Gupta, J., van der Grijp, N., Kuik 2013; Hurlbert 2018b).

Given the complex spatial and temporal dynamics of risk, a portfolio of responses is required to comprehensively manage risk. Operationalising a portfolio response can mean layering, sequencing or integrating approaches. *Layering* means that within a geographical area, households are able to benefit from multiple interventions simultaneously (e.g. those for family planning and those for livelihoods development). A *sequencing* approach starts with those interventions, which address the initial binding constraints, and then further interventions are later added (e.g. the poorest households first receive grant-based support before then gaining access to appropriate microfinance or market-oriented initiatives). *Integrated* approaches involve cross-sectoral support within the framework of one program (Scott et al. 2016).

It is important to understand the nature of risk. If shocks are temporary, then policies aimed at stabilising short-term income fluctuations (such as increasing rural credit or providing social safety net programs) may be appropriate (Ward 2016). Life cycle approaches to social protection are one approach, which some countries (such as Bangladesh) are using when developing national social protection policies. These policies acknowledge that households face risks across the life cycle from which they need to be protected.

If shocks are persistent, or occur numerous times, then policies should address concerns of a more structural nature (Glauben et al. 2012). (Barrett 2005) for example, distinguishes between the role of safety nets (which include programs such as emergency feeding programs, crop or unemployment insurance, disaster assistance, etc.) and cargo nets (which include land reforms, targeted microfinance, targeted school feeding program, etc.). While the former prevents non-poor and transient poor from becoming chronically poor, the latter is meant to lift people out of poverty by changing societal or institutional structures. The graduation approach has adopted such systematic thinking to much success (Banerjee et al. 2015).

The International Organization of Standardization provides risk management principles, guidelines, and frameworks for explaining the elements of an effective risk management program (ISO 2009). The standard provides practical risk management tools and makes a business case for risk management investments (McClean et al. 2010). Insurance addresses impacts associated with extreme weather events (storms, floods, droughts, temperature extremes), but it can provide disincentives for reducing disaster risk at the local level through the transfer of risk spatially to other places or temporally to the future (Cutter et al. 2012) and uptake is unequally distributed across regions and hazards (Lal et al. 2012). Insurance instruments can take many forms (traditional indemnity based, market based crop insurance, property insurance), and some are linked to livelihoods sensitive to weather as well as food security (linked to social safety net programs) and ecosystems (coral reefs and mangroves), and can provide a framework for risk signals to adaptation planning and implementation and facilitate financial buffering when climate impacts exceed current capabilities to manage delivered through both public and private finance (Bogale 2015; Greatrex et al. 2015; Surminski et al. 2016). A holistic consideration of all instruments responding to extreme impacts of climate change (drought, flood etc.) is required in assessing if policy instruments are promoting livelihood capitals and contributing to the resilience of people and communities (Hurlbert 2018b).

Table 7.2 Policies/Programmes/Instruments that address multiple land-climate risks at different jurisdictional levels

Scale	Policy/Programme/ Instrument	Food Security	Land degradation & desertification	Sustainable land management	Energy access	Hazards (Flood)	Hazards (Drought)	Hazards (Forest Fires)	GHG flux climate change mitigation
Global	Multi-tier global tracking framework (IEA and World Bank)				X				
	Paris Commitments			X					
	Forest carbon offsets/REDD				X				X
	SENDAI Framework					X	X	X	
	Global Facility for Disaster Reduction and Recovery (World Bank)					X			
	International risk standards					X			
	Sustainability Certification of biomass			X	X				X
	Global Index Insurance Facility (World Bank)					X			
	Global Alliance for Clean Cookstoves				X				X
	Weather Risk Insurance Facility	X				X			
	Sustainable Energy for All				X				
	Global Alliance for Clean Cookstoves				X				
	International Organization for Standardization (ISO)		X	X	X				X
Regional	Global Alliance for Resilience (Africa)	X		X					
	Renewable Energy Standards/ targets/Incentives (EU)				X				
	Comprehensive Africa Agriculture Development Programme (CAADP)	X							
	Energy Sector Management Assistance Programme (World Bank)				X				
	Land Degradation Neutrality (LDN)			X					X
	Regional Forestry strategy			X				X	
National	Forest Protection Policy/Plans		X			X		X	X
	Index weather insurance	X				X			
	Agriculture Insurance	X							
	Bioenergy policies & targets				X				X
	Clean cookstove programmes				X				X
	Flood insurance					X			
	Forest fire management							X	
	Disaster bonds					X	X	X	
	Disaster risk management Strategy					X	X	X	
	National targets for forests and green cover/ forest carbon sequestration policies		X						X
	Land tenure					X	X		
	Research and deployment of BECCS				X				X
Sub-national	Climate-smart Agriculture policy	X							X

Local	Watershed management	X	X						
	Land use planning		X			X	X	X	X
	State Flood Insurance policy					X			
	State Disaster preparedness/mitigation plan					X	X	X	
	Early warning systems					X	X		
	Landscape governance		X	X					
	Agroforestry programmes	X							
	Drought plans						X		
	Clean Energy/ Biomass Energy Policies & Incentives				X				X
	Hazard information & communication					X		X	
	Waste to energy/Bio-methanation				X				X
	Flood plans/ zoning / management					X			
	Relocation and migration policies					X			
	Spatial planning					X	X		
	Emergency management					X		X	
	Community based awareness programs					X	X	X	
	Microinsurance					X			
	Skill and community development for livelihood diversification	X				X	X	X	

7.4.2.1 *Food security*

A defining policy challenge for this century will focus on delivering food security to 9 to 10 billion people by mid-century with safer, nutritious food from the same area without increasing pressure on land and biodiversity (Rockström et al. 2017a; Smith 2013; Bajželj et al. 2014a; Molotoks et al. 2017). Agriculture contributes 17% of greenhouse gas emissions and uses approximately 40% of terrestrial surfaces, and is the leading user of fresh water resources (Chartres and Noble 2015). Global food demand is expected to increase 60% by 2050 relative to the mid-2000s (Davis et al. 2016). Even greater increases in demand in sub-Saharan Africa (SSA) where population will increase 2.5-fold and demand for cereals will approximately triple (Tittonell and Giller 2013; van Ittersum et al. 2016).

Understanding food systems and patterns of risk in food systems enables design of more resilient systems (Hodbod and Eakin 2015). The scientific community can partner across sectors and industries for better data sharing, integration, and improved modelling and analytical capacities (Janetos et al. 2017; Lunt et al. 2016). Participatory platforms, (such as co-design for scenario planning) can build social and human capital while improving understanding of food system risks and creating innovative ways for collectively planning for more equitable and resilient food system (Himanen et al. 2016). There is *medium agreement and medium evidence* that connections must be made between outcomes of analyses and policies and programs (World Food Programme 2017) and governance and long term planning that target resilience of food systems, prioritising functions that create full food security at multiple scales are key to bringing stability to overcome shocks and sudden changes (Hodbod and Eakin 2015). (Puma et al. 2015a) conclude that policy effort should be on diet diversification to mitigate dependency on major crops, while balancing the efficiency of international trade with increased resilience of domestic productions and global demand diversity, when a crop makes up a large percentage of the diet to reduce country dependency on imports (Puma et al. 2015b).

Food security has a variety of definitions, but key components are food availability, access and use. Policy instruments are needed for each of these. In terms of food availability and supply, several policy alternatives (including expansion and intensification of agriculture, conservation agriculture, organic agriculture, and rewilding abandoned agricultural land) aim to increase yields at the same time as managing or easing associated biodiversity loss and greenhouse gas emissions (Lal 2013).

Provision of water through irrigation and other critical inputs are additional ways to improve food security (Iglesias and Garrote 2015; Ababaei et al. 2014; Tripathi and Mishra 2017; Tittonell and Giller 2013)as well as increasing production, facilitating an increase in yield or in the number of harvests a year (Iglesias and Garrote 2015; Ababaei et al. 2014; Tripathi and Mishra 2017; Tittonell and Giller 2013). However, irrigation has to be carefully managed. Groundwater depletion by irrigation is a growing risk to food security and already a major problem in large parts of the world including Northern India, the Northern China Plain, the Middle East and California (Rodell et al. 2018). There is *strong evidence and strong agreement* that government policies that incentivise conservation or regulate groundwater consumption are needed to avoid risks to food security (Harootunian, 2018; Rodell et al., 2018). Mainstreaming of less water intensive crops (e.g. millets, pulses) through public distribution or price support, for example, can also contribute to adaptation (Khera 2011; Lin and Li 2011a).

Smallholder farmer-dominated agriculture is currently the backbone of global food security in the developing world. Poor nutrient availability and soil fertility are the leading biophysical limitations to crop yields, so that continued cropping with insufficient inputs of nutrients and organic matter contributes to chronic poverty gaps as smallholder farmers face extensive local soil degradation (Tittonell and Giller 2013). Without incentives to manage land and forest resources in a manner that allows regeneration of both the soils and wood stocks, smallholder farmers tend to generate income through inappropriate land management practices, engage in agricultural production on unsuitable land and use fertile soils, timber and firewood for brick production and construction and secondly engage in charcoal production (deforestation) as a coping mechanism (increasing income) against food deficiency (Munthali and Murayama 2013). Research suggests a correlation between conflict risk and areas with food insecurity or a high risk of agricultural expansion into areas with high biodiversity, particularly in the tropics (Molotoks et al. 2017). Today, the cost of soil degradation in individual countries reaches into the billions of US dollars (Global Food Security Programme 2013), in addition to rising implicit costs of biodiversity and ecosystem services like groundwater stress (Tardieu et al. 2013).

Additionally, research finds that appropriate land use allocation from the outset (Law et al. 2015) , combined with land sparing (high-yielding agriculture on a small land footprint) for areas with more common species and land sharing (low-yielding, wildlife-friendly agriculture on a larger land footprint) for areas more sensitive to agricultural disturbance can increase agricultural production while minimising the negative consequences for biodiversity (Baudron et al. 2012; Baudron and Giller 2014; Baudron et al. 2014; Kremen 2015; Navarro and Pereira 2015). Discussions about land sparing and land sharing do not capture the relationship between intact and functioning biodiversity and conventional, conservation, and other forms of farm practices (Tscharntke et al. 2012).

To address soil fertility, smallholder farmers in mixed crop-livestock systems divide their crop residues across mulching the soil, feeding livestock and for use as fuel. Farmers with greater access to extension training retain more crop residues for mulch on their fields while farmers with more livestock use less residues for soil mulch and more for animal feed (Jaleta et al. 2013, 2015; Baudron et al. 2014). Research in Eastern Africa and the Amazon reveals barriers to the uptake of such conservation practices, in part related to livestock-related livelihoods and policies (Baudron et al. 2012)(Lipper et al. 2014b; Branca et al. 2013; Baudron et al. 2012; Faria and Almeida 2016).

Evidence suggests that organic agriculture contributes to public goods and non-commodity outputs (Niggli 2015), such as soil fertility, biodiversity maintenance and protection of the natural resources of soil, water and air. Compared with conventional farming, organic farming systems are more profitable and deliver equally or more nutritious foods with less (or no) pesticide residues which provide co-benefits for soil, social benefits, and ecosystem services (Reganold and Wachter 2016). Consumers in industrialised countries are increasingly willing to pay higher prices for organic agriculture, which yields about 0.2%lower than conventional agriculture in part due to underfunding of research and development (Crowder and Reganold 2015; Niggli 2015). Regulations and practices of organic farming differ little between countries today and reflect the value consumers place on chemical free food products, even though originally the practice aimed primarily to improve soil health and indirectly improve human, animal, and societal health (Seufert et al. 2017). Findings suggest that organic agriculture may be a good model for productive, sustainable food production and livelihood security in disadvantaged sites – evidence suggests that subsistence farming in Sub-Saharan Africa shows *higher* productivity of organic agriculture (Niggli 2015). Nevertheless, systems that allow people to maximise their productive potential while protecting the ecosystem services may not ensure food security in all contexts. Some household land holdings are so small that self-sufficiency is not possible (Venton 2018). Food security cannot be achieved by increasing food availability alone. Ultimately, a mix of production activities and consumption support is needed.

Consumption support can be used to help achieve the second important element of food security – access to food. Policy instruments, which may increase access to food at the household level include safety net programming and universal basic income. The graduation approach, developed and tested over the past decade using randomised control trials in six countries, has lasting positive impacts on income, as well as food and nutrition security (Banerjee et al. 2015; Raza and Poel 2016). The graduation approach layers and integrates a series of interventions designed to help the poorest: consumption support in the form of cash or food assistance, transfer of an income generating asset (such as a livestock) and training on how to maintain the asset, assistance with savings and coaching or mentoring over a period of time to reinforce learning and provide support. Due to its remarkable success, the graduation approach is now being scaled up, now used in over 38 countries and included by an increasing number of governments in social safety-net programs (Hashemi, S.M. and de Montesquiou 2011).

At the national and global level, food prices and trade are critical policy instruments that impact access to food. Fiscal policies, such as taxation or tariffs, can be used to regulate the prices and consumption of certain foods as well as increase revenue. In Denmark, tax on saturated fat content of food adopted to encourage healthy eating habits accounted for 0·14% of total tax revenues between 2011 and 2012 (Sassi et al. 2018). However, increases in prices might impose unfair financial burdens on low-income households, and may not be well received by the public. A study examining the relationship between food prices and social unrest found that between 1990 and 2011, food price increases have led to increases in social unrest, whereas food price volatility has not been associated with increases in social unrest (Bellemare 2015).

Some economists argue that trade can be a mechanism to increase access to foods and also increased access to new markets in cases where enhanced transportation networks and greater national reserves of cash and enhanced social safety nets can minimise risks of increased international competition and market price volatility (Brown et al. 2017b). However, trade can have negative impacts as well. Some research associates trade with deforestation in the Amazon (Nobre et al. 2016; Faria and Almeida 2016). Research on large-scale land acquisition reveals two patterns: targeting forested landscapes and those that target existing cropland, both which can interfere with semi-subsistence farming systems (Messerli et al. 2015).

Demand management for food, including promoting healthy diets, reducing food loss and waste, is covered in chapter 5, however there is a gap in knowledge regarding what policies and instruments support these forms of demand management. Conversely, the European Union promotes meat and dairy production through voluntary coupled direct payments and does not yet internalise external damage to climate, health, and groundwater (Velthof et al. 2014; Bryngelsson et al. 2016). However, promise can be found in a variety of policy instruments that have been found effective in influencing food use, and subsequently in nutrition. There is *strong evidence and strong agreement* that changes in household wealth and parents' education can drive improvements in nutrition (Headey et al. 2017). Bangladesh has managed to sustain a rapid reduction in the rate of child undernutrition for at least two decades. Rapid wealth accumulation and large gains in parental education are the two largest drivers of change (Headey et al. 2017). Educating consumers, and providing affordable alternatives, will be critical to changing unsustainable food use habits relevant to climate change.

Insurance, adaptive capacity, and food security

Early forms of insurance developed in agricultural societies allowed individual households and groups to share risks that climate variability posed to their livelihoods and food security. In villages, customary rules governing access to land for common property as well as individual land parcels fulfilled social security functions and helped achieve equity objectives (Awanyo 2009; Michler and Shively 2015). When population growth and market pressure combine to intensify land use, land tenure and land management arrangements are increasingly defined without regard for equity or risk sharing concerns (Platteau 2005). This trend contributes to land management practices that decrease productivity, decrease ecosystem services which also ameliorate risk (Sidibé et al. 2018; Ma et al. 2013), elevate reliance on credit for farm inputs like seeds and fertiliser, lower crop diversity, and lower levels of agricultural risk sharing (Mohmmed et al. 2018).

Modern insurance design affects the degree to which the tool improves or worsens adaptive capacity: insurance itself is a complex adaptive system which must be embedded in a wider risk management approach (Storey et al. 2015) so as not to dis-incentivise appropriate adaptation such as crop diversification or less intensive land use, and to ensure intact ecosystem services in rural and urban areas (Green et al. 2016) as has been the case with federal crop insurance in the United States (Lo 2013; Annan and Schlenker 2015; Jaworski 2016; Michel-Kerjan et al. 2015; Lamond and Penning-Rowsell 2014).

In contrast, studies suggest that adaptive capacity of communities have improved vis-à-vis climate variability like drought when ex ante tools including insurance have been employed holistically; providing insurance in combination with early warning and institutional and policy approaches that aim to reduce livelihood and food insecurity as well as strengthen social structures (Shiferaw et al. 2014; Lotze-Campen and Popp 2012). Work-for-insurance programs applied in the context of social protection have been shown to improve livelihood and food security in Ethiopia (Berhane 2014; Mohmmed et al. 2018). Bundling insurance with early warning and seasonal forecasting can reduce the cost of insurance premiums (Daron and Stainforth 2014). The regional risk insurance scheme Africa Risk Capacity has the potential to significantly reduce the cost of insurance premiums (Siebert 2016) while bolstering contingency planning against food insecurity. In Europe, modelling suggests that insurance incentives such as vouchers would be less expensive that total incentivised damage reduction and may reduce residential flood risk by 12% in Germany and 24% by 2040 (Hudson et al. 2016).

The ability of insurance to contribute to adaptive capacity also depends on the overall risk management and livelihood context of households — studies find that rain fed agriculturalists and foresters with more years of education and credit but limited off-farm income are more willing to pay for insurance than households who have access to remittances (such as from family members who have migrated)(Bogale 2015; Gan et al. 2014; Hewitt et al. 2017; Nischalke 2015).

7.4.2.2 Sustainable land management

Zero Net Land Degradation (ZNLD**)**

A land degradation neutral world could be achieved by reducing the rate of land degradation and increasing the rate of restoration of degraded land. To enable this, the rate of global land degradation should not exceed that of land restoration (Stavi and Lal 2015; Grainger 2015; Chasek et al. 2015; Cowie et al. 2018; Montanarella 2015). Neutrality implies no net loss of the land-based natural resource relative to a baseline or a reference state (UNCCD 2015; Kust et al. 2017; Easdale 2016; Cowie et al. 2018; Stavi and Lal 2015; Grainger 2015; Chasek et al. 2015). Achieving the target of land degradation neutrality would decrease the environmental footprint of agriculture, while supporting food security and sustaining human wellbeing (Stavi and Lal 2015).

There are socio-economic determinants of land degradation that need to be addressed for achieving sustainable management of land resources (Qasim et al. 2011; Kirui 2016). Studies from different parts of the world (Pakistan, Mediterranean areas, Botswana) underline the importance of socio-economic context in general and livelihoods in particular for reduction of land sensitivity to degradation and for enhancement of the flow of ecosystem services that support livelihoods and for sustainable land management (Salvati and Carlucci 2014; Reed et al. 2015; Easdale 2016)

For effectiveness of implementation of global ZNLD it is very important to integrate lessons learned from existing offset programs designed for other environmental objectives. Furthermore it is necessary to formulate/strengthen supportive policies and regulations for ZNLD (Stavi and Lal 2015; Grainger 2015). ZNLD as a phenomenon of equilibrium of the land system needs further scientific research and development of effective methods to measure the balance between different terrestrial ecosystems' qualities, functions and services (Kust et al. 2017; Montanarella 2015). Scientific knowledge is required to complement existing knowledge of desertification processes as well as those of land use and land cover change processes generally (Grainger 2015).

Facing the challenges of climate change, desertification, land degradation and drought together with population increase, ZNLD actions and activities play an essential role for a land-based approach to climate change adaptation (UNCCD 2015). Achieving ZNLD also supports the achievement of several of the Sustainable Development Goals (SDGs), including SDG 13 on climate action and efforts to tackle other challenges such as poverty alleviation, food, water and energy security, human health, migration, conflict and biodiversity loss. Accordingly, the monitoring of ZNLD should target the quantification of the costs, benefits and impacts of sustainable land management on water availability, food security, and climate change mitigation etc. (Sietz et al. 2017; Stavi and Lal 2015; Cowie et al. 2018)

Operationalisation of ZNLD requires an effective enabling environment that can generate awareness, motivation, human and financial resources as well as provide incentives to encourage adoption of local actions (Chasek et al. 2015; Stavi and Lal 2015). Many researchers underline that monitoring the ZNLD targets requires means of assessing levels of land degradation and restoration. Furthermore, certain measures were identified for achievement of ZNLD which include; effective financial mechanisms (for implementation of land restoration measures and the long-term monitoring of progress), parameters for assessing land degradation, detailed plans with quantified objectives and establishment of a feasibility of the offset program and setting a target year for achieving LDN goal (Kust et al. 2017; Sietz et al. 2017; Cowie et al. 2018; Montanarella 2015; Stavi and Lal 2015).

The importance of the biophysical socio-economic aspects on achievement of ZNLD has been underlined by many researchers. Accordingly, it has been recommended that the role of human dimension on sustainability of drylands should be adequately tackled for successful efforts to reverse degradation through restoration or rehabilitation of degraded land (e.g. consideration of the zero net livelihood degradation) (Easdale 2016; Qasim et al. 2011; Cowie et al. 2018; Salvati and Carlucci 2014).

Monitoring ZNLD status involves quantifying the balance between the area of losses versus areas of gain within different land types and landscape. However, as land degradation is not a static, but rather a dynamic process, many authors underlined challenges related to monitoring of causes, rates, and effects of land degradation. The difficulties associated with monitoring and evaluation are associated with absence of baseline rates, limited national and international scientific capacities to measure desertification and challenges related to mode of data monitoring and management and provision of continuous and sequential updates. It has been argued that monitoring cuts in national rates of desertification is more difficult than monitoring restoration of decertified land by revegetation (Stavi and Lal 2015; Grainger 2015; Chasek et al. 2015; Cowie et al. 2018).

