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

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Table of Contents

7.1 Executive summary

The interactions between climate change and land affect the central issues in sustainable development: how and where people live and work, their access to essential resources and ecosystem services, and food security. This chapter assesses the literature on risk, decision making, policy, and governance of land degradation, desertification and food security in the context of land and climate interactions. The chapter assesses and builds on scientific literature since previous IPCC Reports (IPCC 2012, 2014a) {7.2}.

Changes in land-climate interactions will exacerbate the trend of ecosystems shifting to new biomes and permanent loss of insects, plants, and vertebrates (*high agreement, medium evidence*). In a 1.5°C scenario, combinations of climate and land change will likely drive 7% of current ecosystems to new biome types, such as forest to grassland, and grassland to arid desert (*high agreement, medium evidence*). Risks increase with rising temperature and are not evenly distributed across regions (*high confidence*). Such risks contribute to an increased likelihood of land degradation and desertification, as well as higher rates of food insecurity. At 1˚C and 2˚C, low-latitudes areas are most vulnerable to decreases in yields while in scenarios with over 3˚C of global mean temperature increase significant declines in yields across all regions of the world.

Within the 1.5 degrees range of warming, significant threats exist human settlements near coasts, food systems at low latitudes, and ecosystems related to coral reef tipping points (*high agreement, high evidence*). 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. In the range of 1.5˚C and 2˚C, some of the places and systems already vulnerable to water shortages, such as the Mediterranean (including North Africa and the Levant) are projected to experience more acute dry spells and decreasing water availability {7.3}.

Beyond localised economic effects, a 2˚C warming scenario is likely to be associated with significantly lower economic growth for many countries (*medium confidence, medium agreement*). Warming is likely to amplify global inequalities (*high evidence, high agreement*). Limiting temperature increase to below 1.5˚C will very likely avert a number of impacts and implications that would otherwise be difficult to adapt to. Risks may arise in one domain and cascade through different domains such as human health, biodiversity and ecosystem services, livelihoods, or infrastructure with adverse consequences at regional, national or global scales including increased potential of multi food basket failures.

Achieving the goal of the Paris Agreement and the land-related sustainable development goals requires a suite of climate and land policies. There is *high agreement and medium evidence* that acting early will minimize losses and generate returns on investment {7.4.1}. Delaying deep mitigation in the energy sector and shifting the burden of mitigation to the land sector increases the risk of adverse effects and mitigation failure (*very high confidence*) {7.4.1}. Land-based mitigation entails risks that are currently underplayed in IAM-based future scenarios (*high confidence*). These risks are linked to uncertainties about the mitigation effectiveness of Carbon Dioxide Removal (CDR) options such as BECCS and reforestation; possibility of reversal of carbon uptake due to increasing human and climatic disturbances; potential adverse impacts on biodiversity, ecosystem services and food security and the moral hazard induced by the promises of future CDR delaying political action toward decarbonizing the economy. Delaying decarbonization of economies will likely bring political risks associated with public tolerance of climate impacts including food price changes and food availability, increased pressure on agricultural livelihoods, safety of human settlements in coastal areas, and the possible need for people to move to secure livelihoods and safety (*high agreement, medium evidence*). Continuing fossil fuel subsidies delays decarbonization {7.3.3; 7.5.4; Box 7.2}.

The economic costs of action on sustainable land management, mitigation, and adaptation are less than the costs of inaction. Certain characteristics of decision making affect the degree to which GHG mitigation and adaptation improve or worsen food security and sustainable development, and land degradation and desertification (*high agreement, medium evidence*). **Evidence suggests that policy mixes that are coherent (working in a synchronistic and integrated manner), and comprehensive can overcome these land-climate change challenges** (*medium confidence, medium evidence*) {7.4.1}. Coherent policy mixes that are developed in a comprehensive and integrated manner coordinating levels (global, national, regional, sub-regional, local), across sectors of energy, water, and food, and considered at the local land and community level in the context of a supply chain (Chapter 6) have been found to dampen negative consequences and amplify co-benefits of mitigation, adaptation, and sustainable development {Sections 7.4, 7.5, 7.6}. Fossil fuel subsidies are an example of a policy that detracts from coherent policy mixes that build adaptive capacity and reduce vulnerability {7.5.4}. A socio-economic pathway based on regional rivalry (with limited regulation of land use, low technology development, resource intensive consumption, constrained trade, and delayed international cooperation on mitigation) can result in food prices increases, with strong impacts in the Middle East, Africa and Asia, high numbers of people flooded and significant loss of forest (*high agreement, limited evidence*). In contrast, a sustainable socio-economic pathway (with strong regulation of land use to avoid environmental trade-offs, improvements in productivity, low growth in consumption and limited meat diets, moderate international trade with connected regional markets, and immediate action on mitigation) can result in lower food prices, fewer people affected by floods, and increases in forested land (*high agreement, limited evidence*) {7.6.5}.

Globally harmonized carbon pricing; subsidies, supports, and incentives that foster net zero carbon energy and land use practice; and social- and ecosystem protection schemes reduce risk and vulnerability and build adaptive capacity (*high agreement, medium evidence*). A well-designed carbon tax can reduce GHG emissions but considerations of renewable energy, land use incentives and policies targeting specific climate mitigation measures and/or technologies also need to be considered {7.5.4}.

Purposefully-designed and coherent policy instruments {7.4} **deliver co-benefits like improving food security and also help in managing risks from land-climate change interactions like drought, flood, and forest fires.** The combination of policy instruments – rather than a single policy -- responds to risks so society can prepare for, respond to and recover from these climate change-land impacts. A suite of policy instruments to improve flood resilience, 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 safety net systems. 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 {7.5.2; 7.5.3}. Research has documented diverse agroecological practices of small-scale agriculture which have led to superior recovery from climate stressors. 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. Policies to support those outcomes can deliver the multiple co-benefits and include financial support for agricultural water infrastructure (including dugouts and pipelines) and environmental farm practices preventing soil degradation {Chapter 3.8.5, 7.5.6}.

Adaptive and rapidly updated decision-making tools that utilise new data and knowledge help deal with uncertainty (*high agreement, medium evidence*). Uncertainty exists in scientific findings due to definitional, observational, data unavailability, unreliability, technology limitations, 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 distribution of its consequences, leading to unpredictable decision making of actors at different levels. Scenarios can provide valuable information at all planning stages in relation to land, climate and food, but uncertainty in scenario planning requires that adaptive management with adaptive and flexible solution planning and pathway choices be made and reassessed to respond to new information and data as it becomes available {7.5.4; 7.6.3}.

Traditional and local knowledge systems, and informal decision-making processes and institutions 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 inadequate. Indigenous knowledge and local knowledge (IK&LK) are important for adaptation among farmers, pastoralists, forest-based communities and hunter-gatherers and can be congruent with climate mitigation measures {7.5.1; 7.5.5; 7.5.6}. In many areas the inter-generational transmission of IK&LK and their use in land management are weakening, trends that can be reversed by appropriate policies and programmes. Local level informal institutions such as mothers' groups, community forestry users' groups, water users' group are also important considerations in formal decision-making analysis {7.5.1}.

Including and empowering stakeholders and local populations in decision-making and policy formation related to land improves all levels of governance and may enhance social learning and acceptance (*high agreement*, *medium evidence*). New and long-standing ways of involving residents 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 to manage different framings of issues surrounding climate risks and opportunities. Such processes facilitate social feedback, the exploration of new policy options, and institutionalise new rights and responsibilities. There is *high agreement and limited evidence* that these learning processes are important in engaging with uncertainty and risk and in developing suites of policy and governance systems. Inclusive decision-making and good governance will build resilience to risk and enhance service delivery and food security by incorporating citizen rights, obligations and responsibilities {7.5.6}.

Women play a prominent role in agriculture in many societies and face multiple barriers to adaptation. Land is an important determinant of women's livelihoods; alienation or loss of title, competing uses for land (such as biofuel) or impacts of climate change may contribute towards increased vulnerability. Integrative approaches focused on gender and building on the collective action and agency of women increase resilience {Cross-Chapter Box 6: Gender}.

Measuring performance is important in decision-making and adaptive governance to create common understanding and advance policy effectiveness (*high agreement*, *medium evidence*). Measurable indicators are useful for climate policy development and decision-making of all people (including governments and actors at global, regional, national, sub-national and local levels) and include the Sustainable Development Goals, targets established in the Paris Agreement, land degradation neutrality core indicators, 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. Decision making, policy instrument selection, adaptation decisions and planning for disasters is improved with consideration of these indicators {7.6.6}.

The complex spatial, cultural and temporal dynamics of risk and uncertainty in relation to land and climate interactions and food security, may require a flexible, adaptive, iterative approach to assessing risks and revising decisions and policy instruments (*high confidence*). This adaptive, iterative process occurs at the science and society interface where decisions and policy instruments are to be assessed and revised. Dynamic adaptation pathways are emerging as a mechanism to make decisions recognising that privileging equilibrium may be maladaptation 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 such as droughts and floods, are important learning moments when ecosystem feedbacks in a degraded system are recognised and significant changes may be made {7.6}.

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 (*high confidence*). Land tenure, including individual and community titles and rights to land, the use of land, and ecosystem services, is a key dimension in any discussion of land-climate interactions. Land tenure, which needs to be understood within specific socio-economic and legal contexts providing different routes to land security and land insecurity, will influence the prospects for both adaptation and land-based mitigation in different agro-ecosystems, in forests, and in poor and informal urban areas (*high evidence, high agreement).* Both climate change and climate action will have possible impacts on land tenure and thus land security, especially of marginalized people (*limited evidence, high agreement*). Evidence suggests that selecting policy instruments while also considering land, climate, and system linkages, is more likely to create co-benefits between mitigation, adaptation, and development. Sustainable Development Goals can be mutually reinforcing. There is *high agreement and medium evidence* that policy instrument selection needs to be pursued in a manner that recognises their inherent linkages, context, synergies, specific trade-offs, and co-benefits. These relationships depend on political, national and socio-economic factors. The gaps and omissions in Sustainable Development Goals (e.g., fresh water ecosystems and their ecosystem services) require other frameworks such as Nature's Contribution to People (NCP) 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 {7.5.8, 7.6.4, 7.6.6}.

The growing importance of land use for future mitigation pathways as well as strengthening adaptive capacity will require adaptive governance at multiple levels. The increasing role of biomass for energy in both BECCS and non-BECCS scenarios under 1.5˚C-consistent pathways will require integrated approaches to land use governance. The increasing pace of trade and changes in land use management systems as well as the growing interdependencies with climate policies themselves has extended land-climate interactions beyond local and national jurisdictions: managing such interactions requires multi-level governance {7.6.2}. Inclusive governance with deeper citizen engagement can improve effectiveness of natural resource management but requires specification and allocation of rights, responsibilities and risks {7.6.6}.

7.2 Introduction and Relation to Other Chapters

This chapter focuses on decision-making and policy responses to risks arising from the interactions between climate change, land and humans. The literature surrounding governance, institutions and decision making with respect to risks related to land-climate interactions is assessed. Land is integral to human habitation and livelihoods, providing 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 resilient development and the achievement of the Sustainable Development Goals. This chapter reviews and assesses literature of associated risk and uncertainty surrounding land and climate change, policy instruments and decision-making addressing these risks and uncertainty, and adaptive management and governance to identify policy instruments, decision making tools, and governance practices that advance response options with co-benefits identified in Chapter 6, lessen the socio-economic impacts of climate change and reduce trade-offs, and advance sustainable land management.

This chapter will complement and build on identifying policies, decision making and governance issues in respect to risks 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

This chapter builds on earlier assessments contained in several chapters of the IPCC Fifth Assessment Report (the contributions of both Working Groups II and III), the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)(IPCC 2012), and the IPCC Special Report on Global Warming of 1.5°C (SR15). (IPCC 2018a) The most relevant findings are set out in Box 7.1.

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" (Denton et al. 2014, p. 1104; Fleurbaey et al. 2014).

Significant transformations may be required for climate-resilient pathways (Denton et al. 2014; 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. 2014; 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" including adaptation by local governments, businesses, communities, and individuals (Denton et al. 2014, p. 1104).

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 (Denton et al. 2014; Kunreuther et al. 2014; Kolstad et al. 2014; Somanthan et al. 2014; Lavell et al. 2012).

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 under 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: 293).

Risk and risk management

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. 2014, p. 1042)

“Under any plausible scenario for mitigation and adaptation, some degree of risk from residual damages is unavoidable” (Oppenheimer et al. 2014, p. 1045).

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: 198).

“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: 198).

“Scenarios are a key tool for addressing uncertainty”, either through problem exploration or solution exploration (Jones et al. 2014: 198).

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: 871).

Governance

“Strengthened multi-level governance, institutional capacity, policy instruments, technological innovation and transfer and mobilization of finance, and changes in human behaviour and lifestyles are enabling conditions that enhance the feasibility of mitigation and adaptation options for 12.5degree C –consistent systems transitions (*high confidence)* IPCC 1.5 2018.

Governance is key for vulnerability and exposure represented by institutionalised rule systems and habitualised behaviour and norms that govern society and guide actors and , “it is essential to improve knowledge on how to promote adaptive governance within the framework of risk assessment and risk management” (Cardona 2012: 90).

7.2.2 Treatment of Key Terms in the Chapter

While the term *risk* continues to be subject to a growing number of definitions in different disciplines and sectors, this chapter takes as a starting point the definition used in the IPCC Special Report on Global Warming of 1.5°C (SR15) (IPCC 2018a), which reflects definitions used by both Working Group II and Working Group III in the Fifth Assessment Report: "The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain" (Allwood et al. 2014; Oppenheimer et al. 2014). The definition further specifies: "In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure". In SR1.5 as in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) and AR5 WGII, risk is conceptualised as resulting from the interaction of vulnerability (of the affected system), its exposure over time (to a hazard), as well as the (climate-related) impact and the likelihood of its occurrence (AR5 2014; IPCC 2018a, 2012). In this chapter the conceptualisation of risk takes account of the nature of climate impacts as themselves arising from human actions. In contrast to some definitions (Garrick et al. 2004; Attar 2010; Aven and Renn 2009), risk is not seen as necessarily quantified or quantifiable, or directly contrasted with uncertainty. Climate and land risks are in relation to human values and objectives (Denton et al. 2014). It is closely associated with concepts of *vulnerability* and *resilience*, which are themselves subject to differing definitions across different knowledge communities.

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. 2014, p. 1052) . In this chapter the term is used with reference to risks arising from more than one of the major land-climate-society challenges (desertification, land degradation, and food insecurity), risks partly stemming from mitigation or adaptation actions, and risks cascading across different sectors or geographical locations. Stranded assets in the coal sector due to proliferation of renewable energy and government response to this could be an emergent risk (Saluja, N and Singh 2018; Marcacci 2018). Additionally, the absence of an explicit goal for conserving fresh-water ecosystems and ecosystem services in SDGs (in contrast to a goal (Life Under Water) that is exclusively for marine biodiversity) is related to its trade-offs with energy and irrigation goals thus posing a substantive risk (Nilsson et al. 2016b; Vörösmarty et al. 2010).

Governance is not previously well defined in IPCC reports, but is used here to include all of the processes, structures, rules and traditions that govern, which may be undertaken by actors including governments, markets, organisations, or families (Bevir 2011), with particular reference to the multitude of actors operating in respect of land and climate interactions. Such definitions 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 2017a). Governance 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 are key components of governance and include policy instruments, structures of property rights or land tenure, and decision making. Institutions can play a key role in adaptation as they influence the social distribution of vulnerability and shape adaptive capacity (Cardona 2012). "Well developed institutional systems are considered to have greater adaptive capacity" as institutions influence adaptation and circumscribe the vulnerability of systems (IPCC 2001a: 896).

7.2.3 Roadmap to the chapter

This chapter builds on risk, decision making, and governance identified in previous reports. First risk in relation to land and climate with a specific focus on GHG fluxes, desertification, land degradation, and food security is explored. Emergent risks from land climate interactions, tipping points and cascading risks are identified and uncertainty (see Chapter 1) described. After characterizing risk and uncertainty, policy instruments (a key institution) and responses to the risks of climate change mitigation and adaptation, desertification, land degradation, and food security are identified at multiple governance levels (global, regional, national, sub-national, and local). Policy mixes that provide for adaptation and build resilient institutions are reviewed and barriers and limits to adaptation. Section 7.5 assessing literature surrounding decision making in land and climate interactions covering tools, best practices, adaptive management, and participation for social learning, the assessment of decisions through performance indicators, synergies and trade-offs surrounding decisions and instruments, and barriers of implementation. The penultimate section of the chapter reviews literature on the enabling conditions and governance that advance sustainable development and the chapter ends with the identification of knowledge gaps and a vision for the future.

7.3 Climate-related risks for natural and human land systems

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, assesses risk across different temperature rise, and describes risks and drivers, risks due to climate change and arising from responses to climate change. Substantive risks arising as a consequence of climate and land change for human well-being and sustainable development are identified, as well as economic consideration of what is at stake.

7.3.1 Describing Risk and Drivers

The specific dimensions of risk considered in this chapter relate to consequences of greenhouse gas (GHG) emissions, climate change, and impacts of climate change (drought, flood, fire etc.), which may contribute 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 ecosystems to change, either directly or indirectly; drivers of change in ecosystems may emanate from legal, 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 situation has a series of problems-within problems; linkages with yet additional problems confuse understanding ramifications to the whole system (Waddock 2013; Grundmann 2016). Because of this, uncertainty and risk are not linear or simplistic, requiring conceptual frameworks that provide illumination to complex interactions and unintended consequences of actions (Kunreuther et al. 2014). For example, risk assessment of a hydroelectric dam which provides renewable energy and irrigation water considers not only climate change risk but also variations in stream flow that differ across and within regions (Hamududu and Killingtveit 2012). Such a risk assessment also considers uncertainty about demographic shifts, human development needs, energy and food security, investment and trade patterns (Grumbine et al. 2012) and potentially long term human intervention in the global water cycle tied to urbanization. The damming, diverting and draining of rivers has not only impacts at the local scale but may lead to changes in the regional and global water system over decadal time scales (Higgins et al. 2018a; Leichenko and O'Brien 2008).

7.3.1.1 Norms, Values, Priorities

How governments and societies at all scales of governance respond to different types of risk arising from land-climate-society interactions is a function of agreement and consensus on the nature and potential magnitude of the risk.

Structured responses to land-climate-society interactions can arise where society is in agreement about norms, values and priorities and the science is clear; or society may respond in unstructured ways where there is little agreement on the norms, values and priorities and the science is not clear. Difficulties can arise in such unstructured responses with the “unknown unknowns”, chaotic (where cause and effect is not discernible) and complex situations (where cause and effect may be determined after the event)(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). For example, 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 become augmented through stresses with long fuses or triggering events because of linked nature of climates across different regions of the world (e.g., El Nino Southern Oscillation (ENSO) climatic impacts that result in large-scale droughts with multiple impacts in different countries and regions) (see Box 7.2), 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 maladaptive (see 7.6.7). Risks may be reduced through adaptation, mitigation and policy measures (see 7.5).

The proactive actions of people adapting and mitigating climate change are based on how they perceive the risk of climate change and the magnitude of impacts. This judgement is both an individual and a political act (Fischhoff et al. 1984). While making a scientific 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 act, often upon incomplete information, based on perceptions of benefits, costs and reciprocity of relationships (Ostrom 1998, 2010). Some literature holds 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). For example interventionist approaches to minimizing biodiversity loss in a changing climate (a substantive risk) is still taboo amongst large section of the conservation science and practitioner community and consensus may take some time to emerge (Hagerman et al. 2010; Hagerman and Satterfield 2014). Lack of clarity in objectives can pose substantive risks. Government responses also depend on uncertainty of knowledge and about response options as well as the spatial and temporal scale associated with the vulnerability and exposure aspects of the hazard (Leiserowitz 2006; Brown and Castellazzi 2014; Kasperson and Kasperson 2013; Kasperson et al. 1988). Risks emerging from land-climate-society hazards can be characterized by uncertainty in knowledge, disagreement on priorities and the spatial or temporal scale involved. Risk can also arise from the pursuit of a specific Sustainable Development Goals (SDGs) regionally, nationally or globally that can trade-offs with other SDG goals or with goals that are not explicitly included in the SDGs. How risk is determined or constructed informs actors’ decisions and regulatory choices (Hoppe 2011; Hisschemoller and Gupta 1999). Examples include co-constructing runoff risks at the watershed scale (Souche`re, V., Millair et al. 2010) making decisions surrounding natural capital based on participatory forecasting of ecosystem state and ecosystem services (Clark et al. 2001), and selecting priority actions regarding reduction of emissions from deforestation and forest degradation while minimzing displaced land use change (Miles and Kapos 2008) (see Section 7.6.5).

7.3.1.2 Across Spatial and Temporal 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 neighbouring 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. For example, the pace and location of a hazardous event or process interacts with land topography (coastal plain, slopes of mountains), the spatial dimensions (dispersion, areal coverage) and the type of farming systems (irrigated, dryland, terraced, aquaculture) affect different vulnerabilities and outcomes (Tesfamariam and Hurlbert 2017).

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. Weather forecasting at short time-scales (five to ten days) is improving in performance and in Africa and India is already serving as farmer advisories to reduce risk of crop losses (Singh et al. 2017; Tripathi and Mishra 2017). Prediction of large scale weather and climate phenomena such as ENSO and its relationship to local and regional climate and extreme weather events can be complicated due to non-linearities and non-stationarities (Krishnaswamy et al. 2015; Cane 2005) and this affects how well risks can be anticipated in specific regions or biomes (Jones and Morse 2012).

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. People, other fauna, and flora are impacted by these natural events, and experience vulnerability over time, or at specific points in their life cycle. In a plant lifecycle, regeneration and recruitment phases affect adaptive capacity, distribution and survival of species. Demographic change, urbanisation, and infrastructure construction also affect the inherent spatial and temporary dynamics of socio-economic changes in vulnerability and resilience; 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 be beneficial to the cultivation of certain export-oriented crops in certain areas and contribute to instability in domestic food production (Challinor et al. 2017).

The dynamics of risk change over time as a result of both human and natural process. For example, biological processes, genomic regions, and specific genetic characteristics can influence the vulnerability of individuals, populations and species. With CO_2 fertilization, some edible plants grow faster, reducing nutrition content for humans (Chapter 5). 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 if 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. For example, longer lived species must evolve faster per generation to adapt to a given rate of environmental change (Chevin et al. 2010). There is emerging evidence of an association between genomic regions and specific genes linked to migration and exploratory behavior and climate change adaptation in yellow warblers (Fitzpatrick and Edelsparre 2018). A populations adaptive potential may be limited by genomic vulnerability. 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 further if they are unable to adapt to changes in sea surface temperature at the same rate as their prey (Keogan et al. 2018).

7.3.2 Risks due to climate change

7.3.2.1 Risk of desertification, land degradation and food insecurity

Burning embers figures introduced in the IPCC Third Assessment Report, illustrate risks at different temperature thresholds. Figure 7.1 indicates risks of desertification, land degradation and food insecurity at different temperatures. Risks to specific components of desertification (Water scarcity, soil erosion and vegetation changes; arid climates only), land degradation (soil erosion, fire, vegetation changes, coastal erosion and permafrost degradation; non-arid climates and biomes including semi-arid, sub-humid and others) and food insecurity (nutrition and yield) are highlighted on the lower panel. Risks assessments are based on a review of recent literature (Supplementary tables). Expert judgements were used to assess levels of warming at which impacts are undetectable, moderate, high and very high, based on methods detailed in AR5, SR1.5 and (O'Neill et al. 2017). Components were selected based on availability of published studies and are not intended to be exhaustive.

As indicated in Figure 7.1, unabated future climate change will likely induce high to very high risks of desertification, land degradation and food insecurity. At the current global average temperature increase of 0.87°C above pre-industrial levels, moderate impacts of warming are already detectable on desertification, land degradation and food security, and on their sub-components.

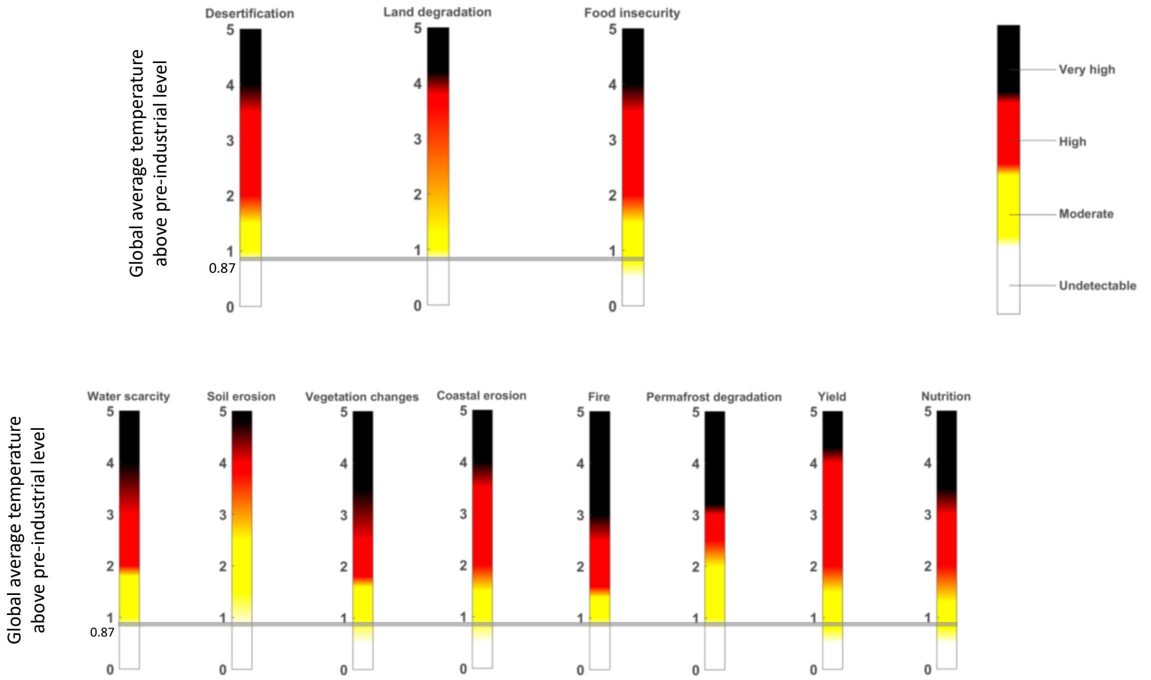


Figure 7.1 Summary of risks of desertification, land degradation and food insecurity at different degrees of warming. The grey line (0.87°C) is a measure of the extent of present day warming. Risks to specific components of desertification (Water scarcity, soil erosion and vegetation changes; arid climates only), land degradation (soil erosion, fire, vegetation changes, coastal erosion and permafrost degradation; non-arid climates only) and food insecurity (nutrition and yield) are highlighted on the lower panel. The risk scale (from undetectable to very high) indicates the level of additional risk posed by climate change. Confidence levels (L=Low, M=Moderate, H=High) for each estimated risk transitions are available in supplementary information (Table Supplementary Material). This risk assessment is based on expert judgement by the authors of this chapter considering previous IPCC report and literature presented in Chapters 3,4,5,6 and 7

Thresholds of risk differ across components (*high confidence*). Very high risks of vegetation changes, permafrost degradation, changes to fire cycles and declines in nutrition are reached at much lower levels of warming. For example, according to IPCC Special Report on 1.5 degrees of warming elevated CO_2 concentrations of 568–590 ppm alone, which corresponds to approximately 2.3°C –3.3°C of warming in RCP6 -reduced the protein, micronutrient, and B vitamin content of the 18 rice cultivars grown most widely grown in southeast Asia. This could create nutrition-related health risks for 600 million people (Zhou et al. 2018). Limiting warming to 1.5°C or 2°C lowers risks across all components: water scarcity, soil and coastal erosion, fire, changes in vegetation, permafrost degradation, decreased crop yields and lower nutrition value of food (*high confidence*) (Chapter 3, Chapter 4, Chapter 5, Chapter 7).

Different regions experience different levels of risk at different temperatures. Small increases in temperature may lead to decreases in yield in low latitudes compared with mid to high latitudes (Chapter 5) (*high confidence*). For example, wheat yield losses are expected to be lower for the United States (−5.5 ± 4.4% per degree Celsius) and France (−6.0 ± 4.2% per degree Celsius) compared to India (−9.1 ± 5.4% per degree Celsius) (Zhao et al. 2017). The African Sahel, the Mediterranean, central Europe, the Amazon, western and southern Africa are at risk of food shortage at 2°C warming (IPCC, 2018). However, at higher temperatures of warming regional differences disappear and there are high risks of declining yields across regions.

Socio-economic developments and policy choices that govern land-climate interactions are an important driver of risk along with climate change (*very high confidence*). As depicted in Figure 7.2, under a given global temperature increase, some socio-economic pathways (i.e., SSP1) strongly reduce the vulnerability and exposure of human and natural systems and thus limit risks associated with desertification, land degradation and food insecurity (*high confidence*). At similar temperatures, risks are higher in SSP3 than in SPP2 and SSP1. Socio-economic choices outlined in SSP3 (including high preference for animal consumption, little regulation of land use, low yield improvements in crops, low efficiency improvements in livestock, higher population growth and little change in per capita GDP, reach higher levels of risk) result in higher risks of food price rise and numbers of people exposed to flooding (Hinkel et al. 2014; Popp et al. 2017a). SSP1 pathways (including globalized trade, reduction of animal consumption, regulation of land use, yield improvements in crops, reduced population growth and increased GDP) also results in lower levels of forest loss (Riahi et al. 2017; Popp et al. 2017a).

Literature is still emerging in this area and there is a need for greater research on impacts of different socio-economic pathways, scaling of GMT and tipping points. 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. 2015; Maynard 2015). Further, reliance on global markets may reduce some risks, as outlined in SSP1 pathways, but the 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. 2015; Jones and Hiller 2017).

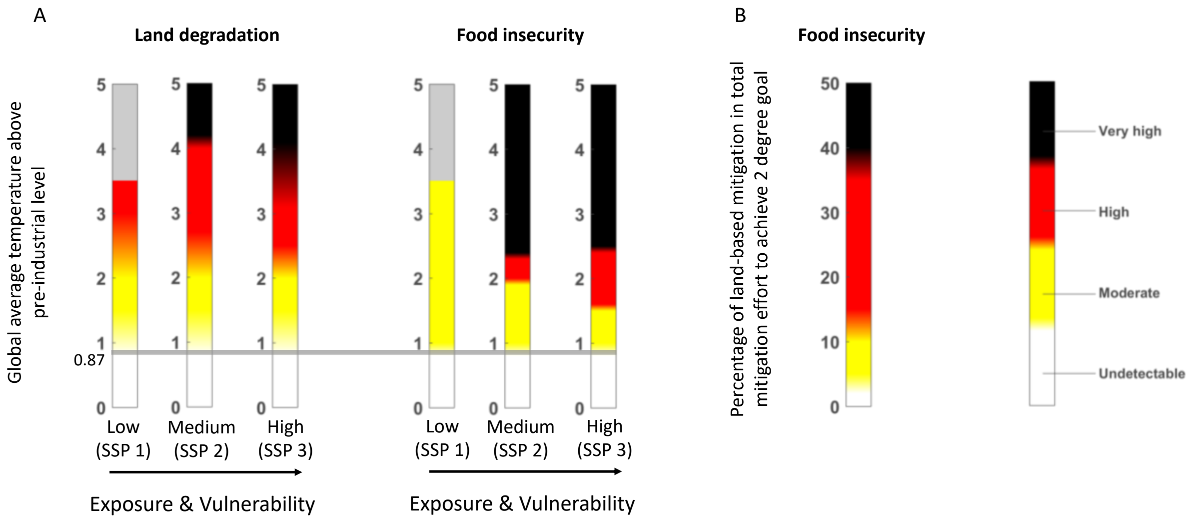


Figure 7.2 A) Summary of risks of land degradation and food insecurity as a function of global warming and under different socio-economic pathways (SSP). SSP1 to 3 reflect increasing levels (from low to high) of exposure and vulnerability of human and natural systems. Areas in grey in SSP1, indicate that this SSP does not reach higher temperature levels. B) Risks to food security as a function of the share of land-based mitigation relative to the total mitigation effort (cumulative in 2100) required for a 2-degree stabilization in 2100. This risk assessment is based on expert judgement by the authors of this chapter considering emerging literature on socio-economic pathways (see Supplementary table for further details). Coastal Erosion was used as the indicator for land degradation and food price rise was used as an indicator for food insecurity

Additional substantive risks discussed in this section include loss of biodiversity and ecosystem services, deteriorating health and nutrition, extreme events, and risks created by land based mitigation as response to climate change.

7.3.2.2 Risks of loss of biodiversity and ecosystem services

Climate change poses significant threat to species survival, and to maintaining biodiversity and ecosystem services. Climate change reduces the functionality, stability, and adaptability of ecosystems

(Pecl et al. 2017) . For example, drought affects cropland and forest productivity and reduces associated harvests (provisioning services). In additional, extreme changes in precipitation may reduce the capacity of forests to provide stability for groundwater (regulation and maintenance services). Prolonged periods of high temperature may cause widespread death of trees in tropical mountains, boreal and tundra forests, impacting diverse ecosystem services including impacting aesthetic and cultural services (Verbyla 2011; Chapin et al. 2010; Krishnaswamy et al. 2014). 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 (UNEP 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). Biodiversity will also 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 related human migration is likely to impact biodiversity as people movement into and contribute to land stress in biodiversity hotspots now and in the future; and as humans concurrently move into areas where biodiversity is also migrating to adapt to climate change (Oglethorpe, J., Ericson, J., Bilsborrow, R.E. and Edmond 2007).

7.3.2.3 Risks related to Health and Nutrition

In addition to risks related to nutrition articulated in Figure 7.1, human health can be affected by climate change through extreme heat and cold, changes in infectious diseases and extreme events (Hasegawa et al. 2016). There are relatively few estimates of the economic implications of these health impacts (Martinez et al. 2015), particularly related to the topics of this report but evidence indicates that action to prevent the health impacts of climate change could provide substantial economic benefits (Martinez et al. 2015; Watts et al. 2015).

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 an important factor in heat waves. Changes related to the increase of impervious surfaces like asphalt, cement, roofs in urban centres, 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).

Case Study: Heat Stress and Urban Development

Urban development involves the replacement of natural areas such as forested and water surface with paved man-made built areas. Transformed urban land-use can cause severe pressure on various natural resources and functions. Consequently, urban development affects the local microclimate in many ways with increased air pollution, altered wind speeds and directions, and heat stress. Urban island heat effect can be exacerbated with heatwaves during an extremely hot summer.

Urban areas consume more energy than nonurban areas, which also leads to the intensity and the impact of urban heat island (Woo and Cho 2018). The conversion of natural, agricultural and other low-population density lands into urban settlements has changed the hydrology (Blanco et al. 2011) and led to vegetation loss and degradation (Fanan et al. 2011; Liu et al. 2015). Climatic parameters are modified by the vegetation decrease and hydrology due to urban development and settlement (Cui and Shi 2012; Kometa and Akoh 2012; Voogt and Oke 2003; Zhao et al. 2006). According to Kalnay and Cai (2003) both the minimum and the maximum temperature increased due to the changes in land cover in the USA. In general, there is the impact of big cities, massive centers of heat-retaining concrete structures on heatwave (Ackerman 1987; Buechley et al. 1972; Oke 1973; Whitman et al. 1997). Rahman et al. (2017) revealed that land surface temperature in Dammam City, Saudi Arabia, increased greatly due to urban expansion during the period of 1990–2014. Based on land cover changes and predictive modelling, this study also projected a dramatic increase in land surface temperatures for the year 2026. (Dousset et al. 2010), in the study of satellite monitoring of summer heat waves in the Paris metropolitan area, showed that a heat island was centered downtown at night, whereas multiple temperature anomalies were scattered in the industrial suburbs during the day, and that heatwave corresponded to elevated nocturnal land surface temperature compared to normal summers.