In spite of opportunities of implementation of restoration projects through payments for improving ecosystem services, as well as other economic mechanisms, the implementation of ecosystem restoration projects that have ZNLD targets is challenged by lack of access and vulnerability to global markets and risk of widespread failure in ecosystem restoration and degradation prevention (even with massive investments). Both opportunities and challenges for cost effectiveness were identified moving towards the ZNLD targets (Sietz et al. 2017; Stavi and Lal 2015; Grainger 2015). Many developing countries are challenged with lack of incentives under UNCCD as well as facing the reality of having resources that are not as economically valuable as those in humid areas (Grainger 2015). In addition to economic barriers to the implementation of non-degrading land use and restoration of degraded land, there are other barriers that include; cultural, social, scientific knowledge, technology and policy (Grainger 2015; Chasek et al. 2015; Stavi and Lal 2015).

Conserving biodiversity and ecosystem services

Climate change and biodiversity are interconnected. Climate change is one of the significant drivers for biodiversity loss. The ecosystem services connected with biodiversity contribute greatly to both climate change mitigation and adaptation. Biodiversity and ecosystem services are fundamental to all life, protection from natural disasters, and human economic activities. There is *high agreement but limited evidence* that ecosystem-based adaptation (biodiversity and ecosystem services) plays a critical part of an overall strategy to help people adapt to the adverse effects of climate change (Secretariat of the Convention on Biological Diversity, 2009), can be cost-effective, generate social, economic and cultural co-benefits, and contribute to the conservation of biodiversity. Ecosystem based adaptation can also promote socio-ecological resilience by enabling people to adapt to the impacts of climate change and reduce their vulnerability (Ojea 2015). Ecosystem based adaptation can promote nature conservation while alleviating poverty and even provide a co-benefits by removing greenhouse gas (Scarano 2017) and protecting livelihoods (Munang et al. 2013). One example is ecosystem-based adaptation utilising mangrove forests at the climate prone coastal zone. Mangroves provide diverse ecosystem services such as erosion protection, water purification, shore-line stabilisation and also regulate storm surge and flooding damages, thus enhancing resilience and reducing climate risk (Rahman, M.M., Khan, M.N.I., Hoque, A.K.F., Ahmed 2014).

Accelerated loss of biodiversity is now considered a major threat to human well-being (Cardinale et al. 2012). Biodiversity and associated ecosystem services are likely to be severely impacted by climate change (Scholze et al. 2006). Furthermore impacts of non-climatic stressors on key ecosystem functions such as pollination are posing an emerging risk to food security and agro-diversity (Potts et al. 2016). Biological invasions are a now a major global threat to ecosystem integrity, biodiversity and ecosystem services, but there are still knowledge gaps which makes communication and policy responses difficult (Simberloff et al. 2013). The loss of fresh-water aquatic ecosystems and their simplification due to degradation, abstraction and regulation is likely to pose risks to future adaptation under global change (Russi et al. 2013). Enhancing the resilience of socio-ecological systems requires careful attention to maintenance of biodiversity and ecological functions to avoid risks of tipping points and thresholds (Rockström et al. 2009).

Land tenure

Land tenure, defined as “the terms under which land and natural resources are held by individuals, households or social groups”, is a key dimension in any discussion of land-climate interactions, including the prospects for both rural adaptation and land-based mitigation, and possible impacts on tenure and thus land security of both climate change and climate action (Quan and Dyer 2008) (*limited evidence, high agreement*). Research focussed on land tenure under climate change remains dominated by reports of development donors, with limited coverage in the peer-reviewed literature.

Discussion of land tenure in the context of land-climate interactions in developing countries, especially in Africa but also in forest zones of other regions has to address the prevalence of informal, customary and modified customary systems of land tenure: in 2005 only 1% of land in Africa was legally registered (Easterly 2008), and forest commons comprise at least 18% of *global* forest area (Chhatre and Agrawal 2008). Research in this area, such as (Fraser et al. 2011; Barbier and Tesfaw 2012, 2013). (Antwi-Agyei et al. 2015a), therefore necessarily recognises earlier literature, for example (Schlager and Ostrom 1992; Toulmin and Quan 2000; Bruce and Migot-Adholla 1994; Easterly 2008) that demonstrates that under certain circumstance, informal and customary systems can provide considerable land tenure security and enable long-term investment in land management such as tree-planting, and that formal titling of land is not a necessary condition for tenure security and may be cost-ineffective or counter-productive. These general insights, particularly applicable to systems where land ownership is communal, but individual usufruct is allocated for cropping, are complemented by findings that communal management of rangelands in pastoral systems is a rational and internally sustainable response to climate variability and the need for mobility (Behnke 1994). For forests, (Robinson et al. 2014) demonstrate through meta-analysis that land tenure security is associated with less deforestation, regardless of whether the tenure form is private, customary or communal. However, this same literature on land tenure recognises that customary and communal systems in various agroecosystems may be subject to institutional weakening and external encroachment, resulting from non-recognition by governments (Lane 1998; Toulmin and Quan 2000).

In dryland areas of developing countries, erosion of traditional communal tenure of rangelands has been identified by many authors as a determinant of increasing vulnerability to drought and climate variability (Morton 2007; López-i-Gelats et al. 2016; Oba 1994) and as a driver of dryland degradation (Fraser et al. 2011). (Dougill et al. 2011), using primarily qualitative data, show that a process of rangeland privatisation in Botswana has increased the vulnerability of pastoralists to drought and therefore to climate change. (Antwi-Agyei et al. 2015b) compare a semi-arid and a more humid area of Ghana, under different systems of modified customary land tenure, and are able to disaggregate impacts of land tenure on climate change adaptation to specific categories of household. In the more humid area, a very large proportion of migrants to the area, some of whom have enjoyed usufruct rights to farm there for decades, see land tenure as a barrier to climate change adaptation, compared with much smaller proportions of households from the land-owning community, specifically as a disincentive to long-term land management. Within each of the migrant and local categories, there is very little difference between male and female farmers. In the drier area, where there are no migrants, female farmers overwhelmingly see land tenure as a barrier to climate change adaptation while only a small proportion of male farmers do. Overall, there is *limited evidence but high agreement* that weak land tenure security, either for households disadvantaged within a customary tenure system, or more widely as such a system is eroded, can be associated with increased vulnerability and decreased adaptive capacity.

Land tenure systems have complex interactions with deforestation processes (Robinson et al. 2014) and interact with REDD+ and other land-based mitigation actions in complex ways (*moderate evidence, high agreement*). (Barbier and Tesfaw 2012) in an extensive review at a time when REDD+ programmes were in their infancy, highlight several risks to forest communities and especially their poorer members in REDD+ schemes. Where tenure security is weak and poorly enforced, increased forest value under REDD+ may encourage private companies or governments to dispossess forest dwellers. Individual freehold land titling programmes risk excluding the poor. There is also a risk that communities who perceive a risk of expropriation may be incentivised to short term exploitation of forest resources, defeating the carbon sequestration objective. There may be positive benefits for

REDD+ schemes of operating through common property tenure systems, through lower transaction costs of working with traditional leaders rather than multiple private owners, although there is a risk that payments for forest management may be captured by elites abusing their leadership roles. (Barbier and Tesfaw 2013) discussing REDD+ initiatives in farmed or partly farmed systems under African customary land tenure, note the incentives such systems give to farmers for planting trees.

Sunderlin et al. (2018), also reviewing earlier studies, note that clarification and strengthening of tenure have been recognised as priorities for fulfilling REDD+, but that these are difficult tasks, both in practical and in political-economic terms. Analysing original data from REDD+ programmes in five countries, (Sunderlin et al. 2018) conclude that national sub-samples present very diverse findings on both direction of change in tenure security and extent to which this has been influenced by REDD+, and positive changes in land tenure in some areas cannot be attributed to the programmes. Pooling the sample, REDD+ programmes tend slightly to increase land tenure insecurity on agricultural (but not on forest) lands. Forest-dwellers attribute increasing land tenure insecurity with weak titles, and problems with external businesses and with governments. However, Quan et al. (2017), reporting on the early stages of REDD+ in Mozambique, report positive attitudes from the private sector toward partnerships with civil society and communities. Work on land tenure within REDD+ programmes needs to be integrated with national-level forest tenure reform (Sunderlin et al. 2018).

Climate change has implications for land policy, land administration and land information systems that cut across vulnerability, adaptation and mitigation concerns. (Quan and Dyer 2008) see the need for land policies to provide both security and flexibility in the face of climate change, through a diversity of forms rather than a sole focus on freehold title, and land policy itself to be climate-proofed and integrated with national policies such as National Adaptation Programme of Action NAPAs. (van der Molen and Mitchell 2016) conclude that land administration systems have a vital role in providing land tenure security, especially for the poor, and that land information systems should include or be linked to an expanded range of information relevant to both mitigation and adaptation.

Standards and certification for sustainability of biomass and land use sectors

During the past two decades, standards and certification have emerged as an important instrument to address sustainability in agriculture, forestry, and other land use sectors, as well as for bio-based products and materials. Standards aim to provide environmental and social sustainability management. While they are normally voluntary they may become obligatory if introduced into the legislative system. It is important to distinguish between standards and certification, which are normally carried out by separate organisations in order to preserve the integrity of these processes. A standard provides specifications, guidelines or characteristics to ensure that materials, products, processes and services are fit for their purpose while certification is the procedure through which a third accredited party provides assurances to companies, organisations or consumers that a product, process or service is in conformity with certain standard. The International Organization for Standardization is a key source for global environmental standards; a recent standard with special relevance for land use management focuses on good practices for combatting land degradation and desertification (ISO 2017). The standard aims at providing guidance on actions or interventions to prevent or minimise degradation of land while proposing forms to recovery degraded land.

Efforts to increase production and use of agricultural and woody biomass can contribute to land degradation, loss of soil fertility and a variety of undesirable environmental and social impacts. As the world transitions away from a primarily fossil-based economy to a bio economy, there are various pathways available to achieve sustainability as the demand for land and biomass increase; there is *medium evidence* on the sustainability implications of different pathways but low agreement as to which pathways are socially and environmentally desirable (Priefer et al. 2017; Johnson 2017). Standards and certification have been seen by many actors in both public and private sectors as providing a set of instruments that can better guide these pathways. Table 7.3 provides a summary of selected standards and certification schemes and shows inclusion of different elements of environmental and social sustainability; nearly all recognise the inherent linkages between the biophysical and social aspects of land use. There are many certification schemes, best practice guidelines and/or technical standards that are specific to a particular agriculture crop (e.g. soy, sugarcane) or a tree (oil palm) that are not included in **Error! Reference source not found.** for reasons of brevity. There is *low evidence and low agreement* on how the application and use of standards and certification has actually improved sustainability outside of the farm or plantation level (Endres et al. 2015).

Different methods, techniques and guidelines have been disseminated by international organisations to promote sustainable land use management. These can generally be classified in four categories: good practices, guidelines, voluntary standards and jurisdictional approaches. The stringency of application and enforcement varies depending on the region and their jurisdictional and governance system as well as on the environmental local conditions (e.g. climatic, edaphic, geological) and the nature of the feedstock produced. Good practices and guidelines focused on land management have been provided by international research organisations: of particular interest are those addressing climate change in drylands in terms of technical measures, policies and governance approaches to reduce risk and increase productivity for small farmers (Pedrick 2012). The Economics of Land Degradation Initiative (ELD) emphasises economic impacts of land degradation, using the Total Economic Value (TEV) framework to provide a common basis for economic assessments of land degradation and aims to develop guidelines for practitioners and decision-makers to avoid or reverse land degradation (Nkonya et al. 2013).

In addition to addressing land use management, agriculture and forestry, there have been an increasing number of efforts during the past decade or so focusing on the sustainability of biomass and especially in relation to biofuels and bioenergy (van Dam et al. 2010; Scarlat and Dallemand 2011). Analyses on the implementation of standards and certification for biomass use have focused on their stringency, effectiveness, geographical application and governance as well as impacts related to the choice of feedstock and socio-economic issues such as land tenure and gender and environmental effectiveness such as land use (Diaz-Chavez 2011; German and Schoneveld 2012; Meyer and Priess 2014). There is *medium evidence and low agreement* as to whether sustainability certification for biomass and bioenergy insures positive socio-economic impacts in general terms. More recently the landscape governance approach is aiming at both conservation of productive and non-productive areas as well as engaging stakeholders in multi-use land areas (Pacheco et al. 2016). While the landscape governance approach has been used in some standards and has potential to address land use and biomass use in an integrated manner, there is not yet a sufficient record of research concerning its effectiveness in terms of sustainable land use management. Certification approaches for biofuel imports are now in place for sugar cane, soya, palm oil with impacts on land management practices in Europe and areas that grow these biofuels (Banse et al. 2011; Kavallari et al. 2014). Certification approaches for biofuel imports are now in place for sugar cane, soya, palm oil with impacts on land management practices in Europe and areas that grow these biofuels (Banse et al. 2011; Kavallari et al. 2014).

The Renewable Energy Directive of the European Union (EU-RED) established sustainability criteria in relation to the EU renewable energy targets in the transport sector, which subsequently also had impacts on land use and trade with third countries (Johnson et al. 2012). In particular, the EU-RED marked a departure in the context of Kyoto/UNFCCC guidelines by extending responsibility for emissions beyond the borders of the end-use market, thus making EU bioenergy users responsible for supply-chain emissions throughout the world and at the same time shifting some of the burden (via the requirements for sustainability certification) to developing countries wishing to sell into the EU market (Johnson 2011b). Another key concern in the EU and also globally, as reflected in Table 7.3 was the impact on food security when developing countries produce non-food crops and export biomass, biofuels or bioenergy products. Increased biofuel production has been found to have rather small effects on food prices and more generally the relation between biofuels and food security is site and context-specific and can be characterised by synergies or conflicts depending on specific baselines conditions and governance approaches (Araujo Enciso et al. 2016; Kline et al. 2017). Certification and standards normally cannot address such wider market effects but are generally aimed at best practices in the local context.

1 **Table 7.3 Selected standards and certification schemes and their components or coverage**

			Sustainability issues covered by scheme											
			Environmental								Social			
Acronym	Name	Commodity/process	Certification scheme	Land Degradation/ Desertification	GHG	Biodiversity	Carbon stock	Soils	Air	Water	Land use management	Land rights	Labour conditions	Food security
ISCC	International Sustainability and Carbon Certification	All feedstocks, all supply chain	√		√	√	√	√	√	√	√	√	√	√
RSB	Roundtable on Sustainable Biomaterials	Biomass, biofuels, bio-based materials	√		√	√	√	√	√	√	√	√	√	√
SAN	Sustainable Agriculture	Framework related to Rain Forest Alliance focused on agriculture				√	√	√	√	√	√		√	
PEFC	Programme for the Endorsement of Forest Certification	Forest management	√			√	√	√	√	√	√	√	√	
FSC	Forest Stewardship Council	Forest Management	√			√	√	√	√	√	√	√	√	
SBP	Sustainable Biomass Programme	woody biomass, mainly pellets and wood chips	√		√	√	√	√	√	√	√	√	√	
ISO 13065:2015	Bioenergy	biomass and processes			√	√	√	√	√	√	√	√	√	√

ISO 14055-1:2017	Land Degradation and Desertification	land use management	√		√	√	√	√	√	√

Source: adapted from (Rosillo-Calle et al. 2015)

7.4.2.3 Energy access and biomass use

An estimated 1.1 billion persons lack access to electricity while more than 2 billion rely primarily on traditional biomass (fuelwood, agriculture residues, animal dung, charcoal) for household energy needs (IEA 2017). Access to modern energy is significant in the context of land-climate systems because heavy reliance on traditional biomass can contribute to land degradation, household air pollution, GHG emissions and food insecurity. A number of hotspots have been identified around the world, particularly in East Africa and South Asia, where overharvesting of biomass leads to net loss of land and net GHG emissions (Bailis et al. 2015). Charcoal production in East Africa is a major source of land degradation (Kiruki et al. 2017; Ndegwa et al. 2016). Indoor air pollution associated with household energy is estimated to lead to nearly 4 million premature deaths per year, making it the highest environmental risk factor in the world (Smith et al. 2014b). There is a high correlation between lack of energy access and food insecurity, as these populations coincide, often in poor rural or peri-urban areas. More generally the lack of energy access coincides with those deficient in other services and capacities that are highlighted in the Sustainable Development Goals (Fuso Nerini et al. 2018). There are also significant constraints on adaptive capacity for these vulnerable households, so that access to modern energy can promote a triple-win for adaptation, mitigation and development (Suckall et al. 2015).

A variety of approaches and policy instruments are aimed at improving energy access and reducing the heavy reliance on traditional biomass. A focus on delivered energy services through specific metrics applied to rural households can support more efficient use of biomass and land and thereby reduce impacts while improving energy provisions (Fuso Nerini et al. 2017). Standards and certification systems can be used to incentivise best practices for both the biomass supply and the demand sides of the value chain (Endres et al. 2015). Certification and standards in the case of commodity crops, including those used for energy purposes, tend to be applied and/or have greater impact for land use and biomass use in developed and emerging economies, whereas in poorer countries or among poorer segments of the population, their impact is lower and thus their role is seen as addressing environmental concerns rather than poverty reduction (Tayleur et al. 2018). In developing countries, best practice guidelines for household energy are found in strategy documents and are normally promoted at Energy Ministries but in practice the poorest households have no margin to pay for higher-cost efficient stoves and there is *medium evidence and medium agreement* that a focus on product-specific characteristics could improve the market take-up (Takama et al. 2012). Subsidies for more efficient end-use technologies in combination with promotion of sustainable harvesting techniques would provide the highest emissions reductions while at the same time improving energy services, since non-renewable biomass harvesting along with low efficiency cookstoves constitute the primary sources of emissions (Cutz et al. 2017).

7.4.2.4 Hazards

Risk management addressing climate change has broadened to include mitigation, adaptation and disaster preparedness in a process of risk management through contingency (Hurlimann and March 2012; Oels 2013) through cross-sectoral planning, social community planning, and strategic, long term planning (Serrao-Neumann et al. 2015a). This comprehensive consideration integrates principles from informal support mechanisms to enhance formal social protection programming (Mobarak and Rosenzweig 2013; Stavropoulou et al. 2017) such that the social safety net, disaster risk management, climate change adaptation are all considered to enhance livelihoods of the chronic poor (see char dwellers and recurrent floods in Jamuna and Brahmaputra basins of Bangladesh (Awal 2013).

Safety nets and social protection schemes have been found very effective for combating poverty and vulnerability (Baulch et al. 2006; Barrientos 2011; Harris 2013; Fiszbein et al. 2014; Kiendrebeogo et al. 2017; Kabeer et al. 2010) and protecting people from shocks thereby enabling them to participate in economic growth in both rural and urban areas. Social protection instruments aim to raise household income and enhance crop production, (e.g. agricultural input subsidies or input trade fairs (Giovannetti et al. 2011; Béné et al. 2012; Tevera and Simelane 2014; Devereux 2016)**.** The use of social safety nets is on the rise in different part of the world, particularly in Africa. From 2010 to 2015, the number of countries in Africa with social safety net programs doubled (Ellis et al. 2009; Kabeer et al. 2010) Safety nets provide additional support in times of crisis, recurring droughts, preventing people from falling further into poverty. Social protection can support very effectively resilience building at scale if early action and preparedness are integrated. It has been recommended that strengthening of social protection schemes could provide concrete solutions, namely linking a forecast-based financing mechanism to a social protection system to enable anticipatory actions based on forecast triggers and guaranteed funding ahead of a shock. Accordingly scaling up social protection based on an early warning could enhance timeliness, predictability and adequacy of social protection benefits (Kuriakose et al. 2012; Costella et al. 2017; Wilkinson et al. 2018; O'Brien, C.O., Scott, Z., Smith, G., Barca, V., Kardan, A., Holmes, R. Watson 2018). Social protection systems can respond to shocks through vertical or horizontal expansion, piggybacking on pre-established programmes, aligning social protection and humanitarian systems or refocusing existing resources (Wilkinson et al. 2018; O'Brien, C.O., Scott, Z., Smith, G., Barca, V., Kardan, A., Holmes, R. Watson 2018).

In spite of the usefulness of social protection systems and its role in improving households' food security and wellbeing, some researchers underline that its positive effects might not be robust enough to shield recipients completely against the impacts of severe shocks. Furthermore it has also been suggested that social protection designed to limit damages from shocks and stresses may not be sufficient in the longer term (Davies et al. 2009; Umukoro 2013; Béné et al. 2012; Ellis et al. 2009). Social protection systems have also been seen as an unaffordable luxury in many developing and low-income countries (Harris 2013).

National systems may be rather patchwork and piecemeal. Safety net programs in low-income countries are primarily donor funded. For example, over 80% of safety net spending in Burkina Faso, Liberia, Mali, and Sierra is donor funded. Fragmented donor support often leaves low-income countries with a set of small, isolated programs. For example, Liberia and Madagascar each have five different public works programs, each with different donor organisations and different implementing agencies. In contrast, the Ethiopian Productive Safety Net Program is 100% donor financed and is considered very effective (Monchuk 2014).

Crop insurance and instruments providing agricultural producers with income stability to respond to drought and poor crops are important adaptation instruments; in the event of continued financial stress bankruptcy and debt restructuring instruments can assist in adaptation and livelihood transition (Hurlbert 2018b). There is a limitation of economic instruments to manage drought risk because drought effects have public good properties although there is still potential to manage part of drought risks using financial risks (Garrido and Gómez-Ramos 2009)

There is increasing support for establishment of public-private safety nets to address climate related shocks by setting insurance related instruments that are affordable to the poor and combining them with activities for proactive preventative (adaptation) measures (Linnerooth-Bayer and Mechler 2006). A paradigm shift is required for business to fully integrate the value associated with managing climate risks, and development of policies needed to incentivise private investments by creating stronger public-private partnerships to augment opportunities and create the correct enabling environment (Biagini and Miller 2013; Crichton 2008; Pauw and Pegels 2013; Surminski et al. 2016). Weather index insurance (such as index based crop insurance) is being presented to low-income farmers and pastoralists in developing countries (e.g. Ethiopia, India, Kazakhstan, China, South Asia) as an alternative to classic insurance to reduce revenue risk in crops production caused by yield variations to complement informal risk sharing (Bogale 2015; Conradt et al. 2015; Dercon et al. 2014; Greatrex et al. 2015; Mcintosh et al. 2013).