Heatwaves increases the risks associated with heat exposure. High temperatures can affect human health and lead to additional deaths even under current climatic conditions. This risk will be much greater with climate changes. The urban residents are particularly vulnerable to the threats of heat stress and under great risk because of the warming from climate change. Ecosystem-based adaptation 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). Adaptive planning and design considers multifunctionality in the urban planning landscape including flood plain parks, permeable pavement, and urban tree canopies to reduce local temperature and intercept rainfall (Ahern 2011).

Recent studies show that interactions between climate change and land-use can influence the geographic expansion of diseases, alter composition and density of reservoir populations (*high confidence*). Vectors of infectious diseases, including mosquitos, ticks, sandflies and others, and infectious agents, such as protozoa, bacteria, and viruses, are extremely sensitive to temperature and precipitation (*high confidence*), variables altered by both climate and land-use change (Naicker 2011; Smith et al. 2014b; Tjaden et al. 2017; Young et al. 2017). Zika virus, chikungunya and dengue are three mosquito-borne diseases that have increased in incidence over the past decade. The ecological ranges of these diseases are likely to expand further under climate and land use change (Ali et al. 2017; Carlson et al. 2016; Colón-González et al. 2017; Tjaden et al. 2017) (*high confidence, medium agreement*). Zika transmission is optimized at 29°C, and could expand north in range as temperatures move towards the predicted thermal optimum (Tesla et al. 2018). Activities such as deforestation and urbanization also increase risks of Zika, increasing contact with animal reservoirs involved in the sylvatic transmission cycle for example (Ali et al. 2017).

The WHO estimates 60,091 additional deaths for climate change induced malaria for the year 2030 and 32,695 for 2050 (World Health Organization 2014). There is an ongoing debate on the impacts of climate change in 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 areas (Yamana et al. 2016). In the Amazon, 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 increased water bodies, social-economic conditions and immunity (Tucker Lima et al. 2017). Here, not only net loss of forest is important, but also edge effects and fragmentation, which have been found to exacerbate malaria transmission (Barros and Honório 2015). In Asia, specifically in China, taking in consideration land use and urbanization simultaneously, Ren et al (Ren et al. 2016) predicts a substantial net increase in the population exposed to the four dominant malaria vectors in the years 2030 and 2050. Here, deforestation has been shown to enhance the survival and development of vector larvae major malaria vectors (Wang et al. 2016b). There are 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.

In recent years there has been a notable increase in the incidence of zoonotic (i.e., animal-derived) diseases in human populations, including the West African Ebola virus epidemic of 2013-2016 (Alexander et al. 2015a) and another outbreak that first emerged in August 2018 in the Eastern Democratic Republic of Congo (Nkengasong and Onyebujoh 2018) This increase has potentially been linked to human encroachment on animal habitat via disruptive practices such as logging and mining in combination with the bushmeat trade. The composition and density of zoonotic reservoir populations, such as rodents, is also influenced by land-use and climate change (*high confidence*) (Young et al. 2017). However, different types of land-use changes have divergent impacts (*high confidence*). In Kenya, pastoral land-use does not impact changes rodent numbers as much as conversion to agriculture or removal of wildlife (Young et al. 2017).

In the case of Ebola, tropical bat species with naturally high circulating virus titres are suspected of being reservoirs for the Ebola virus, with transmission occurring either via direct or indirect (e.g., droppings, saliva) contact potentially infecting either humans or other tropical species. Furthermore, the limitation of resources imposed by habitat destruction has forced greater contact between tropical species, in turn increasing the potential for transmission rates among these groups. The bushmeat trade in many regions of central and west African forests (particularly in relation to chimpanzee and gorilla populations) only serves to elevate the risk by increasing human-animal contact between evolutionarily related species (Harrod 2015) . In addition to anthropogenic habitat destruction, a climate element may also be at play. Fig trees that populate these forests act as a keystone species across much of central and West Africa (Lambert and Marshall 1991). A variety of tropical species are dependent on fig trees for a reliable source of food, including frugivorous bats. A changing climate increasingly disrupts the cycle of fruiting (Chapman et al. 2005a,b) in turn impacting behaviour and range, further increasing human-animal contact (*medium evidence*).

These large-scale outbreaks of zoonotic diseases emphasize the need for greater understanding of the genesis of disease and its anthropogenic antecedents. Despite great scientific strides made in the development of treatment and vaccines for Ebola, there remain complex (and often forgotten) climate and environmental antecedents, as evidenced by novel and persistent outbreaks such as in the Eastern Democratic Republic of Congo. As it stands, effectively addressing both the epidemiology and ecology of the Ebola virus (as well as the effect of a changing climate on the incidence of the disease) remains a formidable challenge for global health and scientific communities and therefore warrants extensive trans-disciplinary research. There is a need to improve health impact models to project outcomes of climate and land use change under different socioeconomic conditions (Sharma 2012). There are relatively few estimates of the economic implications of these health impacts (Martinez et al. 2015). The effect of climate change on crop yields and associated undernutrition could range from -0.1% of GDP to +0.0% of GDP across global regions (Hasegawa et al. 2016). The existing evidence indicates that action to prevent the health impacts of climate change could provide substantial economic benefits (Martinez et al. 2015). Watts et al. (2015) shows how the inclusion of demographic trends, including ageing, migration and population growth on climate impact on global health, makes the affected population larger than expected (Smith et al. 2014a).

7.3.2.4 Risks from Extreme Events

The length or number of warm spells or heat waves has increased in many areas of the world and many are experiencing extreme changes in precipitation, including more intense, frequent, and longer droughts in combination with torrential rains and flooding, and severe heat waves (Mann et al. 2017; Modarres et al. 2016; Parker et al. 2013). 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.

7.3.3 Risks arising from responses to climate change

7.3.3.1 Risk associated with land-based adaptation

[Place holder, sub-section to link to Chapter 6 here]

7.3.3.2 Risk associated with land-based mitigation

Historically, land use activities have been a source of GHG emissions, but there are expectations that the land sector will be an important contributor to climate mitigation in the future, not only reducing its emissions but even providing net negative emissions (Chapter 2 Section 2.6). These negative emissions (or CDR), in the form of re/afforestation and/or BECCS, are essential in future IAM scenarios stabilising temperature change at or below 2°C relative to pre-industrial levels (Smith et al. 2014c; IPCC 2018a; Millar et al. 2017) (Chapter 2). The slower the pace of decarbonization of the economy and energy supply happens, the higher the reliance on CDR options will be toward the end of the century in these scenarios (SR1.5 SPM) (IPCC 2018b). However, land-based mitigation entails risks that are increasing with increasing share of land-based mitigation (Figure 7.2.B). These risks are not or only partly considered in IAM scenarios and are thus currently underestimated (Anderson and Peters 2016). These risks fall into the following categories:

Uncertainty about effectiveness. There are large uncertainties about the amount of CDR that can be realized through land-based mitigation. Using a set of dynamical global vegetation models (Krause et al. 2018) found that the potential cumulative carbon uptake by year 2099 from combined re/afforestation and BECCS ranges between 19 and 130 GtC, typically lower than assumed in IAMs. This estimate does not account for the additional uncertainty about the land area that can be made available for CDR (Smith et al. 2015). Furthermore, the effectiveness of BECCS is strongly determined by the pre-existing conditions before BECCS deployment and would be particularly inefficient if replacing high-carbon content ecosystems (Harper et al. 2018).

Risk of reversal and permanency of carbon storage. In essence, CDR strategies are transferring carbon from fossil fuel reserves into the terrestrial biosphere (re-afforestation and other agricultural and forest management options) or into geological layers or aquifer (BECCS) (Smith et al. 2015). It is *virtually certain* that the carbon in fossil fuel reserves (if fossil fuel emissions are avoided) is more safely and permanently stored at human time scales than the carbon within the biosphere, which is subject to various human and climate disturbances. Climate change is expected to exacerbate disturbances such as extreme events, fires, insect outbreaks, thus there is a risk of reversal inherent to any terrestrial CDR project that can lead to mitigation failures. Heat and drought-related tree mortality (McDowell and Allen 2015) and wildfire (Balshi et al. 2009; Astrup et al. 2018) will increase with climate change and will put global forests at higher risk. Since these processes are insufficiently represented in IAMs (this report Chapter 2) this risk has been possibly underplayed in current climate mitigation scenarios. In the case of BECCS, the issue of the long-term stability of the carbon retention is linked to technical and geological constraints independent of climate change but which remain a cause for concerns (SR1.5, Chapter 4).

Adverse effects and competition for land resources. A number of potential adverse effects and trade-offs have been described in relation with CDR options. Land area requirements -up to two times the size of India for BECCS in some IAM scenarios (Anderson and Peters 2016) and even more for re-afforestation (Popp et al. 2017b)- would increase competition for land. BECCS requirements for water and nutrients may have adverse impacts on other ecosystems and crops (Smith et al. 2015). Re-afforestation put constraints on the availability of land for food production (Kreidenweis et al. 2016) and can exacerbate water scarcity issues (see Cross-Chapter Box 1: Large scale reforestation and afforestation, Chapter 1) but can foster synergies with biodiversity and other ecosystem services (this report, Chapter 6).

Moral hazard. The promise of future CDR deployment could give a political pretext for not engaging in a rapid decarbonisation of energy supply (Anderson and Peters 2016), thus transferring the burden of mitigation to the land sector and to future generations with all the risks outlined above.

Table 7.1 Characterising land-climate risk and indicative policy responses. Table shows hazards from land-climate-society interactions identified in previous chapters or in *other* 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 and response options from Chapter 6. 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; McDowell and Allen 2015; Sunderlin et al. 2017; Belcher et al. 2005; Soizic et al 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)
Extreme events in multiple economic and agricultural regimes or Multi-bread basket failure	Global	• Food importing countries • Low income indebtedness • Net food buyer	• Conflict • Migration • Food inflation • Loss of life • Disease, malnutrition • Farmer suicides	• Insurance • Social Protection encouraging diversity of sources • Climate smart agriculture • Land rights and tenure • Adaptive Public Distribution Systems	(Fraser et al. 2005; Schmidhuber and Tubiello 2007; Lipper et al. 2014a)
Disruption of flow regimes 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	• Loss of livelihoods and identity • Migration • Indebtedness	• Build alternative scenarios for economies and livelihoods based on non-consumptive use (e.g., wild capture fisheries)	(Craig 2010; Di Baldassarre et al. 2013; Verma et al. 2009; Ghosh et al. 2016; Higgins et al. 2018;)

Land-Climate-Society interaction Hazard	Exposure	Vulnerability	Risk	Policy Response (Indicative)	References
		• Fishers • Endangered species and ecosystems		• Define and maintain ecological flows in rivers for target species and ecosystem services • Experiment with alternative less water consuming crops and water management strategies • Redefine SDGs to include fresh-water ecosystems or adopt alternative metrics of sustainability Based on Nature Contributions to People (NCP)	(Hall et al. 2013; Youn et al. 2014)
Depletion/ exhaustion of ground-water	Wide-spread across semi-arid and humid biomes India, China and the United States	• Farmers, drinking water supply • Irrigation • See forest note above • Agricultural production • Urban sustainability (Phoenix, US) • Reduction in dry-season river flows • Sea level rise	• Food insecurity • Water insecurity • Distress migration • Conflict • Disease • Inundation of coastal regions, estuaries and deltas	• Monitoring of emerging ground-water-climate linkages • Adaptation strategies that reduce dependence on deep ground water • Regulation of ground-water use • Shift to less water-intensive rain fed crops and pasture • Conjunctive use of surface and ground-water	(Wada et al. 2010; Rodell et al. 2009; Taylor et al. 2013; Aeschbach-Hertig and Gleeson 2012)

Land-Climate-Society interaction Hazard	Exposure	Vulnerability	Risk	Policy Response (Indicative)	References
Climate change Mitigation impacts	Across various biomes especially semi-arid and aquatic	• Fishers and pastoralists • Farmers • Endangered range restricted species and ecosystems	• Extinction of species • Downstream loss of ecosystem services Loss of livelihoods and identity of fisher/pastoralist communities • Loss of regional food security	• 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)
Competition for land e.g., Plastic substitution by cellulose, Charcoal production	Peri-urban and rural areas in developing countries	• Rural landscapes; farmers; charcoal suppliers; small businesses	• Land degradation; loss of ecosystem services; GHG emissions; lower adaptive capacity	• Sustainability certification; producer permits; subsidies for efficient kilns	(Woollen et al. 2016; Kiruki et al. 2017)
Land degradation and desertification	Arid, Semi-arid and sub-humid regions	• Farmers • Pastoralists • Biodiversity	• Food insecurity • Drought • Migration • Loss of agro and wild biodiversity	• Restoration of ecosystems and management of invasive species • Climate smart agriculture and livestock management • Managing economic impacts of global and local drivers • Changes in relief and rehabilitation policies • Land degradation neutrality	(Fleskens, Luuk, Stringer 2014; Lambin et al. 2001; Cowie et al. 2018; Few and Tebboth 2018; Sandstrom and Juhola 2017)
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. 2005; Tribbia and Moser 2008)

Land-Climate-Society interaction Hazard	Exposure	Vulnerability	Risk	Policy Response (Indicative)	References
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)
Stranded assets	Economies transitioning to low carbon pathways Coastal regions under inundation	Coal based power Large dams	• Disruption of regional economies • Unemployment • Push-back against renewable energy • Migration	• Insurance • Redevelopment using adaptation	(Farfan and Breyer 2017; Ansar et al. 2013)

7.3.3.3 Uncertainty about climate-land interactions and flexible solutions

To address, understand and ultimately cope with uncertainties in the interactions of climate, land and society, decision makers and stakeholders require an understanding 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).

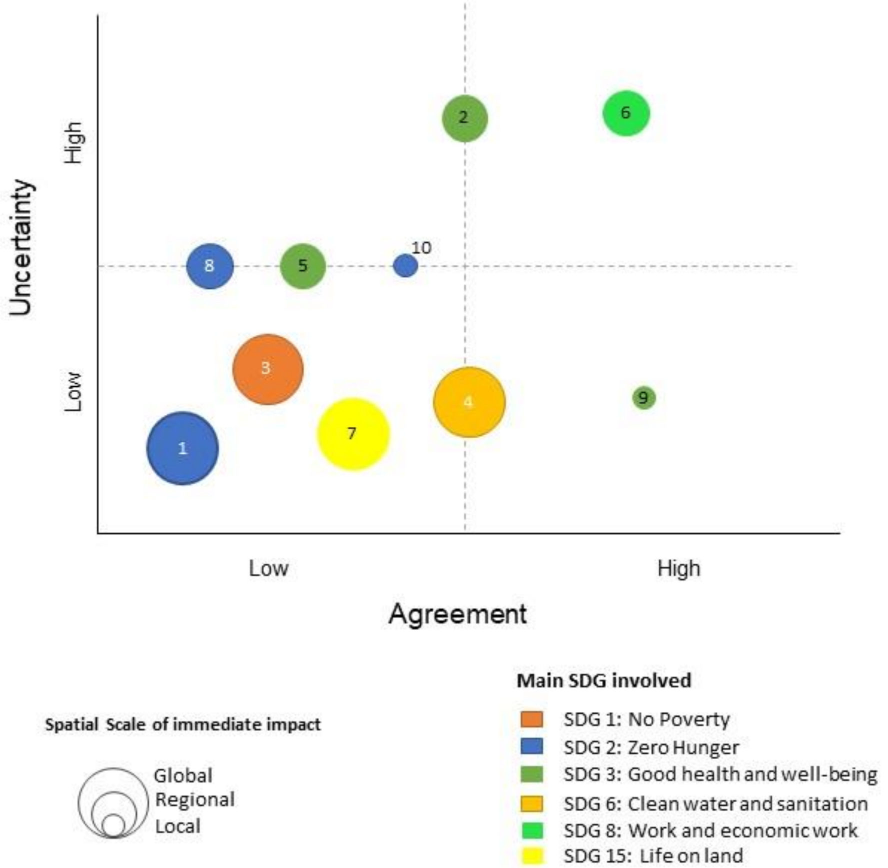
As outlined in Chapter 1, uncertainties exist in scientific observations surrounding land use and cover (Klein Goldewijk and Verburg 2013) and their associated agricultural or forest management practices (Erb et al. 2017), land and climate change model structures, parameterisations, and inputs, early warning and decision support systems and uncertainties arising from unknown futures impacting integrated assessment models and scenarios (Chapter 1). The uncertainty level is particularly acute for new technological solutions such as bioenergy plantations and bioenergy carbon capture and storage (BECCS) which are put forward to counteract climate change, which have not yet been tested at large scales (Boysen et al. 2017a,b; Robledo-Abad et al. 2017; Vaughan and Gough 2016).

In addition to the uncertainty described in Section 7.3.1.1 relating to norms, values and priorities, Chapter 1 describes uncertainties in decision making and specifically information poor decisions that go beyond uncertainty of consequence (see Chapter 1.3.3.2). There is uncertainty in the choice of pathways required to achieve the ambition of keeping global-temperature change below 1.5°C (Millar et al. 2017; Rogelj et al. 2016a). Current Nationally Determined Contributions (NDCs) contain uncertainties and currently are estimated to achieve 3°C global average temperature change (Rogelj et al. 2016b). However, uncertainty need not present a barrier to taking action, and there are growing methodological developments and empirical applications to support decision-making (see Section 7.6).

With an overview of the current and future likely risks and uncertainties emanating from climate and land change, the chapter now examines the potential consequences of these changes for human well-being and sustainable development.

7.4 Consequences of climate – land change for human well-being and sustainable development

Risks outlined above have significant social and economic ramifications for societies across the world. Figure 7.3 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 are 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 7.3. The additional SDG goals include Life under Water which is exclusively about marine life. There is no explicit SDG goal for fresh ecosystems and their ecosystem services. Therefore, these additional SDG goals were added in this chapter. Within the bubbles a number appears; in the box below the figure these numbers appear with the associated references supporting the bubble.



Example	Land-climate-society Hazard	Uncertainty (knowledge, data, evidence)	Agreement On norms, priorities and values	Spatial Scale of immediate impact	SDGs or other goals impacted or involved in mutual trade-offs	Selected Literature
1	Decline of fresh-water and riverine ecosystems	Low	Low	Global	2,3,6,7,8,12, 16 and 18	(Falkenmark 2001; Zarfl et al. 2014; Canonico et al. 2005; Higgins et al. 2018)
2	Forest browning	Medium	High	Regional	3, 8,13,15,	(Verbyla 2011; Krishnaswamy et al. 2014; McDowell and Allen 2015; Anderegg et al. 2013; Samanta et al. 2010)
3	Exhaustion of ground water	Low	Low	Regional and global	1,3,6,8,11,1 2,13,18	(Barnett and O'Neill 2010; Wada et al. 2010; Harootunian 2018; Dalin et al. 2017; Rockström et al. 2009; Falkenmark 2001)
4	Loss of biodiversity	Low	Medium	Global	6,7,12,15,18	(Pereira et al. 2010; Pascual et al. 2017; Pecl et al. 2017; Jumani et al. 2017, 2018)
5	Extreme events in cities and towns	Medium	Low	Regional	3,6,11,13	(Douglas et al. 2008; Chang et al. 2009; Li et al. 2015; Stone et al. 2010)
6	Stranded assets	High	High	Regional	8, 9,11,12,13	(Ansar et al. 2013; Chasek et al. 2015; Neumann et al. 2015; Surminski 2014; Nicholls 2004; Larsen et al. 2008; Nicholls and Cazenave 2010; Hallegatte et al. 2013)
7	Expansion of the agricultural frontier into tropical forests	Low	Low	Regional and Global	15, 13	Bogaerts et al. 2017; Fearnside 2015; Beuchle et al. 2015; Grecchi et al. 2014; Celentano et al. 2017; Soares-Filho et al. 2014
8	Food and nutrition security	Medium	Low	Local, Regional	2,1,3,10, 11	Hasegawa et al. 2017; Frank et al. (2017) and Fujimori et al. (2017)
9	Emergence of Infectious Diseases	High	Low	Local, Regional	3,1,6, 10, 11, 12, 13	Young et al. 2017; Naiker 2011; Smith et al. 2014, Tjaden et al. 2017; Young et al. 2017
10	Decrease in Agricultural Productivity	Medium	Low	Local, regional	2,1,3,10, 11, 13	Porter et al. 2014b; Rosenzweig et al. 2014

Figure 7.3 The conceptualizing key, substantive and emergent risks in relation to trade-offs to SDG and other goals

Case Study: How green is India's Climate Change Mitigation? Biodiversity Conservation vs Global Environment Targets?

Coal is an integral part of India's power sector and accounts for 60% off India's emissions and is a major source of other environmental degradation (Guttikunda and Jawahar 2014).

India made three ambitious commitments in Paris: invest in renewable energy (RE), reduce emissions in all sectors of the economy, and increase green cover. The renewable energy target was to increase the share of non-fossil-based energy resources to 40% of installed electric power capacity by 2030, with help of transfer of technology and low cost international finance including from Green Climate Fund (GCF). In the short term this meant installing by 2022 175 gigawatt (GW) of RE capacity and operationalize it, and raise by 2030 the share of non-fossil fuels in total energy use to 40 per cent. .These 175 gigawatts (GW) initially involved 100 GW of solar, 60 GW of wind, 10 GW of bioenergy and 5 GW of small hydro (SHP).

The above factors of change would mean increasing RE power capacity fivefold in seven years, making India a clean energy leader. India has also set annual targets, which chart a roadmap to achieve the 2022 goal. India has recently revised its target for 2022: 227 GW of RE possibly scaling up its ranking to the top three countries making investments in the sector. Renewable energy's share in the electricity generation mix is likely to rise to around 18 per cent by 2022, from close to 7.8 per cent as of March 2018. Backed by political will at the highest levels, remarkable progress has been made on these targets. By August 2017, India had installed 58.3 GW of RE capacity. This feat has drawn international attention and this is already leading to some negative impacts on the coal sector (Marcacci 2018).

However evidence is emerging that the pursuit of SHPs, wind and solar energy have started to have significant and perhaps irreversible impacts on biodiversity (Premalatha et al. 2014; Jumani et al. 2018; Thaker, M, Zambre, A. Bhosale 2018).

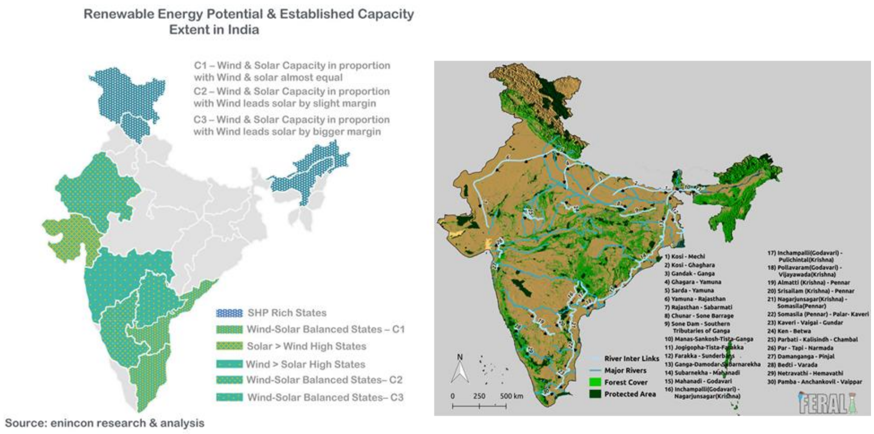


Figure 7.4 (a) India's Renewable Energy and (b) National Waterways Initiative both of which have major impacts on both aquatic and terrestrial biodiversity and ecosystem services even as they are part of India's emerging low carbon economy

SHPs were until recently considered as environmentally benign compared to large dams and is poorly understood. SHPs (<25 MW) are exempt from environmental scrutiny as it is labelled as "green". It is being promoted in global biodiversity hotspots such as the Western Ghats and the Himalayas and has changed the hydrology, water quality and ecology of head-water streams and neighbouring forests significantly. It has created dewatered stretches of stream immediately downstream of the dams and introduced sub-daily to sub-weekly hydro-pulses that have transformed the natural dry-season flow regime. It has severely impacted endemic fish communities, fragmented forests and increased human-elephant conflict in local communities in the Western Ghats and in the Himalayas it has been opposed for threats to local culture and livelihoods (Jumani et al. 2017a, 2018; Chhatre and Lakhanpal 2018).

Another unfortunate victim of India's renewable energy targets is the highly endangered Great Indian Bustard (*Ardeotis nigriceps*) whose last remaining habitats in semi-arid and arid biomes are much favoured for installing solar and wind farms whose lethal power transmission lines cause mortality of a species whose global population is now reduced to about 150 (Collar et al. 2015). The loss of habitat over the decades has been largely due to agricultural intensification driven by irrigation and bad management in designated reserves (Collar et al. 2015; Ledec, George C.; Rapp, Kennan W.; Aiello 2011) but intrusion of power lines in its last remaining refuges is a major worry for its future persistence(Government of India Ministry of Environment and Forests 2012). In general across India, wind-mills and solar farms pose a threat to many other species especially predatory birds and insectivorous bats, whose loss could impact farmers through the lack of biological control of rodent and insect pests (Thaker, M, Zambre, A. Bhosale 2018) and disrupt habitat connectivity (Northrup and Wittemyer 2013).

Additionally, conversion of rivers into waterways has been touted as a fuel-efficient (low carbon emitting) and environment-friendly alternative to surface land transport (IWAI 2016; Dharmadhikary, S., and Sandbhor 2017). India's National Waterways is funded partly by a USD 375 Million loan from the World Bank seeks to cut transportation time and costs and reduce carbon emissions from road transport (Admin 2017). However given the low water levels in India's rivers due to upstream demands and abstraction the programme relies on large scale dredging to maintain deep channels. Evidence from elsewhere suggests that dredging is likely to severely impact the water quality and human health (Martins et al. 2012) and habitat of fish species (Junior et al. 2012), disrupt artisanal fisheries and potentially cause severe threat to the endangered Ganges River Dolphin (*Platanista gangetica*), India's National Aquatic Animal (Kelkar 2016). The most severe impact of dredging and vessel traffic on this unique species is the disruption through under-water noise of the acoustic signals that the endangered and naturally blind animal relies on for navigation, foraging and communication (Dey Mayukh 2018).

Policy response to mitigation the negative impacts of climate change mitigation initiatives include changes in SHP operations and policies to enable the conservation of river fish diversity. These include mandatory environmental impact assessments, conserving remaining undammed headwater streams in regulated basins, maintaining adequate environmental flows, and implementing other mitigation measures based on experiments (Jumani et al. 2018). Location of large solar farms needs to be carefully scrutinized (Sindhu et al. 2017).

For mitigating negative impacts of power lines associated with solar and wind-farms in bustard habitat, suggested measures include diversion structures to prevent collision, underground cables and avoidance in core wildlife habitat as well as incentives for maintaining low intensity rain-fed agriculture and pasture around existing reserves and curtailing harmful infrastructure in priority areas (Collar et al. 2015). Mitigation for minimizing the ecological impact of Inland Waterways on biodiversity and fisheries is more complicated but may involve improved boat technology to reduce under-water noise, maintaining ecological flows and thus reduced dredging, and avoidance in key habitats (Dey Mayukh 2018).

A recent study carried out by the power ministry to determine the right solar-coal mix shows that India's plan to produce 55% energy from renewable sources by 2030 is overambitious and coal will continue to be an important part of India's 24X7 power goals (Saluja, N and Singh 2018). So the negative impacts of coal based power continue even as emerging renewable energy is having its own ecological trade-offs. The management of ecological trade-offs of India's existing and emerging power development projects will be crucial for long-term sustainability of India's emerging low-carbon economy.

7.4.1 Economic considerations – What is at stake?

Healthy functioning land and ecosystems are essential for human health, food and livelihood security. By the end of the first decade of the 21st century, approximately 3 billion people derived their income and employment, food, and from agriculture-related activities that are particularly sensitive to changes in climatic and land conditions and which generates between 1 and 25% of GDP for countries around the world (Dethier and Effenberger 2012). Many countries earn high percentages of GDP through commodity trading, which could be vulnerable if climate and land change contribute to declines in quality and quantity of crop yields.

Understanding the full scope of what is at stake from climate change presents challenges because of inadequate accounting of the degree and scale at which climate change and land interactions impact society, and the importance society places on those impacts (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 result in major losses in human well-being, which are not captured in economic terms.

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 global 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). 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 and land change impacts may become for societies and ecosystems upon which they depend. For example, in Central Asia, it is estimated that land degradation affects between 4–10% of cropped land, 27–68% of pasture land and 1–8% of forested land, or about 40-66% of area degraded in each country in total (Nkonya et al. 2016; Mirzabaev et al. 2016; Hamidov et al. 2016). Annual costs of land degradation due to land use and land cover change are estimated to be about USD 231 billion per year or about 0.41% of the global GDP of USD 56.49 trillion in 2007 (Nkonya et al. 2016).

Most studies show increasing effects on GDP as global mean temperatures increase. In contrast, evidence suggests that climate change and land change impacts correlate with lower economic growth: A range of studies have attempted to estimate the economic impacts of climate change across sectors, and – while the results are not directly comparable due to differences in modelling approaches, assumptions and time periods – the estimates indicate climate change negatively affects global annual average economic growth, ranging 0% of GDP to 11.5% of GDP (Tol 2014). Average global incomes could decline by 23% by 2100 with unmitigated warming (Burke et al. 2015). 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).

Some places and systems most vulnerable to certain impacts already experience negative economic consequences of climate change and land change, 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 climate change negatively affects economic activity in all regions of the world (Burke et al. 2015). Warming is likely to amplify global inequalities (*high evidence, high agreement*) (Burke et al. 2015; Tol 2018).

7.4.1.1 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 large 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).

There is a perception that acting on climate change involves trade-offs with economic growth. In contrast, ample evidence suggests that the cost of inaction in mitigation and adaptation, as well as in land use, exceeds the cost of inaction in both individual countries, regions, and worldwide (Nkonya et al. 2016). Early action on reducing emissions (mitigation) is 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, potentially reduces economic growth and increases the challenges of mitigation as well as adaptation (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).

Additional examples of the cost of action being less than the cost of inaction can be seen 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. 2018a; 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). Modelling 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 2016a). Lack of investment in early action reflects the lack of incentives to allocate funds in advance of crises (Clarvis et al. 2015; Clarke and Dercon 2016a), but evidence shows that the cost of taking action to prevent land degradation is lower than the cost of inaction (Nkonya et al. 2016). A perceived risk in responding early is that funds will be released unnecessarily for situations that turn out not to be disasters. One study suggests that donors could mistakenly fund early action six times in Mozambique before the cost is equivalent to the cost of humanitarian aid for one event (Venton et al. 2013), not measuring the benefit of continuous livelihoods, business continuity, and avoidance of poverty traps related to humanitarian crisis (Jakob et al. 2012; Coughlan De Perez et al. 2015; Kim and Guha-Sapir 2012; Bailey 2012).

Further, the costs of inaction to counteract land degradation in Central Asia are estimated to be six times greater than the cost of action in the form of sustainable land management (Hamidov et al. 2016; Mirzabaev et al. 2016). Evidence from drylands shows that sustainable land management (SLM) provides between 1.43 and 6.53 net benefit cost ratio beyond investment and management costs, using a discount rate between 2.5 and 10% (Nkonya et al. 2016).Sustainable land management practices reverse or minimize economic losses of land degradation related to ecosystem service decline, estimated at between USD 6.3 and 10.6 trillion annually, representing 10–17% per of the world's GDP (ELD Initiative 2015) and more than five times the entire value of agriculture in the market economy (Costanza et al. 2014; Fischer et al. 2017; Sandifer et al. 2015; Dasgupta et al. 2013). Sustainable land management practices can more than double the economic value of pasture land including the market value of pasture forage, current value of livestock with year-round grazing, and commodity costs of livestock product, compared with current practices (Nkonya et al. 2016). Cases of sustainable land management in drylands have shown SLM practices deliver superior economic outcomes for farmer income, stable livelihood systems that help poor communities, improved performance of hydroelectric dams due to less siltation, and more stable and increased crop yields (from 2.5 to 5% increases compared with conventional methods) (Nkonya et al. 2015b; Mythili and Goedecke 2015; Nkonya et al. 2015a; Sorokin et al. 2015).

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; 2) a clear, evidence-based decision-making process, and; 3) financing models to ensure that the plans for early action can be implemented (Clarke and Dercon 2016a).

7.4.1.2 Risks and where and how people live: Migration, Urbanisation, Social Cohesion

The First Assessment Report of the IPCC (1990) noted the relationship between climate change and human mobility, and empirical studies have accelerated since this time (Government Office for Science 2011; Laczko and Piguet 2014). There is *high agreement and medium evidence* that people move to manage risks and seek opportunities to their safety and livelihoods , recognising that people respond to weather change and climate related factors (in tandem with other variables) and people make choices to manage risks and opportunities, including choices about how and where to live (Hendrix and Salehyan 2012)(Lashley and Warner 2015; van der Geest and Warner 2014; Roudier et al. 2014).

People move towards areas offering opportunity such as in rapidly growing coastal settlements, due to drivers of urbanisation (Geddes et al. 2012; Adger et al. 2015); these burgeoning areas may also have changing exposure to climate change and land change risks such as combinations of storm surges and extreme events and sea level rise and soil subsidence and changing soil salinity. Growing urban areas attract rural population migration seeking livelihood and educational opportunities (Seto 2011) may lead to exposure to - and a state of being trapped in precarious, unsafe situations: informal settlements where migrants often first arrive in cities are among the most rapidly growing urban spaces and are often prone to hazard from fire, flooding, and landslides, in addition to often inadequate safety standards in built infrastructure and inappropriate (Geddes et al. 2012; Adger et al. 2015).

Extreme events that threaten the physical safety of people and their properties displace people, who return to their places of origin once conditions return to normal (McLeman 2013; Kaenzig and Piguet 2014; Kelly and Adger 2000; Internal Displacement Monitoring Center 2017; Warner 2018). Livelihood-related migration can accelerate in the short to medium term when weather dependent livelihood systems deteriorate in relation to changes in precipitation, changes in ecosystems, and changes in land quality (Scheffran et al. 2012b; Fussell et al. 2014; Bettini and Gioli 2016). Slow onset climate impacts and risks can exacerbate or otherwise interact with social conflict corresponding with movement at larger scales (see Section 7.3.3.2) and long term deterioration in habitability of regions could trigger spatial population shifts (Denton et al. 2014).

Box 7.2 ENSO, Emerging Risks and Sustainable Land Management

El Nino Southern Oscillation is an ocean-atmosphere phenomenon in the tropical Pacific, occurring every few years. The El Nino Southern Oscillation (ENSO) which occurs quasi-periodically influences climate, agriculture, forests, fisheries, ecosystems and societies regionally and globally(GFDRR World Bank Group 2016; Wang et al. 2016a; Verburg et al. 2015; Allison et al. 2009). It is one of the most important sources of variability in the global carbon and regional water cycles (Kumar et al. 2006; Cox et al. 2000). The future of this phenomena under climate change (Cane 2005) and its implications for sustainable land management and adaptation under future warming is therefore of special interest and concern (Narita and Quaas 2013).

The El Nino of 2015/2016 which impacted several hundred millions of people around the world and caused forest fires, drought and loss of agricultural productivity was one of the strongest tropical climate events in the last hundred years, 20 years after the very strong 1997–1998 event and was associated with a record rise in CO_2 (Betts et al. 2016; Wolter and Timlin 1998). Amongst its other health effects it was also specifically responsible for spread of Zika virus (Paz and Semenza 2016).

Furthermore the interaction of this phenomena with land-use under future climate is likely to influence the success or failure of mitigation and adaptation at diverse temporal and spatial scales (Betts et al. 2016; Cai et al. 2015b; Cane 2005; Paz and Semenza 2016; Wolter and Timlin 1998).

Climatologically western tropical Pacific is warmer with lower atmospheric pressure, deeper convection and higher rainfall and, the east is cooler with higher pressure and lower rainfall. The pressure gradient between the east and west Pacific enables the east to west trade winds. During El Nino events anomalous warming occurs in the central and eastern tropical Pacific moving with it the deep convection and lower pressure, consequently, weakening the trade winds. The associated Walker circulation impact seasonal weather across the tropics. The changes in location of the convection forces large scale atmospheric Rossby waves that propagate into the extratropics – thus influencing northern hemisphere climate (Horel and Wallace, 1981; Karoly 1989). There is a growing body of literature documenting the teleconnections of ENSO to seasonal climate across the globe (Trenberth et al., 1998).