Drought

The feedbacks between drought and people are not fully understood and therefore drought management is inefficient; the human role in mitigating and enhancing drought resilience needs to be considered in relation to drought planning (Van Loon et al. 2016). Drought plans are still predominantly reactive crisis management plans rather than proactive risk management and reduction plans; Reactive crisis management plans treat only the symptoms and are ineffective drought management practices. There is a need for national drought policies focused on reducing risk complemented by drought mitigation or preparedness plans at various levels of government in order to improve the coping capacity of nations (Wilhite 2015). There is a gap in knowledge in empirically examining how well state plans are to what extent they incorporate risk management theory and practice on a nation basis (Fu et al. 2013).

In response to drought some governments have declared emergencies and adopted a system of water rationing while in other jurisdictions water property rights dictate through seniority preference rights who does or does not receive water; a diversity of water property instruments and instruments allowing water transfer, together with the technological and institutional ability to adjust water allocation can improve responsive timely adjustment to drought (Hurlbert 2018b). Supply side managed water that only provides for proportionate reductions in water delivery, prevents the important adaptation of managing water according to need or demand (Hurlbert and Mussetta 2016). Exclusive use of a water market to govern water allocation similarly prevents the recognition of the human right to water at times of drought preventing an important adaptation (Hurlbert 2018b). Effective drought preparedness instruments are those that address the underlying vulnerability associated with the impacts of drought building agricultural producer adaptive capacity (Wilhite et al. 2014)   Programs that provide financial assistance to agricultural producers to build water infrastructure (such as water storage dugouts, pipelines to provide water to livestock etc.) have improved the adaptive capacity of agricultural programs as well as programs that assist producers in planning for environmental risk including drought, soil degradation, pests etc. (Hurlbert 2018b).

Early warning systems, drought monitoring systems or triggers are useful risk management tools and a critical component of drought risk management plan (Botterill and Hayes 2012; Knutson and Fuchs 2016). Monitoring and forecasting systems are practical tools of risk assessment as well as simple, objective criteria to select and implement appropriate drought mitigation measures and key elements for successful drought management strategy (Knutson 2008). Effective early warning systems depend on multi-sectoral, interdisciplinary and collaborative links with the community. Thus far there are weak links with community early warning systems and national and international ones (Wilhite et al. 2014). These indicators have been successfully linked with social media (Tang et al. 2015) There must be care exercised in these instruments not leading to perverse outcomes when linked to some forms of government support (Botterill and Hayes 2012)

Adaptive governance (see 7-78) can be applied to manage drought assistance as a common property resource managing complex, interacting goals to create innovative policy options, facilitated through nested and polycentric systems of governance effected by arenas of natural resource management including landscape care and watershed or catchment management groups (Nelson et al. 2008).

Fire

Instinctively forest fire management includes increasing fire suppression capacity. However this can result in an unintended consequence of degrading the effectiveness of forest fire management in the long run (Collins et al. 2013). Strategies in addition to fire suppression include prescribed fire, mechanical treatments (such as thinning the canopy), and allowing wildfire with little or no active management (Rocca et al. 2014). Different forest types have different fire regimes and require different fire management policies. (Dellasala et al. 2004). For instance Cerrado, a fire dependent savannah, requires a clear fire management policy different than the current fire suppression policy (Durigan and Ratter 2016). The choice of strategy depends on local considerations including land ownership patterns, budgets, logistics, federal and local policies, tolerance for risk and landscape contexts. In addition there are trade-offs among the management alternatives and often no single management strategy will simultaneously optimise ecosystem services including water quality and quantity, carbon sequestration, run off erosion prevention (Rocca et al. 2014). Fire strategies need to be tailored to site specific conditions in an adaptive application that is assessed and reassessed over time (Dellasala et al. 2004; Rocca et al. 2014).

Flood

Flood risk is dominated by planned adaptation, primarily command and control measures including spatial planning and engineered flood defences (Filatova 2014). However if autonomous adaptation is downplayed, (Filatova 2014) found that people are more likely to make land use choices that collectively lead to increased flood risks and leave costs to governments. As a result governments need to provide stimuli including taxes, non-perverse subsidies, flood insurance, marketable permits and transferable development rights to provide price signals to stimulate autonomous adaptation countering barriers of path dependency and the time lag between private investment decision and consequences (Filatova 2014). To build resilience, consideration needs to be made of policy instruments responding to flood including flood zone mapping, flood zone building restrictions, business and crop insurance, and disaster assistance payments, and preventative instruments including environmental farm planning and farm infrastructure projects, and recovery from debilitating flood losses ultimately through bankruptcy (Hurlbert 2018a). Non Structural measures have been found to advance sustainable development as they are more reversible, commonly acceptable and environmentally friendly (Kundzewicz 2002).

Economic instruments: catastrophe bonds, contingency finance, forecast-based finance

A range of economic instruments are used to address impacts from climate change and considering the totality of approaches available as well as their limitations is important (Surminski 2016)(Surminski et al. 2016). One way to organise consideration of these instruments is to distinguish between those that are risk-based (such as catastrophe bonds, insurance and risk pools) and those not based on transferring risk. The latter category includes a range of contingency finance approaches, with finance from donors (humanitarian), national savings, or sovereign debt-based finance (contingent credit/loan, ex post bonds). A second axis for organising analysis extends between risk (ex-ante) financing and loss (ex post) financing. Ex-ante measures are the main instruments for reducing fatalities and limiting damage from disasters (Surminski et al. 2016). Without these, in a warming world post-disaster assistance and insurance will be increasingly unsustainable (Surminski et al. 2016).

Risk layering is an important concept in understanding the use of financial instruments in comprehensive climate risk management. Different financial tools may be used for different categories of risk or different phases (preparedness, relief, recovery, reconstruction) of financial need. For example, catastrophe bonds might be appropriate for ex post finance for recovery and reconstruction from very high impact and very low frequency events. Contingency finance approaches would be appropriate for low to medium risk events and slow onset processes, across the phases of need. As there is no one-size-fits-all instrument or approach, risk layering is a suggested approach to combining financial instruments (Mechler et al. 2014; Surminski et al. 2016).

Catastrophe (CAT) bonds are high-yield debt instruments used to transfer risks from issuer (a company or government) to an investor in the event of a specified catastrophe. In the case of sovereign CAT bonds, the investor provides a certain sum of money, and the recipient government regularly pays coupon interest on the amount. In the case of the pre-defined catastrophe, the requirement to pay the coupon interest or repay the principal may be deferred or forgiven (Nguyen and Lindenmeier 2014). CAT bonds are typically short-term instruments (3-5 years) and are parametric in that the payout is triggered once a particular threshold of disaster/damage is passed (Härdle and Cabrera 2010; Campillo, G., Mullan, M., Vallejo 2017; Estrin and Tan 2016a; Hermann, A., Koferl, P., Mairhofer 2016; Michel-Kerjan et al. 2011; Roberts 2017) . The primary advantage of CAT bonds is their ability to quickly disburse money in the event of a catastrophe (Estrin and Tan 2016b).

Another means of catastrophe finance is the catastrophe risk pool, where multiple countries in a region might pool risks in a diversified portfolio. Examples include ARC, CCRIF, and PCRAFI (Bresch et al. 2017).

There are significant barriers for developing country governments to entry into the CAT bond market: lack of familiarity with the instruments; lack of capacity and resources to deal with complex legal arrangements; limited or non-existent data and modelling of disaster exposure; and other political disincentives linked to insurance. For these reasons the utility and application of CAT bonds is limited to higher-income developing countries (Campillo, G., Mullan, M., Vallejo 2017; Le Quesne 2017).

A broad range of sources make up the category of contingency finance; examples exist at all levels of government of dedicated contingency funds, set aside for unpredictable climate-related disasters. Contingency finance ranges from household savings to Development Policy Loans with Catastrophe Risk Deferred Drawdown Option , a contingent line of credit for immediate disbursement of funds in the event of a disaster, granted by the World Bank to IBRD-eligible governments. Contingency finance is best suited to manage frequently occurring, low-impact events (Campillo, G., Mullan, M., Vallejo 2017; Mahul and Ghesquiere 2010; Roberts 2017) and may be linked with social protection systems. Multilateral development banks manage risk at relatively low cost by providing contingent lines of credit (Mahul & Ghesquiere, 2010). These instruments are limited by uncertainty surrounding the size of contingency fund reserves given unpredictable climate disasters (Roberts 2017) and lack of borrowing capacity of a country (such as small island states) (Mahul & Ghesquiere, 2010).

Forecast based finance links financing with early action as a response to forecasts of hazards and disaster impacts (Wilkinson 2018). Forecast-based mechanisms use “climate or other forecasts to trigger funding and action prior to a shock or before acute impacts are felt, to reduce the impact on vulnerable people and their livelihoods, improve the effectiveness of emergency preparedness, response and recovery efforts, and reduce the humanitarian burden.” (Wilkinson 2018). It can also be linked with social protection systems to effect ex ante impacts of disasters on food security by providing contingent scaled-up finance quickly to vulnerable populations enhancing scalability, timeliness, predictability and adequacy of social protection benefits (Wilkinson 2018; Costella et al. 2017; Programme 2018).

7.4.2.5 GHG fluxes and climate change mitigation

A significant gap still exists between NDCs and achieving commitments to keep global warming below 1.5°C (Höhne et al. 2017; Rogelj et al. 2016) creating a significant risk of global warming. Mitigation actions to achieve NDCs, which include renewable energy, may have trade-offs with food security. The promotion of small hydro-power (<25 MGW) as a clean low carbon alternative to fossil fuels under the NDCs has given a new thrust and justification for small dams (Chakrabarty and Chakraborty 2018). Small dams and solar farms are however already showing trade-offs with fresh-water biodiversity regionally (Jumani et al. 2017b) and with food security locally (Turney and Fthenakis 2011). Large new dams being planned in many countries are clearly linked to national food, water and energy security planning that could be justified under the SDGs but could generate irreversible trade-offs with respect to downstream ecosystem services. The emerging global boom in dam building for renewable energy and water demands has severe consequences for rivers and riverine ecosystem services (Zarfl et al. 2014). The absence of a clear commitment to conserving aquatic ecosystems under the SDGs or NDCS makes the trade-offs with respect to aquatic ecosystem services both a key and an emerging risk.

The Paris Agreement reaffirmed the UNFCCC target that ‘developed country parties provide USD 100 billion annually by 2020 for climate action in developing countries’ (Rajamani 2011) and a new collective quantified goal above this floor is to be set taking into account the needs and priorities of developing countries (Fridahl and Linnér 2016). The Green Climate Fund (GCF) is to: (1) provide a paradigm shift towards low-emission and climate-resilient development pathways for developing countries (Lattanzio 2012); (2) achieve a balanced allocation of resources between adaptation and mitigation (allocating 50% to LDCs, SIDs, and African States and 3 million USD for development of National Adaptation Plans (GCF (Green Climate Fund) 2017; Brechin and Espinoza 2017)),Intended Nationally Determined Contributions and Nationally Determined Contributions

There is a risk of not meeting the goal set in the Paris Agreement of holding global warming to well below 2˚C compared to pre-industrial levels and of pursuing efforts to limit warming to 1.5˚C. Although NDCs constitute only one third of the emission reductions needed to be on a least cost pathway for the goal of staying well below 2˚C, the gap can be closed by 2030 by adopting already known cost effective technology (United Nations Environment Programme 2017). Agriculture is well represented in adaptation and mitigation strategies of parties to the Paris Agreement and the Intended Nationally Determined Contributions with much attention to conventional agricultural practices such as livestock and crop management that can be climate smart, but less to the enabling services that can facilitate uptake that include information services, insurance and credit; 73 parties reference food security and 25 note nutritional security as an important concern, but few specify concrete actions (Richards, M., Bruun, T.B., Campbell, B.M., Gregersen, L.E., Huyer 2015). Much is expected out of the finance, capacity building and technology transfer mechanisms of the UNFCCC (ibid).

Developments in attribution science are improving the ability to detect human influence on extreme weather and some authors argue this broadens the legal duty of government, business and others to manage foreseeable harms and may lead to more climate change litigation (Marjanac et al. 2017); these authors anticipate the first climate litigation most likely to emerge will be claims against governments for failure to adopt or prepare for climate change (Marjanac et al. 2017). Courts are becoming increasingly receptive to employ rights claims in climate change lawsuits (Peel and Osofsky 2017); citizen suits in domestic courts can result in potentially effective enforcement of individual state responsibility for limiting emissions and their impacts and even if these suits are not a universal phenomenon and are unsuccessful, they are important in underlining the high level of public concern (Estrin 2016).

Financing mechanisms

The costs of adaptation needed range from 140 billion to 300 billion USD by 2030, and between 280 billion and 500 billion USD by 2050; (UNEP 2014). (These figures vary according to methodologies and approaches used (de Bruin et al. 2009; IPCC 2014a; Organization for Economic Cooperation and Development 2008; Nordhaus 1999; UNFCCC 2007; Plambeck et al. 1997; World Bank 2010). While the provision of adaptation finance from developed to developing countries has increased from less than 2 billion USD in 2010 to about 12 billion USD in 2014, most developed countries tend to prefer allocating their funding to mitigation rather than adaptation actions. (Abadie et al. 2013). While the Green Climate Fund (GCF) provides opportunity, it is still a new institution with policy gaps, a lengthy and cumbersome process related to approval (Brechin and Espinoza 2017; Khan and Roberts

2013; Mathy and Blanchard 2016) and challenges with adequate and sustained funding (Schalatek and Nakhooda 2013).

A range of financing mechanisms exists (e.g. from the World Bank, the IMF, IFC, and regional development banks, as well as specialized multi-lateral institutions such as the GCF, the Global Environmental Fund (GEF), REDD+, CDM, and the EU Solidarity Fund). Most public finance provided to developing countries flows through bilateral and multilateral institutions, often in the form of concessional loans and grants. Some governments have established state investment banks (SIBs) to close the financing gap, including the UK (Green Investment Bank), Australia (Clean Energy Finance Corporation) and in Germany (Kreditanstalt für Wiederaufbau) the Development Bank has been involved in supporting low-carbon finance (Geddes et al. 2018). Private adaptation finance exists, but is difficult to define, track, and coordinate; efforts are being made to increase its inclusiveness (Nakhooda et al. 2016). A global stocktake of climate finance sources indicates a startling array of diverse and fragmented sources: more than 50 international public funds, 60 carbon markets, 6000 private equity funds, 99 multilateral and bilateral climate funds (Samuwai and Hills 2018).

In 2015, 95% of reported climate finance related to mitigation (Klein Goldewijk and Verburg 2013). The 1.5°C report also addresses finance for achieving the 1.5°C target and emphasises that even greater changes are required to meet the 1.5°C target. Both volume and patterns of investment need to be transformed to get the world on a 2˚C pathway, as well as changes to the type and structure of financial institutions as well as the method of financing (Hoch 2017). However, the dominance of finance for mitigation disregards the financing needs of vulnerable countries with minimal GHG emissions. The returns on investment in countries such as Pacific Small Island Developing States are humanitarian in nature rather than financial as in many mitigation projects (Samuwai and Hills 2018).

Of these climate finance sources, the amount of funding dedicated to climate change in agriculture is very small compared to total climate finance, and significant gaps exist in the provision of resources for agriculture in general (FAO 2010). Much of the funding for agriculture is accessed through adaptation funds, rather than the much larger pool for mitigation, and they may potentially be in competition with each other (Lobell et al. 2013). Focusing on synergies, or triple wins (such as Climate Smart Agriculture (CSA), which promotes the 'triple wins' of mitigation, adaptation, and increased productivity (Lipper et al. 2014a)), may leverage greater financial resources (Suckall et al. 2015). Concerns do exist around the conditions for finance for CSA however, where agricultural mitigation may be required as a precondition of financing adaptation or development projects (Tompkins et al. 2013) and the dominance and influence of the prevailing food regime (Newell and Taylor 2018). Payments for Ecosystem Services (PES) are another emerging area to encourage environmentally desirable practices, although they need to be carefully designed to be effective (Engel and Muller 2016).

Insurance and risk transfer tools face challenges around market imperfections, low insurance education/capacity, low affordability and accessibility (Mechler et al. 2014) and coverage is much broader in developed than developing countries (Marie-Justine Labelle Matthew Johns and Morris 2016).

Innovative financing approaches

Traditional financing mechanisms have not been sufficient in facilitating a rapid transition to a low carbon economy or building resilience – a 'financing gap' (Geddes et al. 2018). More recently there have been developments in more innovative mechanisms including crowdfunding(Lam and Law 2016), often supported by national governments. For example, the UK government has supported the development of crowd funding through regulatory and tax support, and guarantees to support peer to peer lending (Owen et al. 2018). Crowdfunding has no financial intermediaries and thus low transaction costs, and the projects have a greater degree of independence than bank or institution funding (Miller et al. 2018). Other examples of innovative mechanisms are community shares for local projects, such as renewable energy (Holstenkamp and Kahla 2016)

Corporate Power Purchase Agreements (PPAs) are increasingly being used by companies such as Google and Apple to purchase renewable energy directly or virtually from developers, and expected to continue to grow (Miller et al. 2018). The investing companies benefit from avoiding unpredictable price fluctuations as well as increasing their environmental credentials.

Auctioned price floors can be applied to a variety of sectors and are currently being trialled to reduce GHG emissions in developing countries, developed by the World Bank Group, known as the Pilot Auction Facility (PAF). The PAF issues tradeable bonds, providing a guaranteed floor price for future emission reductions (Bodnar et al. 2018).

Distributed ledger technology, such as blockchain, has potential to transform climate finance and environmental governance (*high agreement, low evidence*) (Chapron 2017). Blockchain is a digital ledger that lists ownership of a set of assets as well as a tamper-proof transaction history for those assets, and is operated by a peer-to-peer network of computers (Urban 2018). Such technology has been used to create virtual currencies, such as Bitcoin, launched in 2008 (Conte de Leon et al. 2017). It has enabled a new class of enterprises to raise capital by selling coins or tokens, sometimes with characteristics such as rights to service, to other individuals (Urban 2018). One of the key benefits of distributed ledger technology is that it makes transfers of assets fully transparent and can be used in an environment that is not trust-based and without a central authority (Chapron 2017). Digital contracts can be created that automatically trigger payments to individuals. “Gainforest” has used this technology to enable individuals (“donors”) to make payments to small-scale farmers (“caretakers”) in the Amazon for preserving patches of rainforest over a three to six-month period. The technology also has applications for insurance and for governance (Gatteschi et al. 2018). But such applications are still nascent and uncertainties about the benefits and risk exist (*high agreement, high evidence*).

In order for climate finance to be as effective and efficient as possible, it is necessary for the private, public and third sectors to work together to create an enabling environment for innovation (Owen et al. 2018). While innovative private sector approaches are making significant progress, the existence of a stable policy environment that provides certainty and incentives for long term private investment is critical.

Mitigation instruments

Carbon pricing incorporates the polluter pay principle and adjusts the prices of all goods and services to reflect direct, indirect, and social GHG emission costs (based on the Social Cost of Carbon (SCC)) – the incremental impact of emitting an additional tonne of CO_2, or the benefit of slightly reducing emissions (Tol 2018). Higher costs throughout the entire economy results in reduction of carbon intensity as consumers and producers adjust their decisions in relation to prices corrected to reflect the climate externality (Baranzini et al. 2017). A carbon tax and a cap and trade system are two predominant policy instruments that implement carbon pricing. The advantage of carbon pricing is environmental effectiveness at relatively low cost; non-price policy instruments have considerably higher abatement cost and are less effective at covering diverse sources of emissions (Baranzini et al. 2017). Furthermore, carbon pricing can be used to raise revenue to reinvest in public spending, either to help certain sectors transition to lower carbon systems, or to invest in public spending unrelated to climate change. Both of these options may make climate policies more attractive and enhance overall welfare (Siegmeier et al. 2018).

There is *high agreement and medium evidence* that a carbon tax, if designed properly, can reduce GHG emissions with the advantage of environmental effectiveness at relatively low cost (Metcalf and

Weisbach 2009; Martin et al. 2014; Baranzini et al. 2017). For a small additional cost, one study identifies that a carbon tax in the United States could reduce a large proportion (between 80% and 90%) of emissions (Metcalf and Weisbach 2009). However, the effectiveness of a carbon tax is negated if it is poorly designed (Bruvoll and Larsen 2004); poor design might relate to the scope and nature of tax exemptions and the usage of the tax revenue. For example a broad range of exemption for fossil fuel intensive industries will negate the carbon tax effectiveness (Lin and Li 2011b). A fuel tax has also reduced emissions in the transportation sector (Rivers, Nicholas, Schaufele 2015).

A cap and trade (also known as a carbon market, or emissions trading scheme (ETS)) regulatory option imposes a cost on emissions by regulating specific sectors of the economy, limiting emissions from a specific entity or enterprise by imposing a cap and then allowing the entity to exceed the imposed limit by buying permits in a carbon trading market from entities that have used less than their allowed limit. The trading system allows the achievement of emission reductions in the most cost-effective manner possible and results in a market and price on emissions that create incentives for the reduction of carbon pollution. There is *high agreement and medium evidence* that properly designed, a cap and trade system can be a powerful policy instrument (Wagner 2013) and may collect more rents than a variable carbon tax (Siegmeier et al. 2018).

A cap and trade system has successfully reduced SO_2 in electrical power plants (Assigns et al. 1990). However, depending on how the cap and trade system is established, it can result in little incentive to invest in improvement given the regulator has less ability to control price of energy while ensuring productive efficiency (full diffusion of technology to all producers). Because there will be little incentive to invest in larger improvements than will be fully diffused, it may be that cap and trade limits innovation in comparison to a carbon tax (Scotchmer 2011). Depending on design, a cap and trade system may not adequately capture the dynamic opportunities for allowance banking, borrowing, and inter-temporal arbitrage in response to unfolding information (Murray et al. 2009). Remedies in design might include a set aside reserve to automatically retire emission trading permits and cure the problem of emission cap floors constituting a discouragement from ethically motivated reductions (Twomey et al. 2012). Further, having a cap and trade system adopted in only one jurisdiction and not in surrounding closely connected economies may result in 'leakage' or reduced effectiveness. Products with lower prices not reflecting carbon prices are imported. This leakage can be prevented by banning such resource shuffling (Caron et al. 2015). The opportunity for leakage is reducing as more jurisdictions adopt a cap and trade system. For example, such expansion has recently occurred in China (Deng et al. 2018), Korea (Suk et al. 2017), and Japan (Wakabayashi and Kimura 2018).

In the land use sector, carbon markets present specific implementation challenges due to the large number of small entities based on biological systems, with high uncertainty relating to the volume of emissions and the most efficient point of obligation (the point in the supply chain obliged to report on and surrender units for emissions). New Zealand is currently investigating mechanisms to incorporate agriculture into a national emission trading system after an earlier attempt was reversed (Kerr and Sweet 2008). The two potential points of obligation are at the processor level or at the individual farm level. Setting the point of obligation at the processor level means that farmers would face little incentive to change their management practices, unless the processors themselves rewarded farmers for lowered emissions. Setting it at the individual farm level would provide a direct incentive for farmers to adopt mitigation practices, however the reality of having thousands of individual points of obligation would be administratively complex and result in high transaction costs. Despite these challenges, New Zealand is working to develop an effective system.

Policy instruments that target specific climate mitigation technologies or reductions play an important role in climate mitigation (Bertram et al. 2015; Kriegler et al. 2014). Carbon pricing and technology policies are largely complimentary (Baranzini et al. 2017). However, these policy instruments may have considerably higher abatement cost and be less effective at covering diverse sources of emissions (Baranzini et al. 2017). Technology policies play an important role in achieving zero carbon targets in the short term and there is a concern that delay in taking action on mitigation might result in technology lock in and higher abatement costs in the future (*high confidence*) (Riahi et al. 2015; Kriegler et al. 2015; Bertram et al. 2015). There is *medium agreement and limited evidence* that climate targets can be kept within reach despite a sub-optimal policy mix that includes targeted low-carbon technology policies and fragmented and moderate carbon pricing schemes together with a moratorium on new coal-fired power plants to limit stranded assets (Bertram et al. 2015).

Technology Transfer, land use sectors and Article 6 of the Paris Agreement

Technology transfer has been a key aim under the UNFCCC since its inception and is one of the pillars of international climate mitigation and adaptation efforts embodied in the Paris Agreement. The definition of technology transfer adopted by IPCC is somewhat broader than that used under the UNFCCC by including the notion that technology transfer also:

> "…comprises the process of learning to understand, utilise, and replicate the technology, including the capacity to choose it, adapt it to local conditions, and integrate it with indigenous technologies (Metz et al. 2000).

This broader definition of technology transfer suggests greater heterogeneity in the applications for climate mitigation and adaptation, especially in land use sectors where indigenous knowledge is perceived as important for long-term climate resilience (Nyong et al. 2007b). More generally, technology transfer encompasses the enabling conditions, including 'orgware' as well as hardware, where 'orgware' refers to the organisational capacity to absorb and apply technology to reach the desired aims (Haselip et al. 2015). However, it is difficult to objectively or empirically analyse such organisational impacts in relation to technology transfer as they are not easily formalised. Furthermore, in the case of land use sectors, the typical reliance on trade and patent data for empirical analyses is generally not feasible as the "technology" in question is often related to resource management and is neither patentable nor tradable (Glachant and Dechezleprêtre 2017).

Technology transfer was a key aim of the flexibility mechanisms under the Kyoto protocol. A detailed study for nearly 4000 CDM projects showed that 39% of projects had a stated and actual technology transfer component, accounting for 59% of emissions reductions; however, the more land-intensive projects (e.g. afforestation, biomass energy) showed somewhat lower percentages (Murphy et al. 2015). In relation to broader development benefits, bioenergy projects that rely on agricultural residues are found to offer substantially more benefits than those dependent on industrial residues from forests (Lee and Lazarus 2013). Collaborative Research and Development (R&D) offers longer-term means of technology transfer, although more difficult to measure compared to specific cooperation projects and international mechanisms; empirical research on the effects of R&D collaboration could help to avoid the "one-policy-fits-all" approach that sometimes characterises technology transfer efforts in the international negotiations (Ockwell et al. 2015). For land use sectors, the implications of R&D collaboration are likely to be even more pronounced than might be the case for energy or industry since there are often issues of improved resource management that require many years of interaction between researchers, practitioners and policy-makers rather than simple sharing or financing of technologies or identification of new applications.

Technology transfer has tended to be more associated with mitigation, however there is increasing recognition of its role in climate adaptation. Unlike mitigation there has been a tendency to rely on existing technologies rather than new or innovative technologies, which is due in part to the additional inherent uncertainty in adoption that is associated with adaptation, particularly in land use sectors. Such uncertainties arise from changing climatic conditions, changing agricultural prices and the uncertain suitability of technology applications under future conditions (Biagini et al. 2014).

Engaging the private sector in adaptation efforts is important in this context, as bringing new technologies can only be replicated with significant private sector involvement and furthermore those private companies are also more likely to incorporate adaptation strategies into their modes of work and their technology investments so as to better manage risk (Biagini and Miller 2013). A further distinction with mitigation can be made in that adaptation processes themselves are often intertwined with the processes for adopting technologies for adaptation, so that greater coordination will be needed between technology transfer mechanisms and adaptation strategies, including between the Cancún Adaptation Framework and the Technology Mechanism of the UNFCCC (Olhoff 2015). Such roles are also evolving under the Paris Agreement in light of its new mechanisms for cooperation.

Article 6 of the Paris Agreement brings new opportunities for cooperation between Parties and between Parties and non-state entities in reducing GHG emissions and increasing resilience of land-climate systems while achieving their NDCs (UNFCCC (United Nations Framework Convention on Climate Change) 2016). It sets out several options for international cooperation:

- Cooperative approaches under Articles 6.2-3 that are understood to refer to government-led initiatives giving rise to emission reductions in the form of internationally transferred mitigation outcomes (ITMOs).
- A mechanism under Articles 6.4-7 that establishes a centralised, international crediting mechanism under the governance of the UNFCCC that is to contribute to both mitigation and sustainable development.
- A framework for non-market approaches to sustainable development (which are normally assumed not to involve transfers) under Articles 6.8-9 is seen by many Parties as a means of facilitating improved coordination and exploiting synergies across non-market-oriented policy instruments and institutional arrangements (Obergassel 2017). These approaches can effectively include any combination of measures or instruments related to adaptation, mitigation, finance, technology transfer and capacity-building, which should be of particular interest in land use sectors where such aspects are more intertwined than might the case in energy or industry sectors.

Cooperation under Article 6.2 or 6.4 Paris Agreement is based on principles of environmental integrity, which includes the avoidance of double counting of emissions. There has been good progress in accounting for land-based emissions (mainly forestry and agriculture), but various challenges remain (Macintosh 2012; Pistorius et al. 2017; Krug 2018). The close relationship between emission reductions, adaptive capacity, food security and other sustainability and governance objectives in the AFOLU sector means that Article 6 could bring co-benefits that increase its attractiveness and the availability of finance, while also bringing risks that need to be monitored and mitigated against, such as uncertainties in measurements and the risk of non-permanence (Thamo and Pannell 2016; Olsson et al. 2016; Schwartz et al. 2017).

Considering the special characteristics and challenges associated with land use sectors, the transfer of capacities as well as technologies to developing country Parties will be important to enable full participation. The new mechanisms also illustrate a shift in the technology transfer approach away from an emphasis on obligations of developed country Parties to a more pragmatic, decentralised and cooperative approach compared to the Kyoto protocol (Savaresi 2016; Jiang et al. 2017). While the rules for the implementation of the new mechanisms are still under development, lessons from REDD+ may be useful, which is perceived as more democratic and participative than the CDM (Maraseni and Cadman 2015).

As well as new opportunities for finance and support, the cooperation mechanisms in the Paris Agreement bring new challenges, particularly in emissions accounting in land use sectors. Since developing countries must now achieve, measure and communicate emission reductions, they now have value for both developing and developed countries in achieving their NDCs, but reductions must not be double-counted (i.e. towards multiple NDCs). Developing countries have less incentive to convert emission reductions to ITMOs and transfer them, at least not until they have met their NDCs (Streck et al. 2017). This challenge is particularly prominent in land use sectors where emission reductions take more time to achieve and are less predictable. There is also no agreement whether the cooperative systems that give rise to an “ecological civilization” (Jiang et al. 2017) can or should be facilitated by offsetting and transfers of emission reductions. Experts argue in favour (van der Gaast et al. 2018) and against (Dooley and Gupta 2017) a role for carbon projects and mitigation programs in land use sectors under the Paris Agreement. International emission trading may also lead to welfare loss of developing countries (Fujimori et al. 2016). The benefits of interventions and mechanisms are highly context specific and will most likely continue to be considered on a case-by-case basis and will need to be backed by strong safeguards (Bustamante et al. 2014).

7.4.3 Policy mix and suites of policy instruments

Existing responses to risk provide challenges as well as opportunities. In addition to the uncertainty described (7.3), challenges exist with assessing multiple hazards and sectors (Aalto et al. 2017; Brander and Keith 2015; Williams and Abatzoglou 2016). Mainstreaming adaptation and risk management into on-going development planning and decision making is challenging, faced by developed as well as developing countries (Linnerooth-Bayer and Hochrainer-Stigler 2015), overly focused on sectors instead of sustainable use of biodiversity and ecosystem services (Huq et al. 2017), and often policy capacity and human, financial and technical resource availability act as barriers (Ayers et al. 2014; Huq et al. 2017).

Scaling up is a key challenge for community-based and ecosystem-based adaptation initiatives. Although difficult and often ignored, CBA and EBA initiatives should ensure that communities are central to planning (Reid 2016). There is *high agreement and medium evidence* that one of the greatest challenges is posed by inequalities that influence local coping and adaptive capacity (Field and Intergovernmental Panel on Climate Change. 2012; Kunreuther et al. 2013). Effective and reliable social safety nets will be required to address impacts on the neediest (Jones and Hiller 2017). Social protection coverage is low across the world and informal support systems continue to be the key means of protection for a majority of rural poor and vulnerable (Stavropoulou et al. 2017). There is a need to better understand both positive and negative synergies between formal and informal systems of social protection and how local support institutions might be used to implement more formal forms of social protection (Stavropoulou et al. 2017).

The optimal climate mitigation policy portfolio includes different instruments targeted at emissions reductions, learning, and research and development (*high confidence*) (Fischer and Newell 2008). Consideration of the interactions of policy instruments is important. Research in the area of the interaction of suites of policies working together is just commencing. For instance, dedicated renewable energy programs may not support emissions trading as the price of renewable energy is supplemented by government. However, the addition of a carbon tax can remedy these negative interactions (del Río and Cerdá 2017). The integration between climate policy and public finance is critical in ensuring the efficiency, effectiveness and equity of mitigation policy, and ultimately to make stringent mitigation policy more feasible (Siegmeier et al. 2018).

7.4.4 Effectiveness of instruments

An enabling environment for policy effectiveness must include: 1) the development of comprehensive policies, strategies and programs; 2) human and financial resources that ensure policies, programs and legislation are translated into action; 3) governance coordination mechanisms and partnerships; 4) decision making that draws on evidence generated from functional information systems that make it possible to monitor trends; track and map actions; and assess impact in a manner that is timely and comprehensive (FAO 2017). (Di Gregorio et al. 2017) have found that in Indonesia while internal policy coherence between mitigation and adaptation is increasing, external policy coherence between climate change policy and development objectives is needed. Bureaucratic structures undermine vertical and horizontal policy integration (vertical policy integration to mainstream climate change into sectoral policies and horizontal policy integration by overarching governance structures for cross-sectoral coordination (Di Gregorio et al. 2017)).

Iterative risk management is an on-going process of assessment, action, reassessment and response (Mochizuki et al. 2015). This will be important for developing responsive policies in a changing environment. However, gauging effectiveness of policy instruments is challenging. Timescale may influence outcomes. In order to evaluate effectiveness researchers, program managers and communities should strive to develop consistency, comparability, comprehensiveness and coherence in their tracking. In other words, practitioners should utilise a consistent and operational conceptualisation of adaptation; focus on comparable units of analysis; develop comprehensive datasets on adaptation action; and be coherent_with our understanding of what constitutes real adaptation (Ford and Berrang-Ford 2016). Increasing the use of systematic reviews or randomised evaluations will also be helpful (Alverson and Zommers 2018).

7.4.4.1 Sustainable Development Goals (SDGs) Coherence

Unlike the Millennium Development Goals, the SDGs apply to all countries, and measure progress of sustainable and socially just development of human societies at all scales of governance (Griggs et al. 2013b). The UN SDGs rest on the premise that the goals are mutually reinforcing with global policies and agreements. There exist inherent linkages, synergies and trade-offs between and within the sub-goals. There is high agreement that opportunities, trade-offs and co-benefits are context specific and depend on a variety of political, national and socio-economic factors. “Implicit in the SDG logic is that the goals depend on each other — but no one has specified exactly how. International negotiations gloss over tricky trade-offs” (Nilsson et al. 2016b). Some thematic areas covered by the SDGs are well connected with one another, whereas other parts have weaker connections with the rest (Le Blanc 2015).

At least one gap has been identified in the SDGs relevant to land and climate interactions - the absence of an explicit goal related to sustainable management of rivers and fresh-water ecosystems, especially given the trade-offs with goals related to water supply and clean energy production. This has occurred despite emerging knowledge about the role that rivers and riverine ecosystems play in human development and in generating global, regional and local ecosystem services (Nilsson and Berggren 2000; Hoeinghaus et al. 2009). A goal related to sustaining marine life (“Life under Water”) is included, even though sustainable management of marine life especially in estuaries, deltas and coastal ecosystems, would need corresponding management of rivers and life in rivers (Barbier et al. 2011). Therefore there are twin policy threats to fresh-water biodiversity and ecosystems because of limitations in framing of the SDGs and the proliferation of small dams in biodiversity hotspots (Jumani et al. 2017b) due to INDC commitments made under the Paris Agreement.

There is *high agreement and medium evidence* that SDGs must not be pursued independently, but in a manner that recognises trade-offs and synergies with each other, consistent with a goal of ‘policy coherence.’ Policy coherence also refers to spatial trade-offs and geo-political implications within and between regions and countries implementing SDGs. For instance, food security initiatives of land-based agriculture are impacting marine fisheries globally through creation of dead-zones due to agricultural run-off (Diaz and Rosenberg 2008). There are also spatial trade-offs related to large river diversion projects and export of “virtual water” through water intensive crops produced in one region exported to another, with implications for food-security, water security and downstream ecosystem services of the exporting region (Hanasaki et al. 2010; Verma et al. 2009). Synergies include cropping adaptation that increase food system production and eliminate hunger (SDG2) (Rockström et al. 2017a; Lipper et al. 2014a; Neufeldt et al. 2013). Well-adapted agricultural systems have shown to have positive returns on investment and contribute to safe drinking water, health, biodiversity and equity goals (DeClerck 2016).

There is also *limited agreement and limited evidence* that binary evaluations of individual SDGs and synergies and trade-offs that categorise interactions as either ‘beneficial’ or ‘adverse’ may be subjective and challenged further by the fact that feedbacks can often not be assigned as unambiguously positive or negative (Blanc et al. 2017). The Special Report on Global Warming of 1.5°C notes, “A reductive focus on specific SDGs in isolation may undermine the long-term achievement of sustainable climate change mitigation (Holden et al. 2017)“. Greater work is needed to tease out these relationships, and studies that include quantitative modelling (see Karnib 2017) and nuanced scoring scales (ICSU 2017) of these relationships have started.

There is *high agreement and medium evidence* that to be effective, truly sustainable, and to reduce or mitigate emerging risks, SDGs need knowledge and policy initiatives that recognise and assimilate concepts of co-production of ecosystem services in socio-ecological systems, cross-scale linkages, uncertainty, spatial and temporal trade-offs between SDGs and ecosystem services that recognise biophysical, social and political constraints and an understanding of how social change occurs at various scales (Rodríguez et al. 2006; Norström et al. 2014; Palomo et al. 2016). Complex interactions exist between these goals and within the sub-goals and further research is needed to understand the various relationship dimensions (*high agreement, limited evidence*). These could include temporal and spatial trade-offs, trade-offs at different scales and across sectors. Several methods and tools are proposed in literature to address and understand these interactions. Nilsson et al. (2016a) suggest using a going beyond a simplistic synergies-trade-offs framing to understanding various relationship dimensions proposing a seven-point scale to understand these interactions.

A nexus approach is increasingly being adopted to explore synergies and trade-off between a select subset of goals and targets (such as the interaction between water, energy, and food (see, e.g. Yumkella and Yillia 2015; Conway et al. 2015; Ringler et al. 2015)).

However, even this approach ignores systemic properties and interactions across the system as a whole (Weitz et al. 2017). Pursuit of certain targets in one area can generate rippling effects across the system, and these effects in turn can have secondary impacts on yet other targets. (Weitz et al. 2017) found that SDG target 13.2 (climate change policy/ planning) is influenced by actions in six other targets. SDG 13.1 (climate change adaption) and also 2.4 (food production) receive the most positive influence from progression in other targets. This approach, and the identification of clusters of synergy, can help indicate to government ministries should work together or establish collaborations to reach their specific goals. Finally, context specific analysis is needed. Synergies and trade-offs will depend on the natural resource base (such as land or water availability), governance arrangements, available technologies, and political ideas in a given location (Nilsson et al. 2016b).

Cross-chapter Box: Gender in integrative approaches for land, climate change and sustainable development

When developing integrated responses, it is important to consider social dynamics and interactions, including inequalities. As discussed in the Special Report on Global Warming of 1.5°C, negative impacts can occur when existing inequalities are exacerbated. By contrast "Policy frameworks and strong institutions that align development, equity objectives and climate have the potential to deliver 'triple-wins'." (Chapter 5, SR1.5°C).

The Framework

Women played a dominant role in agriculture (Boserup 1970) and rural economy, forming 43% of the agriculture workforce and taking care of food security (FAO 2011); in sub-Saharan Africa 59% of women are in informal agriculture employment, largely as small-scale farmers (Razavi and Turquet 2016) in the context of male outmigration for work in general or as response to decline in pasture lands or drought (Brockhaus et al. 2013; Djoudi et al. 2016). However, overarching patriarchy in a majority of the countries, in particular the developing ones, has meant, less than 20% of landholders globally are women (FAO 2011); in only 37% of 161 countries men and women have equal land rights to use and control and in 59% the customary, traditional and religious practices discriminate against women (OECD 2014) even if the law grants equal rights. In particular, widows are the victims of land grabbing (Razavi and Turquet 2016).

There are multiple barriers to women participating in land-based adaptive and mitigating actions in response to climate change. They (i) are burdened with unpaid domestic work including care-giving activities (Beuchelt and Badstue 2013); (ii) constantly face risk of violence that restricts their mobility for capacity-building activities (Jost et al. 2016); (iii) face violence at home as well, that reduces their long-term participation in capacity building as well as productive work outside home (Day et al, 2005); (iv) lack ownership of productive assets and resources (Kristjanson et al. 2014; Meinzen-dick et al. 2010) including land, their creditworthiness is low and hence have low access to finance (Jost et al. 2016); (v) are not organised (while organisational membership helps in accessing credit (Carroll et al. 2012))and (vi) have lower endowments such as various capital that increase their individual resilience.

Integrative approaches should focus on 'gender' and not just 'women'. Women are not a homogenous group. Gender, being a socially, economically, culturally, politically and institutionally constructed reality, focuses on what women miss out on, in the dynamics of how gendered inequalities are constructed (Mersha and Van Laerhoven 2016). This understanding helps in action programmes. In particular, contemporary institutions are expected to mediate gender inequalities, however, their effectiveness is constrained through gendered rules, the implementation of which results in unequal gendered outcomes (Lowndes and Robert 2013). (Djoudi et al. 2016) suggest using a framework of intersectionality to integrate gender in climate change discourse as it deals with overlapping and interdependent systems of discrimination or disadvantage. SDG 5 and its interpretation in the context of Climate Change SDG 13, would mean fulfilling women's economic rights, achieving women's equal leadership, influence and participation in decision-making and reducing women's time burden by recognising, reducing and redistributing unpaid care (Rosche 2016; Esquivel and Sweetman 2016).