Multidecadal variability of ENSO and the global teleconnections to regional climate and various sectors have been documented from observations and paleo-proxy data (Diaz and Markgraf, 2000, Rajagopalan et al., 1997). The ENSO amplitude exhibits a quasi-periodic variability over the past millennium (Li et al., 2011). These findings indicate a strong natural variability and furthermore, offers a key observational constraint for improving models and their prediction of ENSO behaviour linked to global warming.

Two flavours of ENSO have been identified in recent years – Central Pacific (CP) and Eastern Pacific (EP). These flavours correspond to the respective location of warm sea surface temperatures during El Nino events. The EP flavour is the more canonical El Nino pattern while the CP flavour is referred as Modoki (Ashok et al., 2007). Depending on the location of the warm SSTs different teleconnection responses are produced. The CP flavour, even of modest magnitude, is shown to be of consequence in producing droughts over India (Kumar et al., 2006). Northern hemisphere atmospheric teleconnections and consequently the seasonal climate are strongly influenced by the flavour of ENSO related warming (Hoerling and Kumar, 2002). The identification of flavours of ENSO in recent years is an important advancement, for it provides nuanced insights into ENSO dynamics and teleconnections – thereby, enabling skilful predictive systems. For a comprehensive review of ENSO refer to Wang et al. (2016).

In order to understand and model the climate variability globally under warming conditions, an important research question is – what will be variability of ENSO and specifically that of the flavours? Paleo-proxy data over the past ~10,000 years indicate a preference for CP flavour during mid-Holocene (Carre et al., 2014). Since mid-Holocene period was warmer than present this could offer insights into the potential preference between the two flavours during a warmer climate in the future.

The current knowledge of changes in ENSO under global warming remains uncertain. Increasing greenhouse gases change the mean states in the tropical Pacific – which is uncertain, hence, the induced ENSO changes. Due to cancellation among the ocean and atmospheric mechanisms the models do not amplify El-Nino conditions (DiNezio et al., 2009, 2010). Thus, a “permanent El Niño” in response to global warming is very unlikely, even if the Walker circulation weakens, as the models seem to suggest. Instead, climate models indicate that the equatorial Pacific may warm slightly more than the tropics due to the effect of the weakening of the Walker circulation and a differential in evaporative damping with the off-equatorial tropics (Liu et al. 2006; DiNezio et al. 2009).

In a recent article authors considered the atmospheric teleconnections of recent El Niños and their variability in the future under a warming climate. They show that the center of ENSO has shifted to the west from 1979–1997 to 1998–2015 – and that the amplitude of El Niño events weakened in recent decades compared to earlier. This indicates that the ENSO properties - spatial pattern and amplitude, change substantially at lower-frequency time scales. The diversity of ENSOs affect the predictability of teleconnections – for the teleconnections are sensitive to the longitudinal location of deep convection in the equatorial Pacific, which vary with ENSO flavour (Yeh 2018). Under warmer climate the models do not exhibit consensus on the ENSO variability and thus, the teleconnections. This is mainly due to model deficiencies in capturing the Inter Tropical Convergence Zone (ITCZ) dynamics in the equatorial Pacific. This is an area of active research. However, the models suggest eastward migration of convection during El Nino and La Ninas with warming climate which will cause the ENSO-forced Pacific North American (PNA) teleconnections to shift eastward and to intensify. The models also suggest increase in frequency of extreme ENSO events. All of this will likely cause more severe droughts and floods globally, but specifically in the tropical Pacific and polar regions. Climate modelling evidence, from simulations indicate a near doubling in the frequency of future extreme La Niña events, from one in every 23 years to one in every 13 years (Cai et al. 2015a)

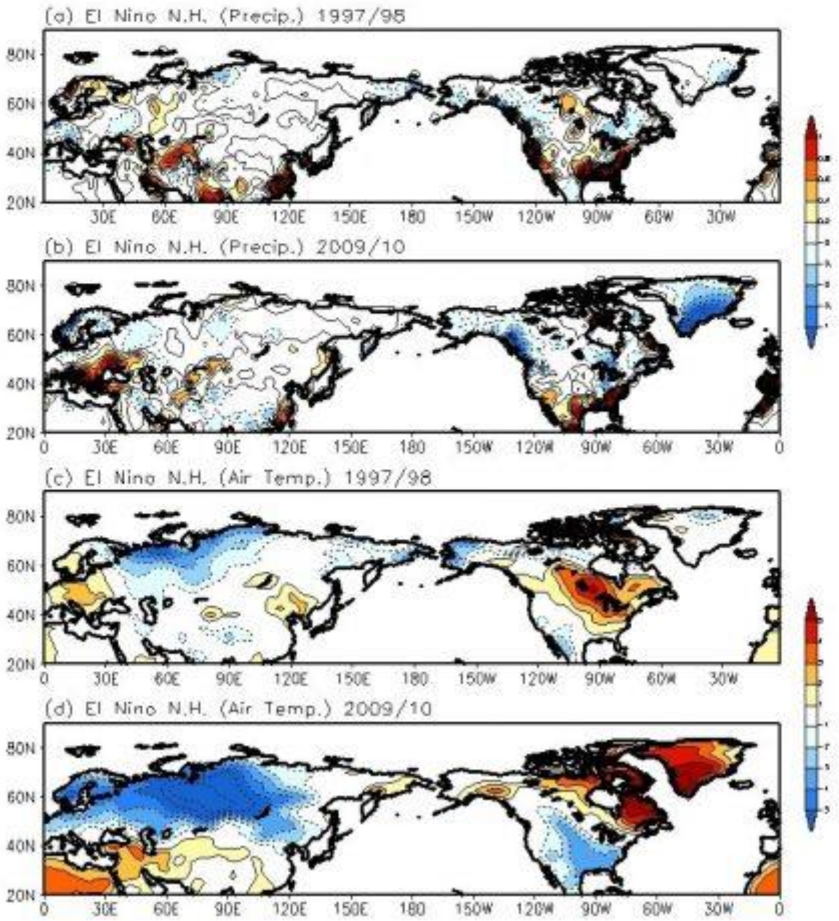


Figure 7.5 Precipitation (upper two figures) and air temperature (lower two figures) anomalies for two distinctive 1997/1998 El Niño (classified as EP El Niño) and 2009/2010 El Niño in the Northern Hemisphere during boreal winter. The spatial pattern of precipitation and surface air temperature anomalies in response to the EP El Niño was quite different from that in response to the CP El Niño in the Northern Hemisphere. Credit: Sang-Wook YehYeh, S.-W. (2018)

Thus there are four aspects of ENSO that are emerging in recent years: the diversity of ENSO as a phenomena and the spatial variability in its influence regionally and globally and complex, non-stationary and non-linear relationship with regional climate such as the Monsoon. (Krishnaswamy et al. 2015) and finally lack of consensus on its future under a warming climate (Yeh 2018). With the current state of knowledge, therefore, it is difficult to say whether ENSO will intensify or weaken, but it is very likely that ENSO will not disappear in the future.

Policy and Response options

Early warning systems for strong ENSO events have improved considerably but high uncertainty exists in our ability to predict which regions or sectors will be impacted in a particular year (Wilkinson et al. 2018b; Anderson et al. 2018; Yeh 2018).

Response options once a forecast has been made have included reinforcement of river banks in Somalia in anticipation of floods, increase the resilience of households, communities and institutions to prevent and address disaster risks that affect agriculture and food and nutrition security in a timely and efficient manner (GFDRR World Bank Group 2016).

This box will further illustrate the scenarios of emerging and cascading risks and possible policy responses at global scales, locally and regionally across diverse socio-ecological systems and sectors from ecosystems and forests to agriculture and human health from changes in the intensity of ENSO

(El Nino/La Nina) under future climate and land scenarios. These will include short term and long term policy responses.

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 affects political tension and links to violent conflict (Barnett and Adger 2007; Scheffran et al. 2012a; Nordaas and Gleditsch 2015). 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 exacerbate tensions 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 disadvantaged or otherwise vulnerable 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).

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.

Box 7.3 Tipping points to illustrate complex problems, deep uncertainties, unknown unknowns

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 (Brook et al. 2013; Scheffer 2010; Benton et al. 2017) - exist in major earth systems. Climate tipping points involve large non-linear effects of small changes in forcing in the internal dynamics. Tipping point examples include irreversible melt of the Greenland ice sheet, dieback of the Amazon rainforest and shift of the West African monsoon (Lenton 2011) (*Medium confidence, high uncertainty*). Although there is low certainty about thresholds, there is *high confidence* that tipping points will be reached in climate scenarios exceeding 1.5°C. Recent evidence event suggests that the Earth System may have already crossed a planetary threshold in the glacier-interglacial cycle, and that at 2°C the Earth may irreversibly enter a “hothouse Earth pathway” (Steffen et al. 2018).

Tipping points may be influenced by biophysical feedbacks from land-climate systems such as permafrost thawing, increased microbial respiration from warming soil and forest dieback(Steffen et al. 2018). Regional large scale forest die back from climate change induced moisture stress and increase in fire frequency and intensity is predicted over Amazonia, Australia, Boreal and Tropical Mountains (Malhi et al. 2009; Adams 2013; Krishnaswamy et al. 2014). This may result in a positive feedback cycle increasing climate change (Nepstad et al. 2008) and other hazards such as malaria and Zika (Barros and Honório 2015; Paz and Semenza 2016). Irreversible tipping points for the Amazonian rainforest are predicted if total deforested area is greater than 40% . This risk increases if global warming ($\Delta T > 3–4$°C) occurs (Nobre and Borma 2009). The frequency of forest fire and drought may increase the likelihood of exceeding a tipping point but this could be counterbalanced by CO_2 fertilization effects, although its effectiveness under warming and droughts is highly uncertain (Nobre and Borma 2009; Nobre et al. 2016).

Other climate related tipping points with impacts for land-systems include shifts in monsoon and regional rainfall patterns due to complex changes in their relationship with large scale phenomena such as ENSO (Krishnaswamy et al. 2015; Turner and Annamalai 2012). However there is high uncertainty of future climate changes due to inability of climate models to currently capture dynamics and observed trends in climate phenomena like the South Asian Monsoon (Saha et al. 2014).

As outlined in Chapter 5, radical and potentially irreversible shifts in coupled biophysical and social systems impact food security. Land degradation alone is projected to reduce global food production by 12% (Pardey et al. 2014; Lal 2016; Ray et al. 2013). Each degree of global mean temperature increase (Celsius) may reduce global yields of wheat by 6%, rice yields by 3.2%, and maize by 7.4% (Zhao et al. 2017), while CO_2 fertilization effects will impact nutrition. Mitigation strategies such as carbon dioxide removal (CDR) can compete with other land uses and significantly impact food systems Figure 7.2B. Such combined interactions of land, climate change and society may bring systems close to tipping points . 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 (Kandlikar et al. 2005).

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. While clarity about policy options is reduced (Lemoine and Traeger 2010), robust methods for decision making under uncertain global and regional changes are emerging (Haasnoot et al. 2013; Kalra et al. 2014). Resilience building strategies that maintain diversity, redundancy, connectivity and learning can help ensure systems ensure stability (*high certainty, high evidence*). Reducing greenhouse gases and enhancing or creating carbon sinks can strengthen negative feedbacks (Steffen et al. 2018). In Amazonia, managing fire regimes as the forest dries out and reducing deforestation through changes in crop choice and food systems could help avert critical transitions (Nepstad et al. 2008, 2014). Social and technological innovations connected to broad institutional resources have the potential to avoid pathways to tipping points with adverse consequences (*medium confidence*) but need nurturing (Westley et al. 2011). Scenarios, projections and early warning systems play a role in planning for adaptation and mitigation under deep uncertainty and potential tipping points. Ultimately, tipping points offer both challenges and opportunities for mitigation (Biermann et al. 2012) and adaptation to emerging novel ecosystems (Hallett et al. 2013),

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. 2017b). 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).

7.5 Policy Response to Risk

This section outlines policy responses to risk. It describes multi-level policy response to risk (0), policy instruments for social protection (7.5.2), policies responding to hazard (7.5.3), GHG fluxes (7.5.4), desertification (7.5.5), land degradation (7.5.6), policies for food security (7.5.7), enabling effective policy instruments through policy mixes (7.5.8), and barriers to sustainable land management and overcoming these barriers (7.5.9).

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 social net benefits. (Pannell 2008) provides a widely-used framework for identifying the appropriate type of instrument depending on whether the actions encouraged by the instrument 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 adaptations, 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 Pannell's (Pannell 2008) framework is useful, 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) 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 7.6.7, 7.7.4). A thorough analysis of the implications of policy instruments temporally, spatially and across other sectors and goals (e.g., climate v. development) is essential before implementation to avoid unintended consequences and policy incoherence (7.5.8).

7.5.1 Policy Response to Multi-Level Risks to Society from Climate – Land Interactions 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/sub-national policy frameworks (Corfee-Morlot et al. 2009).

This section of the chapter identifies policies by level that respond to land and climate risks. As risk management in relation to land and climate occurs at multiple levels by multiple actors, and across multiple sectors in relation to hazards (as listed on Table 7.2), risk governance, or the consideration of the landscapes of risk arising from Chapters 2 through 6 is addressed in Section 7-6. 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 comprehensive, portfolio of instruments and 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) (see 7.5.8, 7.6.7, and 7.7.3).

Climate related risk could be categorised by climate impacts 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, food insecurity, land degradation and desertification, and hazards (flood, drought, forest fire), and GHG fluxes (climate mitigation).

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 and 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					X
	Regional Forestry strategy			X				X	
National	Forest Protection Policy/Plans		X			X		X	X
	Land degradation neutrality								
	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
	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	
Local	Waste to energy/Bio-methanation				X				X
	Flood plans/ zoning / management					X			
	Relocation and migration policies					X			
	Spatial planning and integrated land use 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	

7.5.2 Policies for Social Protection

Safety nets and social protection schemes can substantially reduce poverty, particularly because they provide a way for vulnerable groups to manage weather and other shocks to household income and assets *(Strong evidence, high agreement)* (Baulch et al. 2006; Barrientos 2011; Harris 2013; Fiszbein et al. 2014; Kiendrebeogo et al. 2017; Kabeer et al. 2010; World Bank 2018). The World Bank estimates that globally social safety net transfers have reduced the absolute poverty gap by 45 percent and the relative poverty gap by 16 percent (World Bank 2018). Adaptive social protection builds household capacity to deal with shocks as well as the capacity of social safety nets to respond to shocks.

There is *high agreement and medium evidence* that a combination of structural and non-structural policies is required in responding to land and climate change risk. 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).

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. 2018a; O'Brien, C.O., Scott, Z., Smith, G., Barca, V., Kardan, A., Holmes, R. Watson 2018). There is increasing evidence that forecast-based financing, linked to a social protection, can be used to enable anticipatory actions based on forecast triggers and guaranteed funding ahead of a shock (Jjemba et al. 2018). 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. 2018a; O'Brien, C.O., Scott, Z., Smith, G., Barca, V., Kardan, A., Holmes, R. Watson 2018).

Countries at high-risk of natural disasters often have lower safety net coverage (World Bank 2018). Social protection systems have also been seen as an unaffordable burden on the public budget in many developing and low-income countries (Harris 2013). National systems may be rather patchworked and piecemeal. For example, Liberia and Madagascar each have five different public works programs, each with different donor organisations and different implementing agencies (Monchuk 2014). These implementation shortcomings mean that positive effects of social protection systems might not be robust enough to shield recipients completely against the impacts of severe shocks or from long-term losses and damages from climate change (*high agreement, limited evidence*) (Davies et al. 2009; Umukoro 2013; Béné et al. 2012; Ellis et al. 2009).

There is increasing support for establishment of public-private safety nets to address climate related shocks which are augmented by proactive preventative (adaptation) measures and related risk transfer instruments that are affordable to the poor (Linnerooth-Bayer and Mechler 2006). Studies suggest that adaptive capacity of communities have improved with regard to 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). 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.

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) and Pakistan . The R4 Rural Resilience Program in Ethiopia is a widely cited example of a program that serves the most vulnerable and includes aspects of resource management, access by the poor to financial services including insurance and savings (Linnerooth-bayer et al. 2018a). 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) to complement informal risk sharing, reducing the risk of lost revenue associated with variations in crop yield, and provide an alternative to classic insurance (Bogale 2015; Conradt et al. 2015; Dercon et al. 2014; Greatrex et al. 2015; Mcintosh et al. 2013). The ability of insurance to contribute to adaptive capacity 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). In Europe, modelling suggests that insurance incentives such as vouchers would be less expensive than total incentivised damage reduction and may reduce residential flood risk by 12% in Germany and 24% by 2040 (Hudson et al. 2016).

7.5.3 Policies Responding to Hazard

7.5.3.1 Risk Management Instruments

Risk management addressing climate change has broadened to include mitigation, adaptation and disaster preparedness in a process of risk management through instruments facilitating contingency and cross sectoral planning (Hurlimann and March 2012; Oels 2013), 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, and 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). Iterative risk management is an on-going process of assessment, action, reassessment and response (Mochizuki et al. 2015) (see 7.6.2 and 7.7.3). This will be important for developing responsive policies in a changing environment. However, gauging effectiveness of policy instruments is challenging. Timescale may influence outcomes. To evaluate effectiveness researchers, program managers and communities strive to develop consistency, comparability, comprehensiveness and coherence in their tracking. In other words, practitioners 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).

Many risk management policy instruments are referred to by the International Organization of Standardization which lists risk management principles, guidelines, and frameworks for explaining the elements of an effective risk management program (ISO 2009). The standard provides practical risk management instruments 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 (see 7.5.2 and 7.5.6) 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). Insurance instruments can also 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 when assessing if policy instruments are promoting livelihood capitals and contributing to the resilience of people and communities (Hurlbert 2018b). This holistic consideration of policy instruments leads to a consideration of risk governance (see 7.7).