Gender and climate change literature

Literature on integrating Gender in Climate Change action is limited and is largely adaptation focused (Mersha and Van Laerhoven 2016; Djoudi et al. 2016). All studies report gendered impacts of climate change in rural areas with women of all communities at the lower level of resilience than the men in their communities, albeit through different pathways (Goh 2012; Kakota et al. 2011; Djoudi et al. 2016; Jost et al. 2016). At the same time, women’s overwhelming presence in agriculture provides opportunity to bring gender dimensions into climate change adaptation, in particular with regards to food security, through climate-smart agriculture. Quantitative methods have not helped in mapping these relationships and hence, identifying integrative approaches; in particular there is suggestion participatory adaptation should be adopted (Jost et al. 2016). Literature discusses gender barriers to climate change adaptation (Mersha and Van Laerhoven 2016), suggesting that female-headed households adapt through diversification in livelihood strategies (labour-intensive public-works and individual-based diversity) and communal-pooling of resources; male-headed households have more diverse sets of adaptation measures such as on-farm adaptation (cropping time adjustment, mixed cropping, planting commercial trees, soil conservation), temporary migration and storage of grains.

Climate change adaptation is multi-sectoral and existing literature has attempted to identify, and examine the national and sectoral policies geared towards better climate change adaptation; discussion of gender and its inclusions in natural resources policy documents remain just rhetoric (Ampaire et al. 2015). In particular, there has been introduction of or amendment to the existing land policies to include gender dimensions; however, there seems to be no progress on their implementation (Djoudi et al. 2016).

Some studies do point to an emancipatory role played by adaptation interventions, albeit in a limited manner. Women in socially disadvantaged groups engage in new livelihood activities after adult men out-migrate (Djoudi and Brockhaus 2011); collective action and agency of women, in the case of widows particularly, have led to prevention of crop failure, reduced workload, increased nutritional intake, increased sustainable water management, diversified and increased income and improved strategic planning (Andersson and Gabrielsson 2012). In a developed country context, there has been a shift from agriculture to salaried position (Ford and Goldhar 2012).

Land-based mitigation approaches include policy, technology and market activities in the agricultural, livestock and forestry sectors, such as policies supporting the cultivation of crops like corn, oil palm, sugarcane or soybeans that can be used to produce biofuels; global forest carbon markets to incentivise reductions in deforestation and degradation or increases in forest carbon stocks (one example being REDD+); policies supporting conservation agriculture to reduce emissions from soils; and energy infrastructure that impacts large areas of land, including hydroelectric projects, wind farms and concentrated solar power projects. Each of these options can produce environment and development trade-offs as well as social conflicts (Hunsberger et al. 2017). Their impacts need to be studied in gendered ways. But preliminary theories are that these interfere with traditional livelihoods in rural areas, cause conflicts, lead to decline in women’s livelihoods (Hunsberger et al. 2017), and reinforce existing inequities and social exclusions, if elite capture is not prevented (Mustalahti and Rakotonarivo 2014; Chomba et al. 2016; Poudyal et al. 2016). These activities also can lead to land grabs, which then remain focal point for research and local activism (Borras Jr. et al. 2011; White et al. 2012; Lahiff 2015).

If women's livelihoods get affected due to either land alienation through the creation of a market or appropriation (acquisition) by the government for climate mitigation efforts, the family slips into poverty. Land alienation for biofuels' production unequally impact as they do not adequately address land rights (Hunsberger et al. 2017). In certain contexts, they lead to increased conflicts. In a conflictual situation women are highly vulnerable to personal violence. REDD+ initiatives could be aligned with the SDGs to achieve complementary synergies with gender dimension, examples of which are yet unavailable in literature.

National Determined Contributions (NDCs)

In NDCs, 57 Parties refer to gender but mostly in relation to impacts of climate change; there is less provision for supporting women in actively addressing and participating in adaptation and mitigation actions (Richards Bruun et al. 2015). Richards et al. (2015) conclude that the lack of substantive references and commitments in the INDCs to women and gender equality is due to the limited approach to gender within the UNFCCC but that global climate funds take stronger approaches. They conclude that global institutions still fall short of the gender-transformative approach needed. Recommendations to address gender inequity include earmarking resources to contract women to participate on and equal basis with men in adaptation and disaster recovery responses, and building capacity and ensuring equal access for equal participation in climate decision making and leadership (Meikle et al. 2016)

Enhancing Social Resilience through Empowering Women and Other vulnerable Populations

Policy instrument responses to climate impacts are more successful if they account for the needs of a wide range of actors, target the poor and vulnerable, and incorporate inclusive decision making (Chu et al. 2015). Two policy areas are essential in empowering vulnerable populations: Early warning systems and community-based adaptation and disaster risk reduction.

Early warning systems improve resilience of households to climate related hazards by providing information for early actions. However, to be effective they must include diversity, flexibility, local relevance, learning, acceptance of change and considerations of justice and equity (UNEP 2015). Addressing factors that increase vulnerability such as poverty, inequality, lack of education, can improve early warning systems.

There is high agreement, but limited evidence that community based risk assessment and adaptation, both bottom up approaches to tackle climate change impacts, are superior for operationalising local inclusiveness and prioritising local communities' priorities, needs, knowledge, and capacities, empowering the community to plan and cope with immediate climate variability and climate impacts (van Aalst et al. 2008; Pelling 2007; Carcellar et al. 2011; Liu et al. 2016) moving beyond assessing only physical climate risks (Ayers and Forsyth 2009). However, occasionally local level projections of climate change impacts are unavailable (Forsyth 2013), or local elite capture may occur in the participatory processes (Lucas 2016) inhibiting the reduction of vulnerability.

7.4.5 Adaptation limits and barriers

The adverse effects of climate change cannot be avoided as mitigation efforts can no longer prevent climate change impacts in the next few decades (Klein et al. 2015). Only a small fraction of adaptation measures suggested can be implemented due to financial, institutional, technical, and physical limits giving rise to implementation barriers, which illustrates the narrowing of adaptation from the space of all possible adaptation, to the space of what actual adaptations will be implemented. Forces impacting this narrowing process appear in each respective circle.

An adaptation limit is, "the point at which an actor's objectives or system's needs cannot be secured from intolerable risks through adaptive actions" and implying there are 'no options that could be implemented over a given time horizon to achieve one or more management objectives, maintain values, or sustain natural systems" (Klein et al. 2015). Hard limits include water supply in fossil aquifers, limits to retreat on islands, and loss of biodiversity; soft limits refer to situations where adaptation options could become available in the future, due to changing attitudes or values or innovation and resources becoming available. Constraint, barrier and obstacle are used synonymously and in contrast to adaptation limit which is more restrictive.

Some examples of limits include: uncertainty, lack of coordination, government failures, behavioural obstacles to adaptation, market failures and missing markets, transaction costs and political economy, ethical and distributional issues (Chambwera et al. 2014b). Constraints or barriers identified by (Klein, et al. 2014) potentially surround lack of knowledge, awareness and technology; or consist of physical; biological; economic; financial; human resource; social and cultural; governance and institutional. Considerable literature exists around understanding social and cultural barriers to changing behaviours (Rosin 2013; Eakin; Marshall et al. 2012); literature examining the role of governance and institutions in creating or overcoming barriers in the land use sector exists in pockets around the role of insurance (Foudi and Erdlenbruch 2012; Linnerooth-Bayer and Hochrainer-Stigler 2015) and the existence of perverse incentives and misaligned policies. (Wreford et al. 2017) summarise the literature on barriers to the adoption of adaptation and mitigation practices in agriculture in OECD countries, and identify cost, lack of knowledge and information, social and cultural factors, as well as perceived negative effect on performance as important barriers.

Land tenure can present a barrier to adaptation, most commonly where tenanted farmers are less likely to invest in longer term adaptation or conservation measures due to the insecurity or complexity of their tenure, and particularly among women (Antwi-Agyei et al. 2015a; Baumgart-Getz et al. 2012). Understanding the nature of constraints to adaptation is critical in determining how these may be overcome. Evidence shows that understanding the local context and targeted approaches are generally most successful (Rauken et al. 2014).

Incremental adaptation consists of 'actions where the central aim is to maintain the essence and integrity of a system or process at a given site' whereas transformational adaptation is 'adaptation the changes the fundamental attributes of a system in response to climate and its effects;' the former is characterised as doing different things and the latter, doing things differently (Noble et al. 2014). Transformational adaptation is most likely necessary in situations where there are hard limits to adaptation or desirable to address deficiencies in sustainability, adaptation, inclusive development and social equity (Kates et al. 2012; Mapfumo et al. 2015). In other situations, incremental changes may be sufficient (Hadarits et al. 2017).

For food production systems, the highest potential to build resilience and adaptive capacity lies in diversity of local land, water, risk, and farm management. Research has documented diverse agroecological practices of small scale agriculture to deal with climatic variability which have led to superior recovery from climate stressors (Ahmed and Stepp 2016; Altieri et al. 2015). Additional research has suggested that high levels of on-farm biodiversity, polycultures, agroforestry systems, crop-livestock mixed systems accompanied by organic soil management, water conservation and harvesting, and traditional farming and risk management practices may present the only viable and robust ways to increase the productivity, sustainability and resilience of peasant-based agricultural production under predicted climate scenarios (Nalau and Handmer 2015; Altieri and Nicholls 2017)(Ahmed and Stepp 2016). Fostering or undermining of equity and participation are correlated with the efficacy and limits of local adaptation to secure food and livelihood security (Laube et al.

2012). Additional factors like formal education and knowledge of traditional farming systems, secure tenure rights, access to electricity and social institutions in rice-farming areas of Bangladesh have played a positive role in reducing adaptation barriers (Alam 2015). A review of over 168 publications over 15 years about adaptation of water resources for irrigation in Europe found the highest potential for action is in improving adaptive capacity and responding to changes in water demands, in conjunction with alterations in current water policy, farm extension training, and viable financial instruments (Iglesias and Garrote 2015). Research on the Great Barrier Reef, the Olifants River in Southern Africa, and fisheries in Europe, North America, and the Southern Ocean suggests the leading factors in harnessing the adaptive capacity of ecosystems is to reduce human stressors by enabling actors to collaborate across diverse interests, institutional settings, and sectors (Biggs et al. 2017; Schultz et al. 2015; Johnson and Becker 2015).

Limits in relation to society-land-climate interactions

Combinations of society-land-climate interactions pose barriers and limits to the adaptive capacity of food production systems and ecosystems (Biesbroek et al. 2013; Denton et al. 2015; Fan et al. 2017) . Predicted changes in the key factors of crop growth and productivity—temperature, water, and soil quality—are expected to pose barriers and limits to adapting in ways that allow the world’s population to get enough food in the future (Altieri et al. 2015; Altieri and Nicholls 2017). Barriers and limits to adaptation help determine the degree to which society can achieve its sustainable development objectives through adapting to risks arising from land-climate interactions (Dow et al. 2013a; Langholtz et al. 2014; Klein et al. 2015). Research has investigated biophysical limits to adaptation such as heat stress impacts on crop yields and on mammals including humans, water, and ecosystems. For example, loss of biodiversity in the Amazon and continued deforestation approaching 20% will lead to likely irreversible “savannization” beyond a temperature increase of 4°C or deforestation exceeding 40% of the forest area (Nobre et al. 2016). Freshwater scarcity is increasingly perceived as a limit to adaptation, and is a systemic global risk today. (Mekonnen and Hoekstra 2016) estimate that four billion people today –half of which live in China and India—face severe water scarcity for at least one month per year and an additional half a billion people face severe water scarcity year-round. Limits are also encountered in certain sectors, such as modelled temperature increase limits for the West African cocoa belt, which produces about 70% of the world's cocoa and provides livelihoods for two million farmers. Continued production in this region would require a combination of more shade trees (a reversal of current policy to reduce shade) and offsetting disadvantaged local damages, and could possibly exacerbate deforestation and land degradation (Schroth et al. 2016). Further, improvements in human health have been achieved by economic growth patterns that now drive climate change and land degradation, suggesting that future human health gains could face limits (Whitmee et al. 2015).

Barriers to adaptation in food production

Literature on barriers to adaptation has focused particularly on water-related issues in developed countries, and does not yet provide clear indicators, or systematic assessments (Biesbroek et al. 2014). Literature since the AR5 has cast a light on barriers related to underlying patterns in institutions and groups of people that reinforce inequities or particular development pathways (Denton et al. 2015). Despite substantial and growing investment in coastal adaptation, the capacity for change and transformation is bounded by interconnected systems of values, institutional rules and norms, and knowledge which defines the set of practical, permissible decisions that are considered (Gorddard et al. 2016; Wise et al. 2014). For example, contemporary approaches to environmental and spatial planning in municipal areas can work against building adaptive capacity in greater metropolitan areas, as one study in the conurbation of Greater Manchester showed (Carter et al. 2015). Another study in Sydney, Australia found that locally-based planning processes widely accept climate adaptation yet sectoral biases, silos, and imbalance between mitigation and adaptation priorities pose barriers to meaningful adaptation (Biesbroek et al. 2014, 2013; Measham et al. 2011). 100 or more studies covering more than 100 cities on ecosystem based adaptation in urban areas find conventional, "hard" adaptation measures are often associated with high costs, inflexibility and conflicting interests in urban areas (Matthews et al. 2015). Ecosystem-based adaptation (EbA) has focused mostly on heat or flooding in cities, and reducing risks of hazards through the use of green space including parks and wetlands (Brink et al. 2016).

Barriers to adaptation also arise from a lack of policy coherency, such as when interlinkages between land use, water, and energy are not considered, as documented in case studies in South Asia (Rasul and Sharma 2016). One study in Southern Brazil illustrated that “organised irresponsibility” is purposefully used by some institutions in society to cover up political, scientific, and legal shortcomings in addressing current risks (Bonatti et al. 2016). In other cases, conceptual and empathy failures such as over-reliance on gross domestic product as a measure of human progress, not accounting for future health and environmental harms over present day gains, and disproportionate effect of externalities on vulnerable groups and developing countries also get in the way of adaptation (Whitmee et al. 2015). Additionally, in developing countries the underlying causes of vulnerability and low adaptive capacity pose under-documented barriers (Shackleton et al. 2015).

7.5 Decision-making for climate change adaptation and mitigation to meet sustainable development

The risks posed by climate change generate considerable uncertainty and complexity for decision-makers that are responsible for land use decisions (*robust evidence, high agreement*). At the same time, decision-makers must balance climate ambitions, and Nationally Determined Contributions (NDCs), with other SDGs, which will differ considerably across different regions, sociocultural conditions and economic levels (Griggs et al. 2014). The interactions across SDGs also need to be considered in decision-making processes (Nilsson et al. 2016b). The challenge is particularly acute in Least Developed Countries where a large share of the population is vulnerable to climate change. The structure of decision-making processes and norms should be matched to local needs but also must connect to national strategies and international regimes (Nilsson and Persson 2012). This section explores methods of decision-making to address the risks and inter-linkages outlined in previous sections.

Land-climate-society interactions influence key and emerging risks, and result in trade-offs and synergies in various dimensions of human development and ecosystem services. There is *high agreement and medium evidence* that the risk to human systems is increasing from climate-land interactions and loss of ecosystem services underpinned by biodiversity (Pascual et al. 2017). However, “Interactions of climate change impacts on one sector with changes in exposure and vulnerability, as well as adaptation and mitigation actions affecting the same or a different sector, are generally not included or well-integrated into projections of risk” (Oppenheimer et al., 2015).

It is also important that the interactions across SDGs are considered in particular assessments (Nilsson et al. 2016b). As a result, this section outlines policy inter-linkages including with SDGs and NDCs, trade-offs and synergies in specific measures, possible challenges as well as opportunities going forward. The section then continues the discussion of lenses of assessment for these inter-linkages including livelihood capitals and windows of opportunity.

7.5.1 Formal and Informal decision-making

Decision-making processes and support systems for climate mitigation and adaptation adopted at different levels are often considered as being “formal” in the sense of having a particular structure, specific goals, a key set of participants, etc. (*medium evidence, medium agreement*). Formal decision support tools can be used, for example, by farmers, to answer "what-if" questions as to how to respond to the effects of changing climate on soils, rainfall and other conditions (Wenkel et al. 2013). Other decision-making approaches rely on multi-criteria methods or multi-attribute decision matrices, which examine in detail trade-offs or options that might be faced or chosen under different climate scenarios and response measures (Kueppers et al. 2004).

Formal decision-making structures should be based on realistic behaviour of actors that are important in land-climate systems, through participatory approaches, stakeholder consultations and by incorporating results from empirical analyses. Mathematical simulations and games have also been used to address stylised cases and facilitate participatory approaches (Lamarque et al. 2013). Behavioural models in land-based sectors have been explored in a variety of settings, although there is clearly scope for improvements and more in-depth analyses (Brown et al. 2017a). Agent-based models (ABMs) and micro-simulations that can be used to more formally consider non-economic variables and to capture interactions between actors and their Data visualisation methods are important for making climate futures comprehensible and useful to decision-makers (Bishop et al. 2013).

Although decision-making per se may be viewed as formal, there are nevertheless different ways to incorporate local knowledge, informal institutions and other contextual characteristics that capture non-deterministic elements as well as social and cultural beliefs and systems more generally (*medium evidence, medium agreement*). Decision support systems have evolved considerably from classic scientific tools to a variety of participatory and interdisciplinary methods and approaches (Jones et al. 2014). Consequently, this broader range of approaches may very well capture informal and indigenous knowledge. Incorporation of informal procedures and institutions can improve the participation of indigenous peoples in decision-making processes and thereby promote their rights to self-determination (Malogdos and Yujuico 2015). The role of informal institutions can be particularly relevant for land use decisions and practices in rural areas (Huisheng 2015).

7.5.1.1 Role of informal institutions in relation to sustainable natural resources management

Many studies underline the role of local/informal traditional institutions in the management of natural resources in different part of the world (Yami et al. 2009; Zoogah et al. 2015; Bratton 2007; Mowo et al. 2013; Grzymala-Busse 2010). Conditions that influence the effectiveness of informal institutions include population growth, land use change and the lack of human and financial capacities. Informal institutions have contributed to sustainable resources management (common pool resources) through creating a suitable environment for decision-making. Social, political and demographic conditions are factors that influence institutions' effectiveness (Yami et al. 2009).

Traditional systems have been shaped over time to provide sustainable utilisation of natural resources. There are numerous examples from different parts of the world to support this idea, including: traditional silvo-pastoral management (Iran), management of rangeland resources (South Africa), natural resource management (Ethiopia, Tanzania, Bangladesh) communal grazing land management (Ethiopia) and management of conflict over natural resources (Siddig et al. 2007; Yami et al. 2011; Valipour et al. 2014; Bennett 2013; Mowo et al. 2013).

It has been argued that informal institutions can replace, undermine, and reinforce formal institutions irrespective of strength of the formal institutions (Grzymala-Busse 2010). In the absence of formal institutions, informal institutions gain importance. Therefore, a focus on informal institutions may be most relevant in developing countries with relatively underdeveloped formal institutions for natural resources management and for rights protection of shareholders (Estrin and Prevezer 2011; Helmke and Levitsky 2004; Kangalawe.R.Y.M, Noe.C, Tungaraza.F.S.K 2014; Sauerwald and Peng 2013; Zoogah et al. 2015).

Formal-informal institutional interaction could take different shapes such as: complementary, accommodating, competing, and substitutive. There are also many examples that formal institutions might obstruct and hinder informal institutions (Rahman et al. 2014; Helmke and Levitsky 2004; Bennett 2013). Informal institutions of the traditional community have been exposed to fundamental changes due to government interventions with implications for the regulation of land use, informal institutional functions, and joint-decision-making (Osei-Tutu et al. 2014)

Improving the conditions that obstruct the contributions of informal institutions is crucial to enhance its effectiveness in sustainable resources management. Furthermore, development interventions and policies should strengthen the involvement of effective informal institutions in decision-making in order to achieve sustainable resources management (Yami et al. 2009; Kangalawe.R.Y.M, Noe.C, Tungaraza.F.S.K 2014; Sauerwald and Peng 2013). Research may enhance understanding of the major problems facing organisational effectiveness (Zoogah et al. 2015). furthermore, formation of policy and reform of land tenure have been advocated for complementarity of powers over local land administration. (Bennett 2013; Kangalawe.R.Y.M, Noe.C, Tungaraza.F.S.K 2014)

Need for research on the interaction between formal and informal institutions as well as for advancing the understanding of the role of formal institutions, has been underlined by some researchers (Waylen 2014; Zoogah et al. 2015; Sauerwald and Peng 2013; Helmke and Levitsky 2004).

7.5.2 Decision making tools

7.5.2.1 Decision making under uncertainty

A principal challenge for climate change adaptation decisions is the incorporation and treatment of uncertainty (Hallegatte 2009; Wilby and Dessai 2010). Uncertainty can present particular challenges where long lead-times or lifetimes of projects exist and in these cases uncertainty regarding the timing, location and magnitude of impacts can present barriers. The AR5 Chapter on Decision-making emphasised the importance of targeting the approach to the context: in the context of uncertainty, science first approaches are less appropriate than policy first. Since the AR5 considerable advances have been made in decision making under uncertainty, both conceptually and in the social/qualitative research areas as well as in economics.

There is *medium evidence and high agreement* in the literature that uncertainty need not present a barrier to taking action, and there are growing methodological developments and empirical applications to support decision-making. Many of these approaches involve principles of robustness, diversity, flexibility, learning, or choice editing.

Many of the approaches to handling uncertainty have built on the principles of adaptive management, which uses a monitoring, research, evaluation and learning process (cycle) to improve future management strategies (Tompkins and Adger 2004). More recently these techniques have been advanced with iterative risk management (IPCC 2014b) adaptation pathways (Downing 2012) and dynamic adaptation pathways (Haasnoot et al. 2013). Dynamic adaptation pathways (Haasnoot et al. 2013; Wise et al. 2014) identify and sequence potential actions based on alternative potential futures. Decisions are made at identified decision nodes based on tipping points, linked to scenarios or the changing performance over time (Kwakkel et al. 2016). In order to identify and prioritise threats and opportunities associated with the risks of tipping points and regime shifts, a significant shift from accepted institutional decision making processes towards more socially disruptive – those suggesting the very nature of a system may change – which do not privilege equilibrium may be required (Knight-Lenihan 2016). A key characteristic is rather than make an irreversible decision now, decisions evolve over time, accounting for learning, knowledge and values. This is particularly important for large infrastructure projects and urban expansion which in time may reduce the ability for the landscape/ecosystems to adapt to a changing climate (Hurlimann and Wilson 2018) .

Scenario analysis is also important in identifying technology, policy instruments and ensuring spatial-temporal coherence of land use allocation simulations with scenario storylines (Brown and Castellazzi 2014) and identifying technology and policy instruments for mitigation of land degradation (Fleskens et al. 2014). Multi-criteria decision making continues to be important for making sustainable construction practices and selecting sustainable materials (Govindan et al. 2015).

Economic approaches to DMUU

The approaches described under Section 7.5.2.1 can be complemented by economic approaches for economic or investment appraisal. Traditional approaches to economic appraisal, including cost benefit analysis (CBA) and cost effectiveness analysis (CEA) do not handle uncertainty well (Hallegatte 2009). Improvements have been made to address some limitations of these approaches including modifications to address normatively unappealing negative expected values of future climate information or unfeasible solutions (Neubersch et al. 2014), probabilistic inversions to improve numerical models used in climate change projections (Oppenheimer et al. 2016).

Alternative decision making approaches to appraise and select adaptation options are being explored, both in the academic and policy literature (Dessai and van der Sluijs 2007; Hallegatte et al. 2012; Ranger et al. 2010; UNFCCC 2009). The aim is to better incorporate uncertainty while still delivering adaptation goals, by selecting projects that meet their purpose across a variety of plausible futures (Hallegatte et al. 2012); so-called 'robust' decision-making approaches. These are designed to be less sensitive to uncertainty about the future and are thus particularly suited for deep uncertainty (Lempert and Schlesinger 2000). Instead of optimising for one specific scenario, optimisation is obtained across scenarios: robust approaches do not assume a single climate change projection, but integrate a wide range of climate scenarios through different mechanisms to capture as much of the uncertainty on future climates as possible.

Much of the research for adaptation to climate change has focused around three main economic approaches: Real Options Analysis (ROA), Portfolio Analysis (PA) and Robust Decision-Making (RDM). ROA originates from option trading in financial economics (Black and Scholes 1973; Dixit and Pindyck 1994) and develops flexible strategies that can be adjusted when additional climate information becomes available. It is most appropriate for large irreversible investment decisions. Applications to climate adaptation are growing quickly, with most studies addressing flood risk, sea-level rise (Gersonius et al. 2013; Woodward et al. 2014; Dan 2016) and water storage (Sturm et al. 2017; Kim et al. 2017), but studies in land use decisions are also emerging (Sanderson et al. 2016). PA combines several adaptation options in a portfolio to reduce risk by diversification (Markowitz 1952) , and RDM identifies how different strategies perform under many climate outcomes, trading off optimality for resilience (Lempert 2013). More detail discussing the relative merits of each are provided in (Dittrich et al. 2016; Watkiss et al. 2015).

Different approaches are appropriate in different contexts. Dittrich et al. (2017) provide a guide to the appropriate application in different contexts for adaptation in the livestock sector in developed countries. While considerable advances have been made in the theoretical approaches, a number of challenges arise when applying these in practice (Watkiss et al.), and partly relate to the necessity of assigning probabilities to climate projects. Formalised expert judgement can improve characterisation of uncertainty (Kunreuther et al. 2014) and these methods have been improved utilising Bayesian belief networks to synthesise 150 expert judgements and include fault trees and reliability block diagrams to overcome standard reliability techniques (Sigurdsson et al. 2001) as well as mechanisms incorporating transparency (Ashcroft et al. 2016).

There is *low agreement and limited evidence* that subjective expected utility theory is perhaps of limited value to inform climate policy and alternatives should be explored that assume no probabilistic information (maximin decision rules and minimax regret) and others that recognise many probability distributions (Multiple priors approach such as Maximin expected utility approach and smooth ambiguity model) (Heal and Millner 2014). (Kunreuther et al. 2014) recognise that risk perception, both deliberative and intuitive thinking, emotional thinking of laypersons, uncertainties surrounding the prior agreement on framing of problems and ways to scientifically investigate them (paradigmatic uncertainty), epistemic uncertainty, and incomplete or conflicting scientific findings (translational uncertainty) impact decision making and policy choices surrounding climate change risk management strategies.

7.5.2.2 Windows of opportunities

Windows of opportunity are important learning moments when significant change can be made. These may include: (1) times when ecosystem feedbacks in a degraded system are recognised and strategies can be proposed to break a degraded state (Nyström et al. 2012); (2) Crisis or climate related disasters that trigger latent local adaptive capacities leading to systemic equitable improvement (McSweeney and Coomes 2011), or novel and innovative recombining of sources of experience and knowledge allowing navigation to transformative social ecological transitions (Folke et al. 2010). Windows of opportunity may also occur on the macro level when: (1) a disturbance from an ecological, social, or political crisis is sufficient to trigger emergence of new approaches to governance (Olsson et al. 2006); (2) a shift in power in relation to natural resource management occurs that leads to emergent processes and novel solutions due to a disturbance that causes inconvenience, cost of compliance, or intersection of multiple regulatory requirements not adequately addressed through piecemeal compliance (Cosens et al. 2017). Windows of opportunity may also occur when a series of punctuated crisis such as floods that enhance society’s capacity to adapt over the long term (Pahl-Wostl et al. 2013). Lastly, windows of opportunity can be created by policy mixes that provide for creative destruction of old social processes and thereby encourage new innovative solutions (Kivimaa et al. 2017).

Climate change impacts, especially climate extremes, in many cases, are catastrophic. Usually catastrophic climate events awaken the people, making them keenly aware of the disasters caused by the climate change. Studies have been done, and efforts have been made to respond to climate change related disasters (IPCC, 2012).

PLACE HOLDER - figure illustrating decision making and windows of opportunity

7.5.3 Best practices of decision making toward sustainable land management

There is *medium agreement and medium evidence* that sustainable development must be a decision making strategy in order to achieve it (Waas et al. 2014). In order to achieve sustainable land management, there has been an important rise in sustainable remediation practices as well as critical interventions that are reshaping norms and standards (Hou and Al-Tabbaa 2014).

There is *medium agreement and limited evidence* about what factors consistently determine the adoption of agricultural best management practices - procedures to control toxic pollutants and advance pollution prevention farming methods, control soil erosion and runoff (through shelterbelts, conservation tillage etc. (Herendeen and Glazier 2009), but more often than not, there is positive correlation with education levels, income, acres, capital, diversity, access to information, and social network as well as attending workshops for information and trust in crop consultants (Ulrich-Schad, J.D., Garcia de Jalon, S., Babin, N., Paper, A. 2017; Baumgart-Getz et al. 2012). More research is needed in relation to their sustained adoption over time (Prokopy et al. 2008).

There is *high agreement, and medium evidence* that ecological service mapping practices to support decision-making should be: (1) robust (robust modelling, measurement, and stakeholder-based methods for quantification of ecosystem service supply, demand and/or flow, as well as measures of uncertainty and heterogeneity across spatial and temporal scales and resolution); (2) transparent (to contribute to clear information-sharing and the creation of linkages with decision support processes); and (3) stakeholder-relevant (people-central in which stakeholders are engaged at different stages) (Willemen et al. 2015; Ashcroft et al. 2016). There is medium agreement and medium evidence that environmental decision making takes place in complex adaptive systems where there is often limited information and information processing ability and differing stakeholders make differing decisions on the best future course of action thus experiencing bounded rationality in considering trade-offs and making decisions (Waas et al. 2014).

There is *high agreement and medium evidence* that sustainable land management practices and incentives require mainstreaming into relevant policy; appropriate market based approaches, including payment for ecosystem services and public private partnerships, need better integration into payment schemes (Tengberg et al. 2016). There is *high agreement and medium evidence* that many of the best sustainable land management decisions are made taking into consideration the participation of stakeholders (7.6.4) and social learning (7.6.5) (Stringer and Dougill 2013). As stakeholders may not be in agreement, either practices of mediating agreement, or modelling that depicts and mediates the effects of stakeholder perceptions in decision making may be applicable (Hou 2016; Wiggering and Steinhardt 2015).

Policy to encourage innovation

Innovation can be defined narrowly as new technological or organisational creations that have economic significance (Edquist 2005) or more broadly, as the collective and collaborative dimensions of innovation reflected in adaptation to climate change that is dependent on multi-level institutional linkages (Rodima-Taylor et al. 2012). An innovation can arise from a change in technology, processes, products or practices that gives rise to learning, experimentation, serendipity, and breakthroughs from any sector in any given country (Araujo 2017). National research and development systems as well as social learning play key roles in innovations (Edquist 2005). Disruptive innovation may be needed rather than traditional innovation pathways that begin with particular niches (Kivimaa and Kern 2016). In the context of the land-climate interface, innovation is more likely to be related to longer-term processes of stakeholder engagement and social learning rather than major technology breakthroughs of the kind that can be significant in energy sectors or end-uses. Adaptation itself has a close relation to innovation in certain contexts (Rodima-Taylor et al. 2012).

7.5.4 Adaptive management

Adaptive management is an evolving approach to natural resource management founded on decision making approaches in other fields (such as business, experimental science, and industrial ecology) and structured decision making (Allen et al. 2011; Williams 2011). Structured decision making overcomes management paralysis and mediates multiple stakeholder interests through use of simple steps. These steps include evaluating a problem and integrating planning, analysis and management into a transparent process to build a road map focused on achieving fundamental objectives; requirements of success are clearly articulated fundamental objectives, the explicit acknowledgment of uncertainty, and a transparent response to all stakeholder interests in the decision making process (Allen et al. 2011). Adaptive management builds on this foundation by incorporating a formal iterative process acknowledging uncertainty and achieving management objectives through a structured feedback process (Foxon et al. 2009). In the adaptive management process the problem and desired goals are identified, the system boundaries and context are ascertained, hypotheses are developed and tested which leads to the implementation of policy strategies and monitoring of results in a continuous management cycle of monitoring, assessment and revision (Hurlbert 2015; Newig et al. 2010; Pahl-Wostl et al. 2007).

A key focus on adaptive management is the identification and reduction of uncertainty (as described in Chapter 1 and 7.3.1) and partial controllability whereby policies used to implement an action are only indirectly responsible (for example setting a harvest rate) (Williams 2011). There is *high agreement and medium evidence* that adaptive management is an ideal method to resolve uncertainty when uncertainty and controllability (resources will respond to management) are both high (Allen et al. 2011). Where uncertainty is high, but controllability is low, developing and analysing scenarios may be more appropriate (Allen et al. 2011). Anticipatory governance has developed combining scenarios and forecasting in order to creatively design strategy to address complex, fuzzy and wicked challenges (Ramos 2014; Quay 2010). Even where there is low controllability, such as in the case of climate change, adaptive management can help mitigate impacts including changes in water availability and shifting distributions of plants and animals (Allen et al. 2011). There is *high agreement and medium evidence* that adaptive management can help mitigate anthropogenic impacts of changes of land and climate including: species decline and habitat loss (Fontaine 2011; Smith 2011), harvest of animals (Johnson 2011a), human participation in natural resource-based recreational activities (Martin and Pope 2011), managing competing interests in public lands (Moore et al. 2011), managing endangered species and minimising fire risk through land cover management (Breininger et al. 2014), land use change in hardwood forestry (Leys and Vanclay 2011), and sustainable land management protecting biodiversity, increasing carbon storage, and improving livelihoods (Cowie et al. 2011). There is *medium agreement and medium evidence* that despite abundant literature and theoretical explanation, there has remained imperfect realisation of adaptive management in the real world natural resource management because of several challenges: lack of clarity in definition and approach, few success stories on which to build, management, policy and funding paradigms that favour reactive approaches instead of the proactive adaptive management approach, shifting objectives, and failure to acknowledge social uncertainty (see 7.3.1) (Allen et al. 2011).

7.5.5 Participation

7.5.5.1 Indigenous knowledge

The importance of indigenous or traditional knowledge for climate action has long been recognised (for example, Nyong et al. 2007b; Tschakert 2007; Green and Raygorodetsky 2010; Speranza et al. 2010; Alexander et al. 2011a). It was extensively discussed in IPCC AR5, most importantly by Adger et al. (2014), but also by (Burkett et al. 2015; Porter et al. 2014; Dasgupta et al. 2014; Niang, et al. 2013). In these discussions a variety of terminology is used; Alexander et al. (2011) favour *traditional ecological knowledge* (TEK), defined following (Berkes 1999) as “a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down by cultural transmission, about the relationship of living beings (including humans) with one another and their environment”. TEK in different contexts and geographical regions variously covers perceptions of local climate change, and strategies for adaptation and to a lesser extent mitigation. (Alexander et al. 2011a) at a global level, and authors such as Speranza et al. (2010) and Ayanlade et al. (2017) at a local level, show strong correlation between local perceptions and climate trends. Numerous studies demonstrate the underlying importance of TEK for adaptation, among farmers, pastoralists and hunter-gatherers. Nyong et al (2007) show the congruence of traditional practices like agroforestry based on TEK with the requirements for climate mitigation. However, (Apraku et al.) follow another strand in analysis of TEK by stressing the positive hybridisation of traditional and scientific knowledge in farmers' practices, and the practical and often tacit nature of traditional knowledge that differentiates it from scientific knowledge.

Several important findings are of relevance to a discussion of traditional knowledge in the context of governance and social learning. Nyong et al (2007) see respect for traditional knowledge as both a requirement and an entry strategy for participatory planning of climate action and effective communication of climate action strategies. However, Speranza et al. (2010) stress that non-climate factors such as poverty and lack of resources limit the freedom of action of Kenyan agro-pastoralists to change practices according to their knowledge of drought. In many areas inter-generational transfer of traditional knowledge is weakening, through the decline of direct contact with the environment with livelihood diversification and urbanisation, the modern education system, the association of modernity with scientific and “western” knowledge (Apraku et al.; Speranza et al. 2010). Attempts to integrate traditional and scientific knowledge may be affected by power relations (Alexander et al. 2011b). (Apraku et al.) give examples of policy and programming in Kenya to integrate traditional and scientific knowledge: the Agricultural Sector Development Programme mandates national and county governments in Kenya to use indigenous knowledge in agricultural development, and the Radio Africa Network (RANET) initiative uses the combination of modern science and indigenous knowledge to educate and inform farmers on climate change and agricultural issues; while they found an absence of comparable initiatives in South Africa.

7.5.5.2 Citizen Science

Citizen science is a new democratic approach to science involving citizens in collecting, classifying, and interpreting data to influence policy and assist decision processes involving the environment (Kullenberg and Kasperowski 2016). It has flourished in recent years due to easily available technical tools for collecting and disseminating information (e.g., cell based apps, the Internet, ground sensors, satellite imagery), recognition of the free source of labour provided, and funding agencies requiring project related outreach (Silvertown 2009). There is *medium agreement and medium evidence* that citizen science improves landscape scale conservation planning (Lange and Hehl-Lange 2011; Bonsu et al. 2017; Graham et al. 2015), addressing conflicting societal demands on forest landscapes (Bonsu et al. 2017), creating consensus landscapes (Lange and Hehl-Lange 2011), securing citizen engagement in landscape conservation initiatives (Sayer, J. Margules, C., Boedhihartono 2015) informing land management (McKinley et al. 2017), and boosting advocacy and environmental awareness (Johnson et al. 2017, 2014). (Ballard et al. 2017) found limited evidence of conservation impact and concluded the impact on social learning was not straightforward and (Loos et al. 2015) concluded most cases derive from rich industrialised countries (Loos et al. 2015).

More benefits are derived when citizens actively participate in conservation and management decisions, thus transcending the deficit model (Jansujwicz et al. 2013), drawing on local knowledge, challenging external scientists, and are supported by strong laws, institutions, collaborative platforms, transparency effective solution of conflict and have credible leadership (Couvet and Prevot 2015; Sayer, J. Margules, C., Boedhihartono 2015). There are a variety of practical issues to the concept of citizen science at the local level, which includes the lack of universal implementation framework to communities and differing methods that have been contrasted and debated throughout the literature (Conrad and Hilchey 2011; Jalbert and Kinchy 2016; Stone et al. 2014). Although the literature is sparse, there is medium agreement that combining citizen science and participatory modelling has favourable outcomes and improves environmental decision making (Gray et al. 2017).

7.5.5.3 Stakeholder and citizen participation in policy

There is *high agreement and medium evidence* that including stakeholders and people in decision making and policy formation improves governance (Coenen and Coenen 2009; Hurlbert and Gupta

2015). Participation must be meaningful as: (1) there is *medium agreement, but limited evidence* that proceduralising participation or using models of public acceptance of a policy solution, technology or infrastructure project lowers the value of participation, reducing it to a tool of persuading participants to accept decisions already made (Lee et al. 2013; Armeni 2016; Pieraccini 2015), and; (2) there is *high agreement, but limited evidence* that stakeholder and citizen participation in policy making should go beyond provision of sound technical scientific information, and include deliberation about climate change impacts to determine shared responsibilities creating genuine opportunity to construct, discuss, and promote alternatives (Serrao-Neumann et al. 2015b; Armeni 2016).

The notion of participation, the mechanisms, construction or framing of climate change and environmental problems underpinning participation, are often ambiguous (Serrao-Neumann et al. 2015b). Multiple methods of engagement exist and a limited selection include multi-stakeholder forums, consideration of scenario analyses, public forums and citizen juries (Coenen and Coenen 2009). However, there is *high agreement and medium evidence* that no one method is superior, but each method must be tailored for local context (Blue and Medlock 2014; Voß and Amelung 2016). Strategic innovation in developing policy initiatives requires a strategic adaptation framework involving pluralistic and adaptive processes such as multi-stakeholder forums, consideration of scenario analyses and use of boundary organisations (Head 2014). There is *medium agreement and medium evidence* that sustained, focused, iterative public participation in the issue of climate change is absent in many communities (Hurlbert 2018b).

Although participation is often romanticised, there is *medium agreement and limited evidence* that consideration of the level of uncertainty in respect of science, and/or uncertainty in respect of outcomes of norms, values, and political decision making, can influence the manner of public engagement (Hurlbert and Gupta 2015). (Singh and Swanson 2017) found little evidence that framing climate change as a matter of national security, a human rights issue, or a problem of environmental consequence alters overall perceptions of its importance as a policy issue, however, other studies find local frames of climate change are particularly important (Hornsey et al. 2016; Spence et al. 2012). Consideration of the method of citizen engagement with climate change science in order that reflexive citizen engagement can occur through connected trans-local knowledge development whereby techno-scientific closure is prevented and reflexive opening endorsed (Blue and Medlock 2014; Voß and Amelung 2016).

Citizen science can contribute to policy adoption, implementation, and evaluation through providing valuable systematic scientific observations, identifying public issues, helping in formulating public policy and evaluating the impact of policy.

Figure 7.2 Public and Private Benefits of Decision making (placeholder)

7.5.5.4 Stakeholder and citizen participation in scenario modelling

Despite the need to better coordinate citizen science projects around the world to understand significant issues, such as climate change (Bonney et al. 2014), there is large potential in combining citizen science and participatory modelling to obtain favourable outcomes and improving environmental decision making (Gray et al. 2017).

Despite the general consensus about the value of public participation in environmental decision making, it cannot be decreed nor imposed; participation is an emerging quality of collective-action and social-learning processes (Castella et al. 2014). There is vast experience of public participation in land use and land cover change simulation that can be used in climate scenario modelling. Inclusion in citizen participation in land change simulation has been made in different fronts, for example, in how stakeholders parameterise and evaluate models in analytical and discursive approaches (Hewitt et al. 2014), translation of narrative scenarios to quantitative outputs (Mallampalli et al. 2016), development of digital tools to enable the involvement of stakeholders in co-designing decision making participatory foresight (Bommel et al. 2014), and use of games to understand the preferences of a local decision maker when exploring various (more or less balanced) policies about risks (Adam et al. 2016).

7.5.5.5 Participation and Collective Action

Coinciding pressures of climate change and land use create diverse collective action issues for land use policies and planning practices (Moroni 2018) at local, national, and regional levels. This section examines evidence of land- and climate- related local participation, and what influences the efficacy of collective action in addressing emerging risks. The challenges of addressing emerging risks like land becoming less available or productive for human use and ecosystems can make it implausible that any single actor would act to address the issue alone. In climate change adaptation and mitigation, collective action is important because it may offer solutions for emerging risks, covering a spectrum of options including mutually binding agreements, government regulation, privatisation, and incentive system (IPCC 2014a). Therefore, collective action is viewed as one core mechanism in social transformation but there is currently no systematic research on collective climate action (Bamberg et al. 2015). (Bamberg et al. 2015) in a short survey found that social identity was the core predictor of collective climate action across studies. Most collective action strategies target maintenance or change of land use practices, and sometimes also aim to promote social and economic goals such as reducing poverty. Although several programs and approaches claim to be successful in executing public participation exercises, these practices have rarely been scaled up or replicated in other places (Samaddar et al. 2015).

In a systematic review of public participation studies toward climate change in cities, Sarzynski (2015) finds limited number of cases where robust and sustained civic capacity, which requires participants “pulling together” to solve common problems, occurred in governance of climate adaptation. Specific cases where the inclusion of individuals and communities in land management and climate, include, Liu and Ravenscroft (2017) , which find that, in Chengdu, China, participation of local communities is a key factor in successfully implementing national-level land transfer policy. In Indonesia, Jelsma et al. (2017) find that involving local communities and collective action made it possible to draw on the advantages of both smallholder and large-scale forestry in ways that contributed to rural development and land sparing. Scenario-planning has been found useful as a tool to help rural communities “articulate a shared development trajectory,” and identify trade-offs and barriers for collective action (Nieto-Romero et al. 2016). Further, a case study of two Canadian First Nations showed how communication methods like “collective reflection” of community members affected land use preferences, particularly the perception of the collective benefits associated with specific Indigenous Peoples land use decisions (Nikolakis et al. 2016).