7.5.3.2 Drought

A comprehensive review of drought instruments is provided in Chapter 3 Section 3.8.5. Three broad approaches for responding to droughts are identified and policy instruments outlined. These include response to the disaster of droughts providing early warning systems, crop insurance, and disaster response ex-ante preparation (through drought preparedness plans), and drought risk mitigation (proactive polices to improve water use efficiency, make adjustments to water allocation, funds or loans to build technology such as dugouts or improved soil management practices).

The feedbacks between drought and people are not fully understood and therefore drought management is often inefficient, Because of this, 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. Effective drought preparedness instruments are those that address the underlying vulnerability associated with the impacts of drought thereby building agricultural producer adaptive capacity (*high confidence*) (Wilhite et al. 2014).

There is *medium agreement* and *limited evidence* that 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 drought plans function or reduce vulnerability and to what extent these drought plans incorporate risk management theory and practice (Fu et al. 2013).

7.5.3.3 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, dynamics of local meteorology, 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, or run off erosion prevention (Rocca et al. 2014). There is *high agreement and robust evidence* that 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).

7.5.3.4 Flood

Flood risk management consists primarily of 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. Consequently, governments need to provide stimuli including taxes, subsidies that do not encourage perverse behaviour (such as rebuilding in flood zones), flood insurance, marketable permits and transferable development rights (see case study on Flood and Food Security in Section 7.7). These instruments can provide price signals to stimulate autonomous adaptation, countering barriers of path dependency, and the time lag between private investment decisions and consequences (Filatova 2014). To build resilience, consideration needs to be made of policy instruments responding to flood including flood zone mapping, land use planning, flood zone building restrictions, business and crop insurance, and disaster assistance payments, and preventative instruments including environmental farm planning (including soil and water management (see Chapter 6)) 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).

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

A variety of economic instruments are used to address impacts from climate change. Grants, green bonds, debt financing, payment for ecosystem services, risk insurance, taxes, fees and equity financing are just some of the instruments currently used (Hunzai et al. 2018). It is important that all available approaches and their limitations are considered (S. Surminski 2016; Swenja Surminski, Bouwer, and Linnerooth-Bayer 2016; Linnerooth-bayer et al. 2019) . One way to organise assessment 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, noting that adapting to climate change and reducing risk are very different from disaster response (Vincent et al. 2018). The latter category includes several contingency finance approaches, with finance from donors (public and private), national savings, or sovereign debt-based finance (contingent credit/loan, after-event bonds). Another way of organising analysis extends between risk (in advance of an event) financing and loss (following an event) financing. Measures in advance of events 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 a useful concept to help select financial instruments for comprehensive climate risk management. Governments and citizens define limits of what they consider normal risks, risks for which market solutions can be developed and catastrophic risks that require public protection and intervention. Different financial tools may be used for these different categories of risk or phases of the risk cycle (preparedness, relief, recovery, reconstruction). For example, catastrophe bonds might be appropriate 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).

Bonds are high-yield debt instruments that facilitate the raising of capital from investors for a corporate or government entity. In the case of sovereign Catastrophe (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 2016; 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 2016). Green bond CAT bonds and their thresholds are designed using specialised models taking into account historical weather, likelihood of occurrence and crop (or other variable) prices (Sun et al. 2015). The primary advantage of CAT bonds is their ability to quickly disburse money in the event of a catastrophe (Estrin and Tan 2016). Green bonds, social impact bonds, and resilience bonds are other instruments that being developed to fund land based interventions. However, there are significant barriers for developing country governments to enter into the 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 bonds is currently largely limited to higher-income developing countries (Campillo, G., Mullan, M., Vallejo 2017; Le Quesne 2017).

Another risk transfer instrument is insurance. Coverage is much broader in developed than developing countries (Marie-Justine Labelle Matthew Johns and Morris 2016). Insurance also faces challenges around market imperfections, low insurance education/capacity, low affordability and accessibility (Mechler et al. 2014). Micro-insurance schemes almost always need to subsidized by donors, taxpayers or, international financial institutions (Mechler et al. 2006; Schäfer and Waters 2016). India's National Agricultural Insurance Scheme (NAIS), is one of the largest micro-insurance crop program but is heavily subsidized by Indian taxpayers (Mechler et al. 2006). Significant debates exist to whether or not insurance can contribute to risk reduction or simply risk spreading (Linnerooth-bayer et al. 2019). Finally, insurance is used most often for rapid onset events such as floods. The utility of insurance for slow onset risks such as desertification or land degradation is less clear (Linnerooth-bayer et al. 2019)

In a catastrophe risk pool, multiple countries in a region pool risks in a diversified portfolio. Examples include ARC, CCRIF, and PCRAFI (Bresch et al. 2017). The African Risk Capacity (ARC) was established by the African Union in 2012 as a Specialized Agency. ARC's mandate is to help Member States improve their capacities to plan, prepare, and respond to extreme weather events and natural disasters, helping protect food security (Iyahen and Syroka 2018). ARC combines early warning systems with contingency planning and insurance. To participate, countries must define their risks, develop plans for action if a payment is made and determine risk transfer parameters for payouts. Eight governments participated in ARC's drought risk pool – Kenya, Mauritania, Niger, Senegal, The Gambia, Burkina Faso, Mali, and Malawi—paying premiums from their national budgets. In three years of operation, ARC Ltd. made payouts of over USD 36 million to four countries. These payouts have been used to assist over 2.1 million food insecure people and provide over 900,000 cattle with subsidized feed in the affected countries (Iyahen and Syroka 2018).

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 to eligible governments by the World Bank via International Bank for Reconstruction and Development-. 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. It is less suitable for higher impact events and is likely to become infeasible for multiple, high cost events. 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).

Increasingly there is recognition that in order to protect lives and livelihoods early action is critical, including a coordinated plan for action agreed in advance; a fast, evidence-based decision-making process and financing on standby to ensure that the plan can be implemented (Clarke and Dercon 2016b). Forecast-based finance mechanisms incorporate these principles, using climate or other forecasts to trigger funding and action prior to a shock (Wilkinson 2018). Forecast-based mechanisms can be linked with social protection systems by providing contingent scaled-up finance quickly to vulnerable populations following disasters, enhancing scalability, timeliness, predictability and adequacy of social protection benefits (Wilkinson 2018; Costella et al. 2017; World Food Programme 2018).

7.5.4 Policies Responding to GHG fluxes

7.5.4.1 GHG fluxes and climate change mitigation

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). A significant gap still exists between NDCs and achieving commitments to keep global warming well below 2°C (Höhne et al. 2017; Rogelj et al. 2016b) creating a significant risk of global warming impacting land degradation, desertification, and food security (see 7.3). Although NDCs constitute only one third of the emission reductions needed to be on the least cost pathway for the goal of staying well below 2˚C, action can be taken by 2030 adopting already known cost effective technology (United Nations Environment Programme 2017), improving the finance, capacity building, and technology transfer mechanisms of the UNFCCC, improving food security (listed by 73 nations in their NDCs) and nutritional security (listed by 25 nations) (Richards, M., Bruun, T.B., Campbell, B.M., Gregersen, L.E., Huyer 2015).

One important policy initiative to advance climate mitigation policy coherence (see 7.5.8) and the effectiveness of policy instruments in this section is the phase out of subsidies for fossil fuel production. The G20 agreed in 2009, and the G7 in 2016 agreed to phase out these subsidies by 2025. Subsidies include lower tax rates or exemptions and rebates of taxes on particular consumers (diesel fuel used by farming, fishing etc.), types of fuel, or how fuels are used. The OECD estimates the overall value of these subsides to be between USD 160-200 billion annually between 2010 and 2014 (OECD 2015). The phase out of fossil fuel subsidies has important economic, environmental and social benefits. (Coady et al. 2017) estimate that fossil fuel subsides, economic, and environmental benefits of reforming them are valued at 4.9 trillion in 2013, and 5.3 trillion in 2015. Eliminating subsides could reduce emissions by 21% in 2013 eliminate 55% of fossil fuel air pollution deaths, raise 4% revenue and improve social welfare (Coady et al. 2017).

Potential legal instruments are available to advance climate change mitigation including human rights, and legal liability. 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 human 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).

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 Least Developed Countries, Small Island Developing States, and African States and 3 million USD for development of National Adaptation Plans (GCF (Green Climate Fund) 2017; Brechin and Espinoza 2017)).

7.5.4.2 Financing mechanisms

Estimates of adaptation range from 140 billion to 300 billion USD by 2030, and between 280 billion and 500 billion USD by 2050; (UNEP 2014). While 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) There is a gap between global adaptation needs and available funds (*medium confidence*) (Chambwera et al. 2014a). 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). In 2015, 95% of reported climate finance related to mitigation (Klein Goldewijk and Verburg 2013), although in the land sector the balance is more even, possibly because of the potential for synergies between mitigation and adaptation (Locatelli et al. 2016). The dominance of finance for mitigation disregards the financing needs of vulnerable countries with minimal GHG emissions. The Special Report on Global Warming of 1.5°C emphasizes that there is an urgent need to increase volume of financing, change patterns of investment, the type and structure of financial institutions (Hoch 2017). Other means of implementation, including technology transfer or capacity building, are critical in addition to finance.

Most public finance provided to developing countries flows through bilateral and multilateral institutions such as the World Bank, the International Monetary Fund, International Finance Corporation, regional development banks, as well as specialized multi-lateral institutions such as the Global Environmental Fund, and the EU Solidarity Fund. The Green Climate Fund (GCF) now offers additional finance, but 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). 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 (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).

Of these climate finance sources, the amount of funding dedicated to agriculture, land degradation or desertification is very small compared to total climate finance. 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, between mitigation, adaptation, and increased productivity, such as through Climate Smart Agriculture (CSA), (Lipper et al. 2014a), may leverage greater financial resources (Suckall et al. 2015; Locatelli et al. 2016). Payments for Ecosystem Services are another emerging area to encourage environmentally desirable practices, although they need to be carefully designed to be effective (Engel and Muller 2016).

7.5.4.3 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, subsidies that offer a guaranteed price for future emission reductions, 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) (Bodnar et al. 2018). Price floors can maximize the climate impact per public dollar while incentivizing private investment in low-carbon technologies, and ideally would be implemented in conjunction with complementary policies such as carbon pricing.

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). African Risk Capacity has developed the Extreme Climate Facility, which is designed to complement existing bilateral, multilateral and private sources of finance to enable proactive adaptation (Vincent et al. 2018). It incentives adaptation and disaster risk reduction actions without creating the "moral hazard" sometimes associated with traditional insurance. 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.

7.5.4.4 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) – 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 result 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, fuel tax, and a cap and trade system are 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 could 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).

A fuel tax has reduced emissions in the transportation sector (Rivers, Nicholas, Schaufele 2015). There is *high agreement and medium evidence* that a carbon tax, if designed properly, can reduce GHG emissions in multiple sectors with the advantage of environmental effectiveness at relatively low cost (Metcalf and Weisbach 2009; Martin et al. 2014; Baranzini et al. 2017). One study identifies that a carbon tax in the United States could reduce a large proportion (between 80% and 90%) of emissions for a small additional cost (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 2011).

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). Cap and trade systems on average earmark more of their revenues to environmental or other spending while carbon tax revenue on average is used in general funds or returned to the public (Carl and Fedor 2016).

Poorly designed cap and trade systems 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). It may be that cap and trade limits innovation in comparison to a carbon tax as there is little incentive to invest in larger improvements (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, expansion has recently occurred in China (Deng et al. 2018), Korea (Suk et al. 2017), and Japan (Wakabayashi and Kimura 2018).

Australia’s Carbon Farming Initiative has generated real and additional emission reductions (Verschuuren 2017) through the creation of an Emissions Reductions Fund for projects avoiding emissions and sequestering emissions. Key success factors are a reliable policy that provides certainty for at least ten to twenty years, regulation that focuses on projects and not uniform rules, automated systems for all phases of the projects, and a wider focus of the carbon farming initiative on adaptation, food security, sustainable farm business, and creating jobs (Verschuuren 2017).

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 NDCs (UNFCCC (United Nations Framework Convention on Climate Change) 2016). It sets out several options for international cooperation including internationally transferred mitigation outcomes, a centralised, international crediting mechanism under the governance of the UNFCCC to contribute to both mitigation and sustainable development, and a framework for non-market approaches to sustainable development as a means of facilitating improved coordination and exploiting synergies across non-market-oriented policy instruments and institutional arrangements (Obergassel 2017). These approaches could facilitate co-benefits for land and climate as included are any combination of measures or instruments related to adaptation, mitigation, finance, technology transfer and capacity-building (Thamo and Pannell 2016; Olsson et al. 2016; Schwartz et al. 2017).

Case study: Including agriculture in the Emissions Trading Scheme in New Zealand

Although agriculture accounts for a quarter of global anthropogenic emissions (Smith et al. 2014c), achieving significant emissions reductions in this sector has remained challenging to date, with valid concerns regarding global food security (Frank et al. 2017) and livelihoods. Given the proportion of emissions originating from agriculture, and the urgency of action across all sectors (IPCC 2018a), exploring a variety of mechanisms to achieve emissions reductions will be important.

An emission trading scheme (ETS) has a number of advantages over regulatory based instruments, but primarily economic efficiency, in that it encourages the least-cost abatement (Somanathan et al. 2014). Firms with lower abatement costs are expected to sell their allowances to firms with higher abatement costs, and emissions are theoretically reduced at the lowest cost.

While several countries and regions have ETSs in place (for example the EU, Switzerland, the Republic of Korea, Quebec in Canada, California in the USA (Narassimhan et al. 2018), none have included non-CO_2 (methane and nitrous oxide) emissions from agriculture. For most developed countries agriculture is a small proportion of developed countries' emissions profiles.

New Zealand however has a high proportion of agricultural emissions (49% (Ministry of the Environment 2018), the next highest developed country agricultural emitter is Ireland at around 32% (EPA 2018), and is considering to incorporate agricultural non-CO_2 gases into the existing national ETS. In the original design of the ETS in 2008, agriculture was intended to be included from 2013, but successive Governments deferred the inclusion (Kerr and Sweet 2008) due to concerns about competitiveness, lack of mitigation options and the level of opposition from those potentially affected (Cooper and Rosin 2014). Now though, as the country's agricultural emissions are 12% above 1990 levels, and the country's total gross emissions have increased 19.6% above 1990 levels (New Zealand Ministry for the Environment 2018), there is a recognition that without any targeted policy for agriculture, only 52% of the country's emissions face any substantive incentive to mitigate (Narassimhan et al. 2018). Including agriculture in the ETS is one option to provide incentives for emissions reductions in that sector. Other options are discussed in Section 7.5.4. Although some producer groups raise concern that including agriculture will place New Zealand producers at a disadvantage compared with their international competitors who do not face similar mechanisms (New Zealand Productivity Commission 2018a), there is generally greater acceptance of the need for climate policies for agriculture.

The inclusion of non-CO_2 emissions from agriculture within an ETS is potentially complex however, due to the large number of buyers and sellers if obligations are placed at farm level, and different choices of how to estimate emissions from biological systems in cost-effective ways. New Zealand is currently investigating practical and equitable approaches to include agriculture through advice being provided by the Interim Climate Change Committee (ICCC 2018a). Main questions centre around the point of obligation for buying and selling credits, where trade-offs have to be made between providing incentives for behaviour change at farm level and the cost and complexity of administering the scheme (Agriculture Technical Advisory Group 2009a; 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 limited 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 could result in high transaction costs (Beca Ltd 2018).

Monitoring, reporting and verification (MRV) of agricultural emissions presents another challenge especially if emissions have to be estimated at farm level. Again, trade-offs have to be made between accuracy and detail of estimation method and the complexity, cost and audit of verification (Agriculture Technical Advisory Group 2009b).

The ICCC is also exploring alternatives to an ETS to provide efficient abatement incentives (ICCC 2018b).

Some discussion in New Zealand also focuses on a differential treatment of methane compared to nitrous oxide, Methane is a short-lived gas with a perturbation lifetime of twelve years in the atmosphere; nitrous oxide on the other hand is a long-lived gas and remains in the atmosphere for 114 years (Allen et al. 2016). Long-lived gases have a cumulative and essentially irreversible effect on the climate (IPCC 2014b) so their emissions need to reduce to net-zero in order to avoid climate change. Short-lived gases however could potentially be reduced to a certain level and then stabilised and would not contribute further to warming, leading to suggestions of treating these two gases separately in the ETS or alternative policy instruments, possibly setting different budgets and targets for each (New Zealand Productivity Commission 2018b). Reisinger et al. (2013) demonstrate that different metrics can have important implications globally and potentially at national and regional scales on the costs and levels of abatement.

While the details are still being agreed on in New Zealand, almost 80% of NDCs committed to action on mitigation in agriculture (FAO 2016), so countries will be looking for successful examples.

7.5.4.5 Technology transfer and land use sectors

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, utilize, 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 organizational 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 organizational 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). Intellectual property rights are often ill suited to provide socially beneficially innovation for poorer farmers and rarely help to address the causes that impede technology diffusion in developing countries (Lybbert and Sumner 2012; Baker, Dean; Jayadev, Arjun; Stiglitz 2017). The number of patents in developing countries remain low and the relationship between providing and impeding access to agricultural technologies and those related to climate change mitigation or adaptation remains context-specific and complicated (Lybbert and Sumner 2012).

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 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 characterizes 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). Adaptation processes often require the adopting of technologies, and as such benefit from greater coordination between adaptation strategies and technology transfer mechanisms, 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.

New mechanisms under the Paris Agreement 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). These approaches can effectively include any combination of measures or instruments related to adaptation, mitigation, finance, technology transfer and capacity-building, which could be of particular interest in land use sectors where such aspects are more intertwined than might be the case in energy or industry sectors. Article 6 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 centralized, 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).

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 land sectors 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).