While current research recognises the critical importance to include individuals and communities in the planning process, it has also been important to understand the factors that determine successful participation in climate adaptation and mitigation (Nkoana et al. 2017). In northern Ghana, (Samaddar et al. 2015) reports six critical outcome factors for effectively involving local communities in disaster management and climate change adaptation: ownership, empowerment or self-reliance, time effectiveness, livelihood security, and plan implementation. In land-related decisions, it is common for the efficacy of collective action to be affected by the interests of a few, or by particular constellations of stakeholder groups. Djurfeldt et al. (2018) found that in spite of matrilineal systems where women’s rights to land are relatively strong, decision making about land in rural communities in Malawi depends on control of productive resources like labour and access to institutions—land reform does not necessarily resolve gender or other inequalities, with implications for adaptation policy.

Research also recognised that participation is not always fully necessary, structured climate change problems require minimal participation and can be responded to in a technocratic manner, while moderately structured problems can entail differing degrees of participation depending on trust (Hurlbert and Gupta 2015). There is interest in new methods of public participation, such as on-line action, which have been tested to mobilise citizens using pre-existing online networks, Bojovic et al. (2015) reports successful use of an on-line platform to collect data, validate results and communicate messages.

In terms of adoption of policies, collective action has been shown to be affected by a number of factors, including economic incentives in the form of tenure, payments, subsidies, and other income-targeting approaches are widespread in promoting sustainable land use management. Collective action in land use policy has been shown to be more effective when implemented as bundles of actions rather than as single-issue actions. For example, land tenure, food security, and market access can mutually reinforce each other when they are interconnected (Corsi et al. 2017). For example, (Liu and Ravenscroft 2017) found that financial incentives embedded in collective forest reforms in China have increased forest land and labour inputs in forestry.

In a comparison of local land use planning in Galicia and the Netherlands, (Sánchez and Maseda 2016) found that local adoption of policies depended on whether municipalities were obliged to adopt a land use plan, and the willingness or resistance of municipalities to adopt the policy related to economic or behavioural interests. Local resistance to cooperative action can occur when farm-level, individual agreements do not align with dynamic trust relations among members around specific issues, as was found among UK farmers in a study evaluating the potential of agri-environmental schemes to offer landscape-scale environmental protection (Riley et al. 2018). Some policies target one group, such as land-owners, which can limit the cooperation or even disadvantage those who are not considered in collective policies.

7.5.5.6 Corruption and elite capture

The risks of corruption and elite capture of benefits from planned climate action, that reduce the effectiveness of such action, are closely related to maladaptation but conceptually separate from it, as they concern intentional malfeasance. Peer-reviewed empirical studies that focus on corruption in climate finance and climate interventions are rare, due in part to the obvious difficulties of researching illegal and clandestine activity (Fadairo et al. 2017). (Brown 2010), defining corruption as “misuse of public office for private gain" and reviewing early prospects for REDD (including REDD+), highlights risks arising from the interaction of perverse incentives within emissions reduction schemes in general with the history of corruption in the broader forest sector stemming from the remote and sparsely populated nature of forests, making monitoring difficult, long supply chains for timber with low traceability, and the understaffing and under-resourcing of forest agencies, particularly in the light of the complex trade-offs between production and conservation they are mandated to administer. (Brown 2010) sees three likely inlets of corruption into REDD: in the setting of baselines, the reconciliation of project and natural credits, and the implementation of control of illegal logging. The article does not directly refer to corruption in the actual process of paying forest dwellers for forest protection services,

(Fadairo et al. 2017) do examine the latter types of corruption. Following the position of the international NGO Transparency International (Transparency International 2013b) they defend the use of perception data in assessing corruption levels, reporting a structured survey in south eastern Nigeria of perceptions of households in forest-edge communities served by REDD+, as well as those of local officials. They report high rates of agreement that allocation of carbon rights is opaque and uncertain, distribution of benefits is untimely, uncertain and unpredictable, and REDD+ decision-making process is vulnerable to political interference that benefits powerful individuals. Only 35% of respondents had an overall perception of transparency in REDD+ process as “good”. Of eight institutional processes or facilities previously identified by Government of Nigeria and international agencies as indicators of commitment to transparent and equitable governance, only three were evident in the local REDD+ office as “very functional” or “fairly functional”.

Corruption is only one of the processes by which elites (local or national, economic or official) can capture the benefits of climate intervention. An illustration of the range of types of such capture is given by (Sovacool 2018), combining document review and key informant interviews in Bangladesh, for adaptation initiatives including coastal afforestation. Using an analytical approach from political ecology (Sovacool 2018) discusses four processes: enclosure, including land grabbing and preventing the poor establishing new land rights; exclusion of the poor from decision-making over adaptation; encroachment on the resources of the poor by new adaptation infrastructure; and entrenchment of community disempowerment through patronage. The article notes that observing these processes does not imply they are always present, nor that adaptation efforts should be abandoned.

7.5.5.7 Barriers and enablers to participation

Place holder

7.5.6 Social learning

Social learning is learning in and with social groups through interaction (Argyris 1999) including collaboration and organisation which occurs in networks of interdependent stakeholders (Mostert et al. 2007). It is an important factor contributing to long term climate adaptation whereby individuals and organisations engage in a multi-step social process, managing different framings of issues while raising awareness of climate risks and opportunities, exploring policy options and institutionalising new rights, responsibilities, feedback and learning processes (Tàbara et al. 2010). There is *high agreement and limited evidence* that it is important in engaging with uncertainty (Newig et al. 2010) and addressing the increasing unequal geography of food security and including those excluded by the discourses of food security whose narrow focus is on the two ends of the food system (production by farmers and consumption) (Sonnino et al. 2014). In the context of climate change adaptation and mitigation within agricultural systems, the opportunities presented by social learning approaches have been assessed and case studies presented (Harvey et al. 2012; Ensor and Harvey 2015). Important factors emerging from these studies are a shared view of how change might happen and of how social learning and specific tools fit within it; skilled facilitation; and the need to attend to social difference and power.

There is *low agreement and limited evidence* on the theoretical basis and meaning of social learning, or how to define, measure, and achieve social learning (Baird et al. 2014; Reed et al. 2010). Some literature defines social learning as a change in understanding that is measured by a change in behaviour, and perhaps worldview, by individuals and wider social units, communities of practice and social networks (Reed et al. 2010). Single loop learning is a change in understanding measured by altered behaviour or routine; double loop learning is a change in values, norms and assumptions measured by a revised viewpoint; triple loop learning is a transformative change in context beyond patterns of behaviour and insight, measured by a change in worldviews (beliefs about the world and reality) and understanding of power dynamics (Gupta 2014). Social learning is achieved through reflexivity or the ability of a social structure, process, or set of ideas to reconfigure itself after reflection on performance though open minded people interacting iteratively to produce reasonable and well-informed opinions (Dryzek and Pickering 2017).

7.5.7 Performance indicators

Measuring performance is important in decision-making and governance and can help evaluate policy effectiveness (*high agreement, limited evidence*) (Wheaton and Kulshreshtha 2017). It is necessary to monitor and evaluate the effectiveness and efficiency of performing climate actions to ensure the long-term success of *climate* initiatives or plans. Measurable indicators are useful for climate policy development and decision-making process since they can provide quantifiable information regarding the progress of climate actions. The Paris Agreement (UNFCCC 2015) made great focus on reporting the progress of implementing countries' pledges, i.e., Intended Nationally Determined Contributions (INDC) and national adaptation needs in order to examine the aggregated results of mitigation and adaptation actions that have already been implemented. For individual sector level, specific key indicators should be used. For the case of measuring progress toward achieving land degradation neutrality, it was suggested to use land based indicators, i.e., trend in land cover, trends in land productivity or functioning of the land, and trends in carbon stock above and below ground (IUCN 2015).

There is limited research on the effect of climate change using agri-environmental indicators of environment sustainability (soil water quality, desertification, water supply and demand, soil erosion, soil salinisation, water quality and quantity, soil contamination)(Wheaton and Kulshreshtha 2017). Metrics and indicators for measuring biodiversity and ecosystem services in response to governance at local to international scale need to meet the criteria of parsimony, scale specificity, linked to some broad social, scientific and political consensus on desirable states of ecosystems and biodiversity and ensuring that normative aspects such as environmental justice or socially just conservation are included (Layke 2009) (Van Oudenhoven et al. 2012) (Turnhout et al. 2014)(Häyhä and Franzese 2014), (Guerry et al. 2015)(Díaz et al. 2015). Furthermore the choices of metrics and indicators needs to incorporate understanding that the science, linkages and dynamics in systems are complex, not amenable to simple economic instruments and often unrelated to short term management or governance scales (Naeem et al. 2015) (Muradian and Rival 2012). Thus, use of indicators for biodiversity and ecosystem services for monitoring impacts of governance and management regimes on land-climate interfaces need participation of relevant stake-holders as well as periodic and effective communication.

Recent studies increasingly incorporate the role of stakeholders and decision makers for land systems (Verburg et al. 2015) including agriculture (Kanter et al. 2016) and for bioenergy sustainability (Dale et al. 2015). Kanter et al. (2016) propose a four-step cradle-to-grave approach for agriculture trade-off analysis, which involves co-evaluation of indicators and trade-offs with stakeholders and decision-makers. Local communities understand local dynamics of deforestation and can be involved in mapping drivers, data validation and carbon stock measurement.

PLACEHOLDER - figure illustrating decision making for sustainable land, climate, food management

7.5.8 Coherence and maladaptation

While opportunities exist to capitalise on the synergies outlined above, ensuring policy coherence, minimising costs and risks of maladaptation are challenges that need to be addressed.

If policy mixes are designed appropriately, acknowledging and incorporating trade-offs and synergies, there is *medium evidence and medium agreement* that they can be expected to have a higher probability of delivering an outcome like transitioning to sustainability (Howlett and Rayner 2013; Huttunen et al. 2014). Further, this transition is encouraged by having policies within the suite that stimulate 'elements of creative destruction' whereby disruptive innovation can occur through processes by which resources, skills and knowledge held by incumbent old technologies become obsolete (Kivimaa and Kern 2016). However, there is *medium agreement and medium evidence* that evaluating policies for coherence in responding to climate change and its impacts is not occurring, and policies are instead reviewed in a fragmented manner (Hurlbert and Gupta 2016).

There is *high agreement and medium evidence* that a suite of agricultural business risk programs (which would include crop insurance and income stability programs) increase farm financial performance, reduce risk, and also reinforce incentives to adopt stewardship practices (beneficial management practices) improving the environment (Jeffrey et al. 2017). Consideration of the suite of instruments responding to climate change and its associated risks, and the interaction of policy instruments, improve agricultural producer livelihoods (Hurlbert 2018b).

Coherent policies can also reduce the likelihood of maladaptation, which is the opposite of sustainable adaptation (Magnan et al. 2016) -adaptation that "contributes to socially and environmentally sustainable development pathways including both social justice and environmental integrity" (Eriksen et al. 2011). In AR5 there was medium evidence and high agreement that maladaptation is 'a cause of increasing concern to adaptation planners, where intervention in one location or sector could increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change' (Noble et al. 2014). AR5 recognised that maladaptation arises not only from inadvertent badly planned adaptation actions, but also from deliberate decisions where wider considerations place greater emphasis on short-term outcomes ahead of longer-term threats, or that discount, or fail to consider, the full range of interactions arising from planned actions (Noble et al. 2014).

There is *high agreement and medium evidence* that maladaptation is a process and:

> "A result of an intentional adaptation policy or measure directly increasing vulnerability for the targeted and/or external actor(s), and/or eroding preconditions for sustainable development by indirectly increasing society's vulnerability" (Juhola, Glaas, Linnér, & Neset, 2016 at p. 139).

Three types of maladaptation are identified by (Juhola et al. 2016): (1) Rebounding vulnerability – increased current or future climate change vulnerability of implementing actor (or one targeted by policy) by increasing exposure, increasing sensitivity, or decreasing adaptive capacity; (2) Shifting vulnerability – increasing current or future vulnerability for one or several external actors through a spill over effect by increasing exposure, increasing sensitivity, or decreasing adaptive capacity; and (3) Eroding sustainable development – adaptation action that increases GHG emissions and negatively impact environmental conditions and/or social and economic values (Juhola et al. 2016). Maladaptation has temporal and spatial scales (Magnan 2014). Maladaptation may result from adaptation action that does not adequately account for multiple drivers or neglects direct and/or indirect drivers of vulnerability such as social characteristics of cultural values (Magnan 2014). There is *low agreement and limited evidence* that maladaptation also includes (1) high opportunity costs (including economic, environmental, and social such as when water desalinisation is chosen instead of less costly options that do less environmental harm); (2) reducing incentives to adapt (adaptation measures that reduce incentives to adapt by not addressing underlying causes); and (3) path dependency or trajectories that are difficult to change (Barnett and O'Neill 2010).

In practice, identifying maladaptation requires a framework specifying the type, aim and target audience of an adaptation action, decision, project, plan, or policy designed initially for adaptation, but actually at high risk of inducing adverse effects either on the system in which is was developed, or another connected system, or both. The assessment requires identifying system boundaries including temporal and geographical scales at which the outcome are assessed (Magnan 2014; Juhola et al.

2016). Excluded from maladaptation are negative outcomes resulting from autonomous adaptation (that adaptation that occurs without explicitly occurring to manage the effects of climate change) as well as avoidant adaptation actions (built on perceptions such as denial of a threat, wishful thinking or fatalism); exclusion advances the operationalisation of the term and delineation of the methodological boundaries.

7.5.9 Trade-offs and synergies

As new knowledge about trade-offs and synergies amongst land-climate processes emerges regionally and globally, concerns over emerging risks and the need for planning policy responses grow. There is *medium agreement and medium evidence* that trade-offs currently do not figure into existing climate policies including NDCs and SDGs being vigorously pursued by some countries (Woolf et al. 2018). Clearly, there is an urgent need to evaluate and mitigate risks due to the social, economic, and ecological inter-linkages mentioned above.

There is *very high confidence* that significant synergies and trade-offs exist between mitigation and adaptation measures (AR5, SPM3.3). Since the challenge for adaptation increases with increasing global temperature, there is a strong co-benefit of combining adaptation and mitigation policies from a global perspective. But adaptation and mitigation measures can involve both synergies or trade-offs at the local scale (Duguma et al. 2014) and can in addition generate synergies and trade-offs with other SDGs such as food security, biodiversity conservation, water quality, etc.

Examples of trade-offs include the implications for food security due to reduced micronutrients under enhanced CO_2 (Myers et al. 2014), the impact of afforestation as a climate change mitigation response on water resources (Farley et al. 2005). The introduction of exotic and invasive species while providing alternative food security in some regions is possibly approaching biodiversity tipping points unless regulated and managed (Canonico et al. 2005).

The subsequent sub-sections outline land based GHG mitigation and associated trade-offs and synergies in terms of food security, biodiversity, bio-geophysical processes. The desirable low carbon pathways in line with Goal 13 on climate action could be achieved through land-based mitigation options including forest conservation, biofuel production, and negative emissions technologies. However, such mitigation policies could result in could lead to large scale land acquisition and changes in land ownership and cause adverse outcomes such as counteracting food security or increasing land conflicts (Hunsberger et al. 2017). Conversely, evidence from Nordic countries show positive impacts of bioenergy markets on new and diversified market opportunities and farmers' incomes (Nilsson et al. 2016a).

7.5.9.1 Trade-offs and synergies from land-based mitigation measures

7.5.9.1.1 Re/afforestation and Avoided deforestation (e.g. REDD+)

Re/afforestation and avoided deforestation are very important components of climate mitigation and are expected to play a key role in low carbon pathways in line with SDG 13 on climate action (Griscom et al. 2017; Popp et al. 2017). However, policies promoting these land-based mitigation approaches are facing trade-offs and synergies in terms of food security, biodiversity, biogeophysical processes. For instance, such mitigation policies could lead to large scale land acquisition and changes in land ownership and cause adverse outcomes increasing land conflicts (Hunsberger et al. 2017) or threatening food security (Erb et al. 2016) and biodiversity (Griscom et al. 2017). Reforestation can also create emerging opportunities to foster mitigation and adaptation co-benefits. For instance, reforestation in tropical or arid regions provides adaptation benefits (in addition to the GHG mitigation effect) through the local cooling effect of forests (Bright et al. 2017; Duveiller et al. 2018) which is particularly significant during heat waves (Lejeune et al. 2018). In temperate or boreal regions, surface albedo change may lead to trade-offs (Bright et al. 2017; Duveiller et al. 2018), but there is *low confidence* concerning the magnitude and temporal variability of these effects (Chapter 2). These adaptation co-benefits or trade-offs from biogeophysical processes are usually not accounted for in the design of policies addressing re/afforestation/avoided deforestation (e.g. REDD+ and the Paris Agreement) but there is increasing scientific evidence that they should be part of the policy design (Findell et al. 2017; Hirsch et al. 2018; Bright et al. 2017).

Adopted by the Conference of Parties in 2007, Reduced Emissions from Deforestation and Degradation (REDD+) was a mechanism to reduce emissions from deforestation and forest degradation in developing countries. The Paris Agreement recognises and encourages policies and incentives for reducing emissions from deforestation and forest degradation. Initial findings from Myanmar and Indonesia show that it is possible to align REDD+ and SDGs to ensure both mitigation and sustainable development benefits (Bastos Lima et al. 2017). A recent assessment of the California forest offset program shows that such programs, by compensating individuals and industries for forest conservation, can deliver mitigation and sustainability co-benefits (Anderson et al. 2017).

7.5.9.1.2 Bioenergy plantations and BECCS

Bioenergy has the potential to be a carbon-neutral means of energy production (assuming steady state conditions where the same amount of carbon is sequestered by biomass growth as is released during energy generation), or even a carbon sink if combined with CCS (Fuss et al. 2014). Bioenergy and BECCS are currently put forward as an almost unavoidable element of climate mitigation in scenarios compatible with the Paris Agreement goal (Rockström et al. 2017b; Popp et al. 2017; Fuss et al. 2014), but various concerns have been raised about the sustainability of bioenergy production. Most of these concerns relate to trade-offs with food production, biodiversity and local bio geophysical effects (Humpenöder et al. 2017; Krause et al. 2017; Robledo-Abad et al. 2017; Boysen et al. 2016, 2017a,b). Examples of synergies are between carbon stocks and biodiversity- oriented conservation (Strassburg et al. 2010) and some agro-ecosystems that provide regulating services such as flood control, water quality control, carbon storage and climate regulation (Power 2010). The extent of these trade-offs will largely depend on the land area affected to bioenergy production [placeholder for the input coming from ch2 about range of estimates for land area affected to bioenergy in IAM scenarios]. Forest and water protection schemes, improved fertilization efficiency, and agricultural intensification could alleviate the trade-offs from bioenergy production (Humpenöder et al. 2017). Trade-offs with biodiversity can be managed for instance by prioritising bioenergy trees (e.g. willow, poplar or eucalyptus) over bioenergy crops (e.g. miscanthus or switchgrass) since there is evidence that the former are more compatible with biodiversity conservation and can provide local bio-geophysical cooling effect (O'Halloran and Bright 2017). Locating new bioenergy plantations strategically by considering landscape context and impact to biodiversity and ecosystem services could help mitigate some of the adverse impacts (Manning et al. 2015). Synergies between bioenergy and food security could be achieved by investing in a combination of strategies including technology and innovations, infrastructure, pricing, flex crops, and improved communication and stakeholder engagement (Kline et al. 2017). Managing these trade-offs might also require demand side interventions including shift in dietary patterns.

7.5.9.2 Trade-offs and synergies in the agricultural sector

In the agricultural sector, there has been little published empirical work on interactions between adaptation and mitigation strategies. (Smith and Olesen 2010) describe potential relationships, focussing particularly on the arable sector and predominantly on mitigation efforts. The important potential of the agro-forestry sector for synergies and contributing to increasing resilience of tropical farming systems is discussed in (Verchot et al. 2007)with examples from Africa. Many adaptation and mitigation measures will be complementary, but there are also examples of trade-offs. These often result from increasing productive efficiency in livestock with a resulting lack of resilience to stress (Hoffmann 2010).

‘Climate Smart Agriculture’ has emerged in recent years as an approach to integrate food security and climate challenges. The three pillars of CSA are: (1) to adapt and build resilience to climate change; (2) to reduce GHG emissions, and; (3) to sustainably increase agricultural productivity, ultimately delivering ‘triple-wins’ (Lipper et al. 2014c). While the concept is conceptually appealing, a range of criticisms, contradictions and challenges exist in using CSA as the route to resilience in global agriculture, notably around the political economy (Newell and Taylor 2017), the vagueness of the definition and consequent assimilation by the mainstream agricultural sector, as well as issues around monitoring, reporting and evaluation, and the requirement to include mitigation in resilience building projects (Arakelyan et al. 2017). Nonetheless, CSA does highlight the potential for synergies and examples are presented in Table 7.4.

Table 7.4 Examples of potential CSA measures

Measure	Adaptation/Resilience	Mitigation	Productivity
On-farm tree planting	Shelter/shade for livestock	Carbon sequestration	Reduced heat stress for livestock
Planting hedgerows and buffers	Preventing drought through reducing run-off	Carbon sequestration	Avoided pasture/crop loss
Soil management practices	Increased crop/pasture resilience	Increased soil organic Carbon	Avoided pasture/crop losses
Manage animal health and disease	Avoid disease outbreaks	Unwell animals are less efficient & emit more methane per unit	Avoided mortality and illness
Livestock diet management	An appropriate diet can reduce heat stress	Appropriate diet can reduce methane emissions	Avoided mortality or reduced production
Natural flood management (e.g. woodland and peatland restoration, riparian planting)	Reduced flood damage	Carbon sequestration	Avoided or reduced pasture/crop/livestock loss

Agroecology has been identified as an alternative to CSA, and has at its core the principle that agroecosystems should mimic the biodiversity levels and functioning of natural ecosystems (PIMBERT 2015). While there are some areas of overlap with CSA, agroecology does not include practices that undermine the health of the ecosystem and has a much greater focus on alternative forms of knowledge and practice.

There are opportunities to minimise trade-offs related to food security. Since human diet will be a key driver of future food demand, promoting healthier diets (reduced meat consumption) is an effective way to prevent further cropland expansion thus preventing further deforestation and leaving more land available for afforestation and bioenergy production (Bajželj et al. 2014b; Erb et al. 2016)

7.5.9.3 Trade-offs and synergies in fresh-water and river systems

The transformation of river ecosystems for irrigation, hydro-power and water requirements of societies worldwide is the biggest threat to fresh-water and estuarine biodiversity and ecosystems services (Nilsson and Berggren 2000; Vörösmarty et al. 2010). These projects address important energy and water related demands, but their economic benefits are often overestimated in relation to trade-offs with respect to biodiversity and downstream ecosystem services (Winemiller et al. 2016). The changes in sediment transport, reduction in silica and organic carbon transportation due to hydro-power dams under construction or proposed in the Himalayan region as well inter-linking of rivers in in India could potentially alter regional and global carbon sinks and coastal and marine food-webs (Humborg et al. 2000; Galy et al. 2007; Higgins et al. 2018).

The Sustainable Development Goals were defined to maximise synergies and minimise trade-offs (Griggs et al. 2013a) , however while there is an explicit goal to conserve and sustainably use marine biodiversity and ecosystems (Life Under Water, SDG 17), there is no equivalent explicit goal for conservation of fresh-water biodiversity in rivers making them vulnerable to irreversible changes and transformations. Furthermore hydro-power development on head-water streams in many countries is emerging as a new threat to aquatic biodiversity (Abbasi et al. 2011; Jumani et al. 2017b) even as it forms an important part of NDC based decarbonisation in energy production (Vedachalam et al. 2017).

There are however now powerful new analytical approaches, high-resolution data and decision making tools that help to predict cumulative impacts of dams and and asses trade-offs between engineering and environmental goals and can help funders and decision makers to compare alternative sites for dam building as well manage flows in regulated rivers based on experimental releases and adaptive learning which could minimise ecological costs and maximising synergies with other development goals under climate change (Poff et al. 2003; Winemiller et al. 2016)

7.5.9.4 Trade-offs and synergies arising from land-based adaptation measures

7.5.9.4.1 Adaptive forest management

Forest management can both promote carbon sinks (*high confidence, low evidence*) while improving the resilience of forests thus safeguarding their economic and ecological value (Astrup et al. 2018). There has been claims that historical forest management did not contribute to climate mitigation and even contributed to a slight warming effect over Europe due to the replacement of broadleaf species by coniferous trees (Naudts et al. 2016). However, there is scientific evidence that adaptive forest management, for example by a careful selection of drought-resilient species, can deliver both mitigation and adaptation co-benefits (Astrup et al. 2018) compatible with biodiversity conservation (O'Halloran and Bright 2017).

7.5.9.4.2 Adaptive cropland management

PLACE HOLDER-climate-smart agriculture - There are opportunities to minimise trade-offs related to food security. Since human diet will be a key driver of future food demand, promoting healthier diets (reduced meat consumption) is an effective way to prevent further cropland expansion thus preventing further deforestation and leaving more land available for afforestation and bioenergy production (Bajželj et al. 2014b; Erb et al. 2016).

7.5.9.4.3 Climate-smart/green cities

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7.5.10 Barriers of implementation

Despite the growing understanding of the challenges and increasing advances in approaches to tackling them, gaps exist both in the area of adapting to climate change (the adaptation deficit (Burton 2009) as well as mitigation. The reasons for this are varied and related to the trade-offs involved in making decisions about land. A large and increasing body of literature exists around the barriers to adoption or implementation of desirable practices with regard to the environment. Many of these barriers relate to cognitive and behavioural barriers (Hornsey et al. 2016; Prokopy et al. 2015) , others relate to social and cultural factors (Burton et al. 2008); others to finance and economics (Rochecouste et al. 2015; Baumgart-Getz et al. 2012), as well as institutional and structural barriers (Sánchez et al. 2016; Greiner and Gregg 2011) (*high evidence, medium agreement*).

Many of these barriers and their drivers are captured in the Values, Rules and Knowledge Framework of (Gorddard et al. 2016). Decision-makers at all levels require a combination of values, rules (system that empowers actors to make decisions) and knowledge in order to be able to make effective decisions. They have to want to make a change (values), they have to be allowed to make a change (rules), and they have to know what their options are and what their implications will be (knowledge). The space where these elements overlap is the decision-making space: all of these elements must be present and changes in any one may drive changes in others.

7.6 Governance: Governing the land-climate interface

An important concept used in this chapter, and not previously well defined in IPCC reports, is governance. Governance situates decision making and selection or calibration of policy instruments within the reality of the multitude of actors operating in respect of land and climate interactions. The act of governance "is a social function centred on steering collective behaviour toward desired outcomes and away from undesirable outcomes" (Young 2017). This definition of governance allows for it to be decoupled from the more familiar concept of government and studied in the context of complex human-environment relations and environmental and resource regimes (Young 2017). Emphasizing governance also represents a shift of traditional resource management (focused on hierarchical state control) towards recognition that political and decision making authority can be exercised through interlinked groups of diverse actors (Kuzdas et al. 2015)

Governance includes all of the processes, structures, rules and traditions that govern and these processes may be undertaken by actors including a government, market, organisation, or family (Bevir 2012). They determine how people in societies make decisions (Patterson et al. 2017) and involves the interactions among formal and informal institutions through which people articulate their interests, exercise their legal rights, meet their legal obligations, and mediate their differences (Plummer and Baird 2013). Institutions (defined in 7.6.4) are a fundamental component of governance.

Governance encompasses the development and implementation of laws, regulations, and organisations, as well as governmental policies and actions, domestic activities, and networks of influence including international market forces, the private sector, and civil society (Demetropoulou et al. 2010). The institutional context of adaptive capacity can be studied through an investigation of the institutions involved in governance (Hurlbert and Diaz 2013). There is *high agreement and robust evidence* that resource and disaster crises are crises of governance (Pahl-Wostl 2017; Villagra and Quintana 2017; Gupta et al. 2013).

7.6.1 Adaptive Management and governance

There is *high agreement and robust evidence* that more research to improve understanding of institutions and adaptation is needed as appropriate institutions are increasingly regarded as essential to advancing adaptation (Eisenack et al. 2014; Adger et al. 2009).

In the 1990s adaptive governance emerged from adaptive management (Holling 1978, 1986), combining resilience and complexity theory, and reflecting the trend of moving from government to governance (Hurlbert 2018b). Adaptive governance is "a process of resolving trade-offs and charting a course for sustainability" (Boyle, Michelle; Kay, James J.; Pond, 2001 at p. 28) through a range of "political, social, economic and administrative systems that develop, manage and distribute a resource in a manner promoting resilience through collaborative, flexible and learning based issue management across different scales" (Margot A. Hurlbert, 2018 at p. 25). Few alternative governance theories handle processes of change characterised by nonlinear dynamics, threshold effects, cascades and limited predictability; however, the majority of literature relates to the United States or Canada (Karpouzoglou et al. 2016). Combining adaptive governance with other theories has demonstrated good evaluation of important governance features such as power and politics, inclusion and equity, short term and long term change, and the relationship between public policy and adaptive governance (Karpouzoglou et al. 2016).

Closely related to (and even arguably components of) adaptive governance are adaptive management (a regulatory environment that manages ecological system boundaries through hypothesis testing, monitoring, and re-evaluation (Mostert et al. 2007)), adaptive co-management (flexible community based resource management (Plummer and Baird 2013), and anticipatory governance (flexible decision making through use of scenario planning and reiterative policy review (Boyd et al. 2015).

Box 7.4: Governance and inter-linkages of food, water, energy and land

Emerging literature and case studies recognise the connectedness of the environment and human activities and the interrelationships of multiple resource-use practices in an attempt to understand synergies and trade-offs (Albrecht et al. 2018). Case studies of integrated water resources management (IWRM), landscape approaches, and ecosystem based approaches illustrate important dimensions of institutions, institutional coordination, resource coupling and local and global connections (Scott et al. 2011). Case studies in this box will illustrate integrated governance, policy coherence, and use of multi-functional systems that advance synergies across land, water, energy and food sectors (Liu et al. 2017). This box will summarise policy and governance approaches that have advanced sustainable land management (for example: Ethiopia (policy improving response to drought) South and North Korea (policy impacts on food security)) and trade-offs (for example: Jamaica (trade-offs between food security and trade)). Sustainable adaptation - or actions contributing to environmentally and socially sustainable development pathways (Eriksen et al. 2011) - requires consideration of the interlinkage of different sectors (Rasul and Sharma 2016). Integrating considerations can address sustainability (Hoff 2011) showing promise (Allan et al. 2015) for effective adaptation to climate impacts in many drylands (Rasul and Sharma 2016).

7.6.2 Resilient Institutions

"Institutions are rules and norms held in common by social actors that guide, constrain, and shape human interaction. Institutions can be formal, such as laws and policies, or informal, such as norms and conventions. Organisations – such as parliaments, regulatory agencies, private firms, and community bodies – develop and act in response to institutional frameworks and the incentives they frame. Institutions can guide, constrain, and shape human interaction through direct control, through incentives, and through processes of socialization" (AR5, 2014 at p. 1768). Nations with "well developed institutional systems are considered to have greater adaptive capacity," and better institutional capacity to help deal with risks associated with future climate change (IPCC, 2001 at p. 896). Institutions contribute to the management of a community's assets, the community members' interrelationship, and their relationships with natural resources (Hurlbert and Diaz 2013).

Thinking on adaptive governance, adaptive institutions and kindred concepts in relation to climate change and land has been advanced by incorporating into it concepts of resilience, and specifically of the resilience of socio-ecological systems (Boyd and Folke 2011). In their characterisation, "resilience is the ability to reorganise following crisis, continuing to learn, evolving with the same identity and function, and also innovating and sowing the seeds for transformation. It is a central concept of adaptive governance" (Boyd and Folke 2012). In the context of complex and multi-scale socio-ecological systems, important features of adaptive institutions that contribute to resilience include "shared visions, social capital, networks, collaborative decision-making and learning platforms" (Boyd and Folke 2012). Traditional or locally-evolved institutions, backed by cultural norms, can contribute to resilience and adaptive capacity: (Anderson et al. 2010) suggest these are particularly a feature of dryland societies that are highly prone to environmental risk and uncertainty. Because of the multi-scale nature of the challenges to resilience, dissemination of ideas, networking and learning need to be undertaken across different scales and sectors, implying the importance of social Indigenous knowledge

7.6.3 Multi-level and polycentric governance

Different types of governance can be distinguished according to their intended levels (e.g. local, regional, global), domains (national, international, transnational), modes (market, network, hierarchy), and scales (global regimes to local community groups) (Jordan et al. 2015b). Sub-national governance efforts for climate policy, especially at the level of cities and communities, have become significant during the past decade or so (*medium evidence, medium agreement*).

Transnational governance efforts have increased in number, with application across different economic sectors, geographical regions, civil society groups and non-governmental organisations. When it comes to climate mitigation, transnational mechanisms generally focus on networking and may not necessarily be effective in terms of promoting real emissions reductions (Michaelowa and Michaelowa 2017). There is a tendency for transnational governance mechanisms to lack monitoring and evaluation procedures (Jordan et al. 2015a).

Implementation of climate change adaptation has been impeded by institutional barriers including multi-level governance and policy integrations issues (Biesbroek et al. 2010). Climate governance has evolved significantly beyond the national and multilateral domains that tended to dominate climate efforts and initiatives during the early years of the UNFCCC. The climate challenge has also been placed in an "earth system" context, showing the existence of complex interactions and governance requirements across different levels and thus calls for a radical transformation in governance rather than minor adjustments (Biermann et al. 2012). A transformation of sorts has indeed been underway through deepening engagement from the private sector and NGOs as well as Government involvement at multiple levels. Polycentric governance considers the interaction between actors at different levels of governance (local, regional, national, and global) for a more nuanced understanding of the variation in diverse governance outcomes in the management of common-pool resources (such as forests) based on the needs and interests of citizens (Nagendra and Ostrom 2012). A more "polycentric climate governance" system has emerged that incorporates bottom-up initiatives that can support and synergise with national efforts and international regimes (Ostrom 2010). Although it is clear that many more actors and networks are involved, the effectiveness of a more polycentric system remains unclear (Jordan et al. 2015a). At the same time, climate adaptation and mitigation goals must be integrated or mainstreamed into existing governance mechanisms around key land use sectors such as forestry and agriculture. In the EU, mitigation has generally been well-mainstreamed in regional policies but not adaptation (Hanger et al. 2015). Climate change adaptation has been impeded by institutional barriers including the inherent challenges of multi-level governance and policy integration (Biesbroek et al. 2010).

Integrative approaches to land use and climate interactions take different forms and operate with different institutions and governance mechanisms. Integrative approaches can provide coordination and linkages to improve effectiveness and efficiency and minimise conflicts. Different types of integration with special relevance for the land-climate interface can be characterised as follows:

1. Cross-level integration: local and national level efforts must be coordinated with national and regional policies and should also be capable of drawing direction and financing from global regimes, thus requiring multi-level governance.
2. Cross-sectoral integration: rather than approach each application or sector (e.g. energy, agriculture, forestry) separately, there is a conscious effort at co-management and coordination in policies and institutions, such as with the energy-water-food nexus (Biggs et al. 2015).
3. Landscape integration: rather than physical separation of activities (e.g. agriculture, forestry, grazing), uses are spatially integrated by exploiting natural variations while incorporating local and regional economies (Harvey et al. 2014).
4. End-use/market integration: often involves exploiting economies of scope across products, supply chains, and infrastructure (Nuhoff-Isakhanyan et al. 2016; Ashkenazy et al. 2017).

Another way to analyse or characterise governance approaches or mechanisms might be according to a temporal scale with respect to relevant events, e.g. those that may occur gradually vs. abruptly (Cash et al. 2006). Desertification and land degradation are drawn-out processes that occur over many years, whereas extreme events are abrupt and require immediate attention. Similarly, the frequency of events might be of special interest, e.g. events that occur periodically vs. those that occur infrequently and/or irregularly. In the case of food security, there is a distinction between “hunger months” and longer-term food insecurity. Some indigenous practices already incorporate hunger months whereas structural food deficits have to be addressed differently. Governance mechanisms that facilitate rapid response to crises are quite different from those aimed at monitoring slower changes and responding with longer-term measures.

7.6.4 Institutional dimensions of adaptive governance

There is *high agreement and medium evidence* that the characteristics of governance systems in Table 7.5 facilitate adaptation and enhance the adaptive capacity of institutions. The table represents a summation of characteristics, evaluative criteria, elements, or institutional design principles of institutions that advance adaptive governance.

Table 7.5 Institutional Dimensions of Adaptive Governance

Characteristics	Description	References
Variety	• Room for a variety of problem frames reflecting different opinions and problem definitions • Involving different actors at different levels, sectors, and dimensions • Availability of a wide range or diversity of policy options to address a particular problem • Redundancy or duplication of measures, back-up systems	(Biermann 2007; Gunderson and Holling 2001; Hurlbert and Gupta 2017; Bastos Lima et al. 2017; Gupta, J., van der Grijp, N., Kuik 2013; Mollenkamp and Kasten 2009; Nelson et al. 2010; Olsson et al. 2006; Ostrom 2011; Pahl-Wostl 2009; Verweij et al. 2006; Weick and Sutcliffe 2001)
Learning	• Trust • Single loop learning or ability to improve routines based on past experience • Double loop learning or changed underlying assumptions of institutional patterns • Discussion of doubts (openness to uncertainties, monitoring and evaluation of policy experiences) • Institutional memory (monitoring and evaluation of policy experiences over time)	
Room for autonomous change	• Continuous access to information (data institutional memory and early warning systems)	

	• Acting according to plan (especially in relation to disasters) • Capacity to improvise (in relation to self-organization and fostering social capital)
Leadership	• Visionary (Long term and reformist) • Entrepreneurial which leads by example • Collaborative
Resources	• Authority resources or legitimate forms of power • Human resources of expertise, knowledge and labour • Financial resources
Fair governance	• Legitimacy or public support • Equity in relation to institutional fair rules • Responsiveness to society • Accountability in relation to procedures

This table represents a summation of characteristics, evaluative criteria, elements or institutional design principles of institutions that advance adaptive governance

Institutional systems that are strong in relation to the characteristics on Table 7.5, or demonstrate these performance characteristics are more resilient and enhance the adaptive capacity of the system to a greater degree than institutional systems that do not demonstrate these dimensions (Gupta et al. 2010; Mollenkamp and Kasten 2009).

7.6.5 Inclusive governance

In governing natural resources focus has been on rights of citizens in relation to natural resources; as there are increasing pressures on natural resources a change of focus is needed to include citizen obligations and responsibilities. This citizen engagement is important in enhancing service delivery by including citizens and engagement with them in management and governance decisions (Karar and Jacobs-Mata 2016; Chaney and Fevre 2001). This style of governance makes important contributions to the management of risk. Inclusive risk governance integrates people’s knowledge and values by involving them in decision making processes where they are able to contribute their respective knowledge and their variety of values in order to make effective, efficient, fair, and morally acceptable decisions (Renn and Schweizer 2009). Representation in decision making would include major actors including government, economic sectors, the scientific community and representatives of civil society (Renn and Schweizer 2009).

PLACE HOLDER - Figure illustrating governance in relation to scenarios, risk and sustainable land management

7.7 Key uncertainties and knowledge gaps

Uncertainties exist in the science of land-climate processes (7.3.1.1) including in observations, unknown futures, methods for near-term forecasting, model structures, parameterisations, and inputs (Chapter 1) and in social and political dimensions including: uncertainty of consequences of economic and political measures; moral uncertainty; uncertainty of demarcation (Chapter 1) and; uncertainty or disagreement in norms, values and priorities in decision making (7.3.1.2). These uncertainties make decision-making in regard to land, climate, society, ecosystem services and food interactions complex (where cause and effect may be determined after the event) or chaotic (where cause and effect are not discernible) (Snowden 2002) and unknown unknowns may be present. However, uncertainty need not present a barrier to taking action and decision-making can occur in iterative manners to account for uncertainties (7.5.2.1).

More research is required to understand the complex interconnections of land, climate, society, ecosystem services and food, including:

- Interactions of land, climate and society that are changing vulnerability, hazards, and exposures over time and at different spatial scales in relation to short-term or acute shocks, and slow-onset or chronic events such as drought and flood;
- How policy instruments and responses can augment or reduce risks in relation to these acute shocks and slow-onset events when implemented in a manner considering the entire policy mix;
- How policy response and instrument mix can reduce or augment the cascading impacts of land, climate and food security and ecosystem services interactions through different domains such as health, livelihoods, and infrastructure especially in relation to non-linear and tipping-point changes in natural and human systems. There is a gap in considering trade-offs in climate, land, ecosystem services and food policies and an urgent need to evaluate and mitigate risks (7.5.7);
- Increasing use of land due to climate mitigation measures such as BECCS, carbon centric afforestation/REDD+ and/or solar energy, increasing urban development, and resource substitution to replace plastics, and their impacts on human conflict, livelihoods and displacement (7.3.3.6);
- Understanding the full cost of climate change is not fully understood in the context of disagreement on accounting for climate change interactions and their impact on society as well as issues of valuation (7.3.4), and attribution uncertainties (7.3.1.1).

More research is required into the feedbacks between drought and people and the human role in mitigating drought and enhancing drought resilience including how effective state drought plans are and which specific suite of policy instruments are appropriate and at which level (7.4.2).

Actions to mitigate climate change are rarely evaluated in relation to impact on adaptation, sustainable development goals, and trade-offs with food security. For instance, there are many renewable energy and irrigation initiatives around the building of small and big dams, however, these may have irreversible trade-offs with downstream ecosystem services impacting food security and ecosystem services (7.3.3.6,7.4.2.5). It is not clear that the sustainable development goals are all implemented in a coherent manner advancing each goal and more research is required to determine this. Further, research is needed to identify if any gaps exist in relation to sustainable development goals and land, climate, food interactions (7.5.2; 7.4.4.1). Incorporation of social sciences in fostering inter-disciplinary approaches and new decision-making tools that build on experiments is likely to reduce disagreement and uncertainty about conservation planning for biodiversity and ecosystem services under future climate-land scenarios (7.5.4; 7.5.9). Policy mixes are not assessed in relation to multiple hazards or interconnected sectors such as health and agriculture. More research is needed in relation to scaling up community-based adaptation and selection of optimal climate mitigation portfolios (7.4.3). There is growing research concerning agri-environmental indicators, but more research on how climate change and policy measures can be evaluated using these indicators and which indicators are optimal is needed (7.5.7).

There is a gap in understanding the institutional governance system and policy mix that will advance adaptation and integrate across levels, sectors, landscapes, supply chains and infrastructure (7.6.1). How policy instruments advance adaptation to climate change and mitigation, interact and change values and norms and the role of informal institutions are research gaps (7.5.1; 7.6.1). More research is required to understand the interconnections of land with water, food and energy (7.6).

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