Like the participation in the Clean Development Mechanism and other existing carbon trading mechanisms, the participation in Article 6.2 and 6.4 Paris Agreement also demands certain institutional and data management capacities to effectively benefit from the cooperation opportunities, as technology-oriented interventions alone may not be enough to achieve a sustainable transformation in the land sectors (Totin et al. 2018). 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 Clean Development Mechanism (Maraseni and Cadman 2015). Experience with REDD+ programs emphasize the necessity to invest into “readiness” programs, which provide assistance for countries to engage in strategic planning, build management and data collection systems to develop the capacity and infrastructure to participate in REDD+ (Minang et al. 2014). The overwhelming majority of countries (93%) cite weak forest sector governance and institutions in their applications for REDD+ readiness funding (Kissinger et al. 2012). Achieving readiness also requires the transfer of capacities, as well as technologies to developing country Parties, such as advanced remote sensing technologies that help to reduce uncertainty in the monitoring of forests (Goetz et al. 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 cannot be double-counted (i.e., towards multiple NDCs). All countries have to prepare and communicate NDCs, and many countries have included in their NDCs either economy-wide targets that include the land use sectors, or specific targets for the land use sectors. While most countries confirm they intend to account for their emissions using IPCC guidelines, there are discrepancies as to whether the 1996 or 2006 Guidelines will be used, and only a handful of countries indicate their intention to use the 2003 IPCC Good Practice Guidance for the land sector. In total, the ambiguity in how countries incorporate LULUCF into their NDC is estimated to lead to an uncertainty of more than 2 $GtCO_2$ in 2030 (Fyson and Jeffery 2018).

Under the Paris Agreement, developing countries will have an interest to meet the emission reduction goals formulated in their NDCs, and consequently less incentive to convert emission reductions to ITMOs and transfer them (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, 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).

7.5.5 Policies Responding to Desertification – Land Degradation Neutrality (LDN)

At its twelfth session, the Conference of Parties (COP) to the United Nation Convention to Combat Desertification adopted Land Degradation Neutrality and defined it as "A state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems" (decision 3/COP.12, UNCCD, 2015). The land degradation neutrality evolve from the concept of Zero Net Land Degradation, which was promoted by the UNCCD to overcome the problem of slow sustainable land management; as underscored in the relevant scientific literature (Kust et al. 2017; Stavi and Lal 2015; Chasek et al. 2015). The aim of LDN is spelled out in goal 15 of the Sustainable Development Goals (SDGs) as: “Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss”, and target 15.3: “By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation neutral world” (United Nations - General Assembly 2015).

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/benchmark 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). Global neutrality is the sum of neutralities achieved by local communities and nations around the globe (Kust et al. 2017). Achieving the target of land degradation neutrality would decrease the environmental footprint of agriculture, while supporting food security and sustaining human wellbeing (UNCCD 2015; Safriel 2017; Stavi and Lal 2015; Kust et al. 2017).

Land degradation neutral world could be achieved through planned effective actions; particularly those that play essential role in a land-based approach to climate change adaptation. It needs motivated stakeholders (stakeholder preferences for ecosystem services) and investments to improve land management. Such actions, including those for forests and improvements of land-based activities, could contribute to ensuring carbon cycle balance (Willemen et al. 2016; UNCCD 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 to reduce land sensitivity to degradation and to enhance 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 effective implementation of global LDN it is critical to integrate lessons learned from existing offset programs designed for other environmental objectives. Furthermore it is necessary to formulate/strengthen supportive policies and regulations (Stavi and Lal 2015; Grainger 2015). Despite the fact that land degradation neutrality was introduced into the global dialogue to stimulate a more effective policy response to land degradation, however turning international policies into national policies has been identified as a challenge (Cowie et al. 2018; Grainger 2015). Land degradation neutrality 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, LDN actions and activities play an essential role for a land-based approach to climate change adaptation (UNCCD 2015). Achieving LDN also supports the achievement of several of the Sustainable Development Goals, 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 LDN 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).

Land degradation neutrality indicators as set by the UNCCD; are land cover (physical land cover class), land productivity (metric: net primary productivity) and carbon stocks (metric soil organic carbon stocks). However, these indicators have also been recommended as sub-indicators for the indicator 15.3.1, "Proportion of land that is degraded over total land area", adopted to measure progress toward the SDG target 15.3 (Cowie et al. 2018; UNCCD 2015; United Nations - General Assembly 2015; Kust et al. 2017).

Monitoring the targets of LDN requires means of assessing levels of land degradation and restoration. Furthermore, certain measures were identified for achievement of LDN 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 to achieve LDN goal (Kust et al. 2017; Sietz et al. 2017; Cowie et al. 2018; Montanarella 2015; Stavi and Lal 2015).

To achieve LDN it has been underscored that it is important to consider biophysical and socio-economic aspects. 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 livelihood and degradation) (Easdale 2016; Qasim et al. 2011; Cowie et al. 2018; Salvati and Carlucci 2014).

Monitoring the status of land degradation 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 static, but rather a dynamic process, some authors underlined challenges related to monitoring of causes, rates, and effects of land degradation neutrality (Sietz et al. 2017; Grainger 2015; Cowie et al. 2018). The difficulties associated with monitoring and evaluation are associated with absence of baseline rates, Identification of appropriate indicators for monitoring and assessment, 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 desertified land by revegetation (Stavi and Lal 2015; Grainger 2015; Chasek et al. 2015; Cowie et al. 2018). (Kust et al. 2017) stressed that; conducting comprehensive assessment of the components of land systems and their mutual equilibrium, is important for assessing the potential for sustainability. That latter have been underscored as a basis for selection of the most relevant indicators and measures of LDN at different level (global, regional and local levels) and consequently LDN could serve as a target and indicator of sustainable land management.

Despite of opportunities for implementing restoration projects; including through payments for improving ecosystem services, as well as other economic mechanisms, the implementation of ecosystem restoration projects that have LDN 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 LDN targets (Sietz et al. 2017; Stavi and Lal 2015; Grainger 2015). Many developing countries are challenged with lack of incentives under UNCCD, however provision of extra funds to developing countries in LDN scheme should give a new incentive for national action (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).

7.5.6 Policies Responding to Land Degradation

7.5.6.1 Land Use Zoning

Land use zoning divides a territory (including local, sub-regional or national) into zones with different rules and regulations for land use (mining, agriculture, urban development etc.), management practices and land cover change (Mettermicht 2018). Integrated land use planning can contribute to sustainable land management through protection of natural capital by preventing or limiting vegetation clearing, avoiding degradation of planning for rehabilitation of degraded land or contaminated sites, promoting conservation and enhancement of ecosystems and ecological corridors. Land use planning can also enhance management of areas prone to natural disasters such as floods and resolve issues of competing land uses and land tenure conflicts (Mettermicht 2018).

7.5.6.2 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 (Bonan 2008; Millar et al. 2007; Thompson et al. 2009). 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 (UNEP 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 carbon storage, fisheries, non-timber forest products, erosion protection, water purification, shore-line stabilisation and also regulate storm surge and flooding damages, thus enhancing resilience and reducing climate risk from extreme events such as cyclones (Rahman, M.M., Khan, M.N.I., Hoque, A.K.F., Ahmed 2014; Donato et al. 2011; Das and Vincent 2009; Ghosh et al. 2015; Ewel et al. 1998).

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).

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 Convention on Biological Diversity, but also ecosystem-based adaptation and climate change mitigation under the UNFCCC, striving towards land degradation neutrality" (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 (Aronson and Alexander 2013). 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 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (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).

7.5.6.3 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 combating 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 methods for recovery of 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 Selected standards and certification schemes and their components or coverage

Scheme				Sustainability issues covered by scheme													
				Environmental							Social				Economic		
Number	Acronym	Name	Commodity/process	Certification scheme	GHG	Biodiversity	Carbon stock	Soil	Air	Water	Land use management[a]	Land rights	Labour conditions	Food security[b]	Management practices	Good business practices	Wages[c]
1	ISCC	International Sustainability & Carbon Certification	All feedstocks, all supply chains	√	√	√	√	√	√	√	√	√	√	√	√		
2	Bonsucro	BonsucroEU	Sugar cane and derived products	√	√	√	√	√	√	√	√	√	√			√	
3	RTRS	Roundtable on Responsible Soy EU	Soy based products	√	√	√	√	√	√	√	√	√	√			√	
4	RSB	Roundtable on Sustainable Biomaterials EU	Biomass for biofuels and biomaterials	√	√	√	√	√	√	√	√	√	√	√	√	√	
5	SAN	Sustainable Agriculture	Linked to Rain Forest Alliance			√	√	√	√	√	√		√				√
6	RSPO RED	Roundtable on Sustainable Palm Oil RED	wide range of different biofuels and bioliquids	√	√	√	√	√	√	√	√	√	√	√		√	
7	PFSC	Programme for Endorsement of Forest Certification	Forest management	√		√	√	√	√	√	√	√	√	d		√	
8	FSC	Forest Stewardship Council	Forest Management	√		√	√	√	√	√	√	√	√			√	
9	SBP	Sustainable Biomass Programme	woody biomass, mostly wood pellets and wood chips	√	√	√	√	√	√	√	√	√	√			√	
10	ISO 13065:2015	Bioenergy	biomass and process		√	√	√	√	√	√	√	√	√	√e	√	√	
11	ISO 14055-1:2017	Land Degradation and Desertification	land use management		√				√	√	√	√	√	√			

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., soya, sugarcane) or a tree (oil palm) that are not included 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 into 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 local environmental 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 as well as socio-economic impacts 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. 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 . New risk assessments that include such integration have been considered across various certification schemes but there is not yet wide agreement on how they can be applied for instance in a landscape governance system, where different land users are brought together through stakeholder engagement. Certification approaches for biofuel imports are now in place for sugar cane, soya and palm oil in terms of impacts on land management practices in Europe and areas that grow these crops (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-party 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). The relation between biofuel production and food security is somewhat site and context-specific depending on baselines conditions and governance approaches (Araujo Enciso et al. 2016; Kline et al. 2017). Certification and standards cannot address global systemic concerns such as impacts on food prices or other market-wide effects but rather are aimed primarily at insuring best practices in the local context.

7.5.6.4 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).

Case Study: Forest conservation instruments: REDD+ in the Amazon and India

In the Amazon, a critical issue has been the real incorporation of indigenous people in the planning and distribution of benefits of REDD+ projects. While REDD+, in some cases, has enhanced real participation of community members in the policy-planning process, fund management, and carbon baseline establishment increased project reliability and equity (West 2016), it is clear that, in this region, insecure and overlapping land rights, as well as unclear and contradictory institutional responsibilities, are probably the major problems for REDD+ implementation (Loaiza et al. 2017). Despite legal and rhetoric recognition of indigenous land rights, effective recognition is still lacking (Aguilar-Støen 2017). The key to the success of REDD+ in the Amazon, has been the application of both, incentives and disincentives on key safeguard indicators, including land security, participation, and well-being (Duchelle et al. 2017).

On the other hand, REDD+ has been unable to shape land-use dynamics or landscape governance, in areas suffering of strong exogenous factors, such as extractive industries, and in the absence of effective regional regulation for sustainable land use (Rodriguez-Ward et al. 2018; Bastos Lima et al. 2017b). Moreover, at the subnational level, projects with weak financial incentives, engage households with high off-farm income, which already are better off than the poorest families (Loaiza et al. 2015). Beyond, operational issues, clashing interpretations of results might bring clashes between implementing countries or organizations and donor countries, which have revealed concerns that the performance of projects (van der Hoff et al. 2018)

Methodological issues have arisen in the Amazon, including how to assess the opportunity cost among landholders, including for informing REDD+ implementation (Kweka et al. 2016). Programs like REDD+ depend on consistent environmental monitoring methodologies for measuring, reporting and verification and, in the Amazon, land cover estimates are crucial for environmental monitoring efforts (Chávez Michaelsen et al. 2017).

In India forests and wildlife concerns are on the concurrent list of the Constitution since an amendment in 1976 thus giving the central or federal government a strong role in matters related to governance of forests. High rates of deforestation due to development projects led to the Forest Conservation Act (1980) which requires central government approval for diversion of forest land in any state or union territory. Approval of forest land diverted for any development project requires compensatory afforestation and compensation costs (Net Present Value) to be paid into an account managed by an authority called CAMPA (Compensatory Afforestation Fund Management and Planning Authority). As of February 2018, 6825 Million USD had accumulated in CAMPA funds in lieu of NPV paid by developers diverting forest land throughout India for non-forest use. Funds are released by the central government to state governments out of this fund for afforestation and conservation related activities to "compensate" for diversion of natural forests. This is now governed by a legislation called CAMPA Act passed by the Parliament of India in July 2016. The CAMPA mechanism has invited criticism on various counts in terms of undervaluation of forest, inequality, lack of participation and environmental justice (Temper and Martinez-Alier 2013).

The other significant development related to forest land was the landmark legislation called the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 or Forest Rights Act passed by the Parliament of India in 2007. This is the largest forest tenure legal instrument in the world and attempted to undo a historical injustice to forest dwellers and forest dependent communities whose traditional rights and access were legally denied under forest and wildlife conservation laws. The FRA recognizes the right to individual land titles on land already cleared as well as community forest rights such collection of forest produce. Till November 2018, a total of 64,328 community forest rights and a total of 17,040,343 individual land titles had been approved and granted up to end of 2017.

As per the FRA, the forest rights shall be conferred free of all encumbrances and procedural requirements. Thus, the community forest land recognized under FRA cannot be used for the purpose of Compensatory Afforestation thus restricting the area that can be considered under REDD or REDD+. Furthermore, it poses legal and administrative hurdles in using existing forest land for implementation of India's ambitious Green India Mission that aims to create an additional carbon sink of **2.5 to 3 billion tonnes of CO_2 equivalent** by 2030. This commitment could push India's forest and forest restoration towards a more top-down carbon centric model to the detriment of local participation and livelihoods, non-carbon ecosystem services and biodiversity (Vijge and Gupta 2014).

India has also experimented with the world's first national inter-governmental ecological fiscal transfer (EFT) from central to local and state government to reward them for retaining forest cover. In 2014, India's Finance Commission added forest cover to the formula that determines the amount of tax revenue the central government distributes annually to each of India's 29 states. It is estimated that in four years it would have distributed 6.9–12 billion USD per year to states in proportion to their 2013 forest cover, amounting to around 174– 303 USD per hectare of forest per year (Busch and Mukherjee

2017). State governments in India now have a sizeable fiscal incentive to protect existing forests, contributing to the achievement of India's climate mitigation and forest conservation goals. India's tax revenue distribution reform has created the world's first EFTs for forest conservation, and a potential model for other countries. It's still too early but its impact on trends in forest cover in the future and its ability to conserve forests without other investments and policy instruments is promising but untested (Busch and Mukherjee 2017; Busch 2018).

In spite of all the new developments on forest rights and fiscal incentives, only further investments in monitoring (Busch 2018), decentralization (Somanathan et al. 2009) and promotion of diverse non-agricultural forest and range land based livelihoods (e.g., sustainable non-timber forest product extraction, regulated pastures, carbon credits for forest regeneration on marginal agriculture land and ecotourism revenues) as part of individual and community forest tenure and rights could help reconcile climate change mitigation, REDD+ and environmental justice (Vijge and Gupta 2014; Temper and Martinez-Alier 2013; Badola et al. 2013; Sun and Chaturvedi 2016).

7.5.7 Policies for Food Security

Rising temperatures but also policy choices related to food systems and socio-economic pathways influence food security (see Figure 7.1 and Figure 7.2). As outlined in Chapter 5, key aspects of food security are food availability including diversity, access, use and stability. A large portfolio of measures is available to shape outcomes in these areas from the use of tariffs or subsidies to payments for production practices (OECD 2018).

While comprehensive reviews of policy are rare and additional data is needed (Adu et al. 2018), evidence indicates the result of food security interventions vary widely. In the past, efforts to increase food production through significant investment in agricultural research including crop improvement have benefited farmers by increasing yields and reducing losses, and have helped consumers by lowering food prices (Pingali 2015, 2012; Alston and Pardey 2014; Popp et al. 2013). Public spending on agriculture research and development has been more effective at raising sustainable agriculture productivity than irrigation or fertilizer subsidies (OECD 2018).Yet, on average between 2015 and 2017, governments spent only around 14% of total agricultural support on general services, which includes physical and knowledge infrastructure, transport and ICT.

Extension services, and policies supporting agricultural extension systems, are also critical. Smallholder farmer-dominated agriculture is currently the backbone of global food security in the developing world. Without education and 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). Through extension services, governments can play a proactive role in providing information on climate and market risks, animal and plant health. Farmers with greater access to extension training retain more crop residues for mulch on their fields (Jaleta et al. 2013, 2015; Baudron et al. 2014).

Agricultural technology transfer can help optimize food and nutrition security. Policies that affect agricultural innovation span sectors and include "macro-economic policy-settings; institutional governance; environmental standards; investment, land, labor and education policies; and incentives for investment, such as a predictable regulatory environment and robust intellectual property rights". 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). To better 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). 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).

In terms of increasing food availability and supply, producer support, including policies mandating subsidies or payments, have been used to boost production of certain commodities or protect ecosystem services. Incentives can distort markets and farm business decisions in both negative and positive ways. For example, the European Union promotes meat and dairy production through voluntary coupled direct payments. These do not yet internalize external damage to climate, health, and groundwater (Velthof et al. 2014; Bryngelsson et al. 2016). New evidence indicates that a government policy supporting producer subsidy could encourage farmers to adopt new technology and reduce GHG reductions in agriculture (*medium evidence, high agreement).* However this will require large capital (Henderson, 2018). Since a 1995 reform in its Forest Law, Costa Rica has effectively used a combination of fuel tax, water tax, loans and agreements with companies, to pay landowners for agroforestry, reforestation and sustainable forest management (Porras and Asquith 2018). In most countries producer support has been declining since the mid-1990s (OECD 2018).

Inland capture fisheries and aquaculture are an integral part of nutrition security and livelihoods for large numbers of people globally (Welcomme et al. 2010; Hall et al. 2013; Tidwell and Allan 2001; Youn et al. 2014) and are increasingly vulnerable to climate change and competing land and water use (Allison et al. 2009; Youn et al. 2014). Future production may increase in some high-latitude regions (*low confidence*) but production is likely to decline in low latitude regions under future warming (*high confidence*)(Brander and Keith 2015; Brander 2007). However over-exploitation and degradation of rivers has resulted in a decreasing trend in contribution of capture fisheries its contribution to protein security in comparison to managed aquaculture (Welcomme et al. 2010) . Aquaculture however competes for land and water resources with many negative ecological and environmental impacts (Verdegem and Bosma 2009; Tidwell and Allan 2001). Inland capture fisheries are undervalued in national and regional food security, ecosystem services and economy, are data deficient and are neglected in terms of supportive policies at national levels and absent in Sustainable Development Goals (Cooke et al. 2016; Hall et al. 2013; Lynch et al. 2016). Revival of sustainable capture fisheries and converting aquaculture to environmentally less damaging management regimes is likely to succeed by investment in recognition of their importance, improved valuation and assessment, secure tenure and adoption of social, ecological and technological guidelines besides upstream-downstream river basin cooperation and maintenance of ecological flow regimes in rivers (Youn et al. 2014; Mostert et al. 2007; Ziv et al. 2012; Hurlbert and Gupta 2016; Poff et al. 2003; Thomas 1996; FAO 2015a).

Food security cannot be achieved by increasing food availability alone. Interventions 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). Value chain development has in the past increased farm income but delivered fewer benefits to vulnerable consumers (Bodnár et al. 2011). 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 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) (*strong evidence, high agreement*). 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 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 price and trade policies impact access to food. Fiscal policies, such as taxation, subsidies, or tariffs, can be used to regulate production and consumption of certain foods and can affect environmental outcomes. 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). A global tax on GHG emissions for example has large mitigation potential and will generate tax revenues, but may also result in large reductions in agricultural production (Henderson 2018). Consumer-level taxes on GHG intensive food may be applied to address competitiveness issues between different countries, if some countries use taxes while others do not. However, increases in prices might impose disproportionate financial burdens on low-income households, and may not be publicly acceptable. 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).

Demand management for food, including promoting healthy diets, reducing food loss and waste, is covered in Chapter 5. There is a gap in knowledge regarding what policies and instruments support demand management. There is *strong evidence and strong agreement* that changes in household wealth and parents' education can drive changes in diet and 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.

7.5.8 Enabling effective policy instruments – Policy mix coherence

An enabling environment for policy effectiveness includes: 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) 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 (see 7.5); 4) governance coordination mechanisms and partnerships; and 5) a long term perspective in terms of response options, monitoring, and maintenance (see 7.6) (FAO 2017a). Supporting the study of enabling environments, the study of policy mixes has emerged in the last decade in regards to the mix or set of instruments that interact together and are aimed at achieving policy objectives in a dynamic setting (Reichardt et al. 2015). The study of policy mixes includes studying the ultimate objectives of a policy mix (such as biodiversity (Ring and Schröter-Schlaack 2011)), the interaction of policy instruments within the mix (including climate change mitigation and energy (del Río and Cerdá 2017)) (see Trade-offs and Synergies, 7.5.9), and the dynamic nature of the policy mix (whether it is increasing incrementally or in another manner (Kern and Howlett 2009)).

Studying policy mixes allows for a consideration of policy coherence which is broader than the study of discrete policy instruments in rigidly defined sectors, but entails studying policy in relation to the links and dependencies among problems and issues (FAO 2017b). Consideration of policy coherence is a new approach rejecting simplistic solutions, but acknowledging inherently complex processes involving collective consideration of public and private actors in relation to policy analysis (FAO 2017b). A coherent, consistent mix of policy instruments can solve complex policy problems (Howlett and Rayner 2013) as it involves or lateral, integrative, and holistic thinking in defining and solving problems (FAO 2017b). Such a consideration of policy coherence is required to achieve sustainable development (FAO 2017b). A study in Indonesia found while internal policy coherence between mitigation and adaptation is increasing, external policy coherence between climate change policy and development objectives is still required (Di Gregorio et al. 2017).

In relation to hazards, the policy mix has been found to be a key determinant of the adaptive capacity of agricultural producers. In relation to drought, the mix of policy instruments including crop insurance, sustainable land management practices, bankruptcy and insolvency, co-management of community in water and disaster planning, and water infrastructure programmes are effective at responding to drought (Hurlbert and Gupta 2018) . Similarly in relation to flood, the mix of policy instruments including flood zone mapping, land use planning, flood zone building restrictions, business and crop insurance, disaster assistance payments, preventative instruments including environmental farm planning (including soil and water management (see Chapter 6)) and farm infrastructure projects, and recovery from debilitating flood losses ultimately through bankruptcy are effective at responding to flood (Hurlbert 2018a).

Considerations of policy coherence potentially addresses challenges that exist with assessing multiple hazards and sectors (Aalto et al. 2017; Brander and Keith 2015; Williams and Abatzoglou 2016), challenges in mainstreaming adaptation and risk management into on-going development planning and decision making (Linnerooth-Bayer and Hochrainer-Stigler 2015) in countries overly focused on sectors, instead of sustainable use of biodiversity and ecosystem services, challenges in scaling up community and ecosystem based initiatives (Reid 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).

When evaluating a new policy instrument, its design in relation to achieving an environmental goal or solving and land and climate change issue, includes consideration of how the new instrument will interact with existing instruments operating at multiple levels (international, regional, national, sub-national, and local) (Ring and Schröter-Schlaack 2011)(see 7.5.1). In respect of land conservation and management goals, consideration of differing strengths and weakness of instruments is necessary. While direct regulation may secure effective minimum standards of biodiversity conservation and critical ecosystem service provision, economic instruments may achieve reduced compliance costs as costs are borne by policy addressees (Rogge and Reichardt 2016). In relation to GHG emissions and climate mitigation a comprehensive mix of instruments targeted at emissions reductions, learning, and research and development is effective (*high confidence*) (Fischer and Newell 2008). The policy coherence 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). 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). Further, recycling carbon tax revenue to support clean energy technologies can decrease losses from unilateral carbon mitigation targets with complementary technology polices (Corradini et al. 2018).

7.5.9 Barriers to Sustainable Land Management and Overcoming Barriers

7.5.9.1 Inequality

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).

Cross-Chapter Box 6: Gender in integrative approaches for land, climate change and sustainable development

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When developing integrated responses to climate change, it is important to consider social dynamics and interactions, including social inequalities. As discussed in the *Special Report on Global Warming of 1.5°C*, negative impacts can occur when existing social inequalities are exacerbated by climate change. Gender is a key axis of social inequality that intersects with other systems of power and marginalization—including "race", culture, socioeconomic status, sexuality, and age—to cause unequal experiences of climate change vulnerability and adaptive capacity. However, "policy frameworks and strong institutions that align development, equity objectives and climate have the potential to deliver 'triple-wins'" (Chapter 5, SR1.5°C), including enhanced gender equality.

Gender-Inequitable Access to Land

Differential vulnerability to climate change is related to inequality in rights-based resource access, established through formal tenure systems. Women play a significant role in agriculture (Boserup 1970) and rural economies globally. They constitute 43% of the agricultural labour force in developing countries, ranging from 20% in Latin America to 50% in Eastern Asia and sub-Saharan Africa (FAO, 2011a, pp. 5). Women also hold important responsibilities for food provision and food security at household and community levels, and such responsibilities are exacerbated in the context of male outmigration for work or as a response to drought or decline in pasture lands (Brockhaus, Djoudi, & Locatelli, 2013; Djoudi et al., 2016). Despite their significant role in agriculture and food-related activities, patriarchal structures in many countries, particularly developing ones, has meant that less than 20% of landholders globally are women (FAO 2011). In only 37% of 161 countries do men and women have equal rights to use and control land, and in 59% customary, traditional and religious practices discriminate against women (OECD 2014) even if the law formally grants equal rights. Widows, in particular, are likely to become victims of land grabbing (Glemarec, 2017 pp. 59).) In Bangladesh women only own 10% of land, and in Nigeria only 4% of women can take decisions on the sale of land, compared to 87% of men (FAO, 2015). Studies from the USA show that even in rich countries, women may lack decision-making power over agricultural land they own or co-own (Carter 2017; Petrzelka and Marquart-Pyatt 2011). Thus, longstanding gender inequality in land rights and security of tenure may constrict livelihood diversification and thereby limit adaptation options and global food security (Smucker and Wangui, 2016). According to FAO (2011), if women had the same access to land as men, the number of hungry people in the world would be reduced by 150 million.

Due to engrained patriarchal social structures and gendered ideologies, women face multiple barriers to participating in land-based adaptive and mitigating actions in response to climate change. These barriers include: (i) disproportionate responsibility for unpaid domestic work including care-giving activities (Beuchelt and Badstue 2013) and provision of water and firewood (UNEP, 2016); (ii) risk of violence in both public and private spheres, which restricts their mobility for capacity-building activities and productive work outside the home (Day et al., 2005; Jost et al., 2016; UNEP, 2016); (iii) lack of ownership of productive assets and resources (Kristjanson et al., 2014; Meinzen-Dick et al., 2010), including land (Lastarria-Cornhiel et al. 2014), and less access to credit and financing (Jost et al. 2016); (iv) lack of organizational social capital, which may help in accessing credit (Carroll et al. 2012); and (v) lack of decision-making power in agriculture and in management of land and natural resources (Alkire et al., 2013; Quisumbing et al., 2014) (*high confidence*). Despite efforts to improve women's access to land, pervasive gender inequalities persist (Campos et al, 2015).

Access to land is important not only as a key resource to produce food, but also because only through this access can women participate in governance and decision-making structures in many villages, including decisions related to adaptation to climate change, resulting in more egalitarian institutions. Thus, restrictions in women's decision-making and access to land and other productive assets affect their resilience to climate shocks and longer-term climate change (FAO, 2011; Frankema, 2009) whilst positive effects of land tenure security have been shown on productive and environmentally-beneficial agricultural investments as well as on female empowerment and household well-being through improved cash incomes and decision-making (Higgins et al, 2018; Namubiru-Mwaura, 2014 (Gabrielsson and Ramasar 2013)).

Since constraints to land access include not only state policies, but also customary laws and norms (Bayisenge, 2018), legal and policy changes are necessary first steps but are not sufficient by themselves to secure women's property rights (Namubiru-Mwaura, 2014). Given the social, cultural and religious beliefs that people attach to land, analysing contextual conditions is essential to determine the most appropriate way to enable gender-responsive reforms (Namubiru-Mwaura 2014; Giovarelli et al. 2013).

Gender and Climate Change

Existing literature on gender and climate change is largely focused on adaptation (Djoudi et al., 2016; Mersha & Van Laerhoven, 2016), centred on the Global South (Cohen 2017), and mainly highlights women's vulnerabilities (Alston, 2013; Arora-Jonsson 2011) or implies their disproportionate responsibility for mitigation (MacGregor 2010). Studies report gendered impacts of climate change in rural areas, with women generally experiencing more vulnerability than the men in their communities, albeit through different pathways (Djoudi et al., 2016; Goh, 2012; Jost et al., 2016; Kakota, Nyariki, Mkwambisi, & Kogi-Makau, 2011). At the same time, women's strong presence in agriculture provides opportunity to bring gender dimensions into climate change adaptation, in particular with regards to food security (Glemarec 2017). Authors have suggested that qualitative research methods and participatory adaptation approaches should be adopted to help elucidate such gender dimensions (Jost et al., 2016; Doss, Meinzen-Dick, Quisumbing, & Theis, 2017). Literature discusses gender differences in climate change adaptation (Mersha and Van Laerhoven 2016). For example, in the context of rural Ethiopia, female-headed households adapt through diversification in livelihood strategies, such as labour-intensive public-works and individual-based diversity and communal pooling of resources (Mersha & Van Laerhoven, 2016: pp. 1708), while male-headed households have other 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 ((Mersha & Van Laerhoven, 2016: pp. 1708).

Climate change adaptation is multi-sectoral and existing literature has attempted to identify and examine the national and sectoral policies geared towards improved climate change adaptation; however, discussion of gender and its inclusions in natural resources policy documents remain mostly rhetorical (Ampaire et al. 2015). In particular, there has been introduction of or amendment to the existing land policies to include gender dimensions, but there seems to be little progress on their implementation (Djoudi et al., 2016).

Some studies do point to an emancipatory role played by adaptation interventions and strategies, albeit in a limited manner. For example, women in socially disadvantaged groups engage in new livelihood activities after adult men out-migrate (Djoudi & Brockhaus, 2011). Widows in Western Kenya, as main livelihood providers, are gaining increased decision making and bargaining power, working together in formalized groups of collective action that capitalize on the pooling of natural and human resources and planned financial management. As such, they invest in sustainable innovations like rain water harvesting systems and agroforestry that allow both adaptation and mitigation to climate change (Gabrielsson and Ramasar 2013). In a developed country context, there has been a shift from agriculture to salaried positions (Ford and Goldhar 2012). Studies in rural Australia have shown that adaptation to disaster can challenge gender roles by positioning women as financial providers (Alston 2006); however, a side-effect of this trend is further masculinization of agriculture as women move into paid employment (Clarke & Alston, 2017). Collective action and agency of women, including widows, 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). Acknowledging the agency of women and other marginalized groups is important to avoid universalizing discourses of vulnerability (Arora-Jonsson, 2011; Ravera, Iniesta-Arandia, Martín-López, Pascual, & Bose, 2016).

Land-based mitigation approaches include policy, technology and market activities in the agricultural, livestock and forestry sectors, such as policies supporting the cultivation of biofuel crops; 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). Research on the gendered impacts of these developments is necessary; however, existing explanations suggest that these developments may interfere with traditional livelihoods in rural areas, cause conflicts, lead to decline in women's livelihoods (Hunsberger et al. 2017), and can 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 are affected due to either land alienation through the creation of a market or appropriation (acquisition) by the government for climate mitigation efforts, families may be at risk of poverty. Land alienation for biofuel production unequally impacts women due to inadequately addresed 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 dimensions, examples of which are yet unavailable in literature.

Emergence of an Intersectional Approach

Despite these gendered trends in climate change vulnerability and adaptation, women are not a homogenous group. There is *high agreement* that climate change research should focus on "gender" as a relational and contextual construct rather than presenting women as a uniformly and consistently vulnerable category (Arora-Jonsson, 2011; Mersha & Van Laerhoven, 2016; Ravera, Iniesta-Arandia, Martín-López, Pascual, & Bose, 2016). Some gender analyses have highlighted the mental health effects of drought on male farmers (Alston, 2012; Fletcher & Knuttila, 2016); however, further research on men, masculinity, and climate change is needed (Bunce and Ford, 2015). Acknowledging the diversity of gender and sexual identity, studies are also beginning to emerge on the experiences of LGBT (lesbian, gay, bisexual, and transgender) people in the context of climate disaster and/or natural hazards. These analyses emphasize impacts, but also agency and resilience (Balgos, Gaillard, & Sanz, 2012; Gorman-Murray et al., 2016) and diversity within such groups (Dominey-Howes, Gorman-Murray, and McKinnon, 2014).

An intersectional approach enables consideration of the various social identifiers that give rise to different situations of power (Rao et al, 2017). There is *high agreement* that using a framework of intersectionality to integrate gender into climate change research helps to recognize overlapping and interdependent systems of power (Djoudi et al., 2016; Fletcher, 2018; Kaijser & Kronsell, 2014; Moosa & Tuana, 2014; Thompson-Hall, Carr, & Pascual, 2016), which create particular and context-specific experiences of climate vulnerability and adaptation. Some empirical analyses of gender and climate change have employed an intersectionality approach by analyzing the experiences of particular groups, such as low-income racialized women (Weber & Hilfinger Messias, 2012), rural women (Fletcher & Knuttila, 2016), and Indigenous women (Dowsley, Gearheard, Johnson, & Inksetter, 2010). Emerging work on Indigenous women and climate change contains a strong emphasis on agency and the value of Indigenous women's knowledges for sustainability (Cameron, 2012; Whyte, 2014).

Strengthening Gendered Approaches in Global Commitments

In Nationally Determined Contributions (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 NDCs 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 an 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 adaptive capacity for vulnerable groups.

7.5.9.2 Barriers to Adaptation

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). Constraints or barriers to adaptation 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; institutional and governance. Only a small fraction of adaptation measures suggested can be implemented due to financial, institutional, technical, cognitive, ecological, 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 (shown on the center of Figure 7.6).

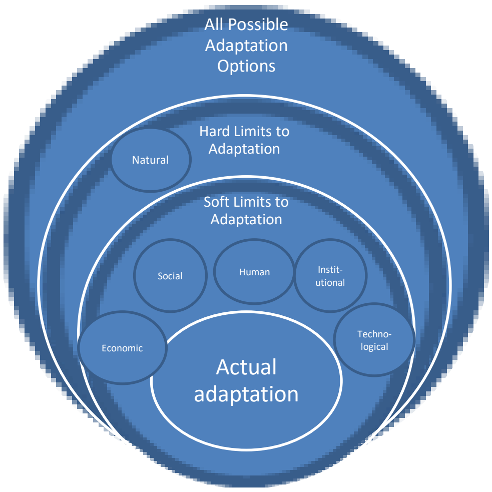

Figure 7.6 Adaptation Limits: Soft and Hard

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 adaptation limits include limits to natural capital such as 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 (Jones 2010). Constraint, barrier and obstacle are used synonymously and in contrast to adaptation limit, which is more restrictive. Natural limits, that is ecological and physical limits, comprise hard limits to adaptation, and range from ecosystem thresholds to geographical and geological limitations (Jones 2010). 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).

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).

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). Soft adaptation limits to land and climate change impacts relate to human, social, economic, and institutional barriers as described on Table 7.4 (*high agreement, medium evidence*). Considerable literature exists around changing behaviours through response options targeting social and cultural barriers (Rosin 2013; Eakin; Marshall et al. 2012) (See Chapter 6 Value chain interventions).

Table 7.4 Soft Barriers and Limits to Adaptation

Category	**Description**	**References**
Human	Cognitive and behavioural obstacles. Lack of knowledge and information.	(Hornsey et al. 2016; Prokopy et al. 2015) (Wreford et al. 2017)
Social	Undermined participation in decision making and social equity	(Burton et al. 2008) (Laube et al. 2012)
Economic	Market failures and missing markets, transaction costs and political economy, ethical and distributional issues. Perverse incentives.	(Chambwera et al. 2014b) (Wreford et al. 2017) (Rochecouste et al. 2015; Baumgart-Getz et al. 2012)
Institutional	Mal-coordination of policies and response options, unclear responsibility of actors and leadership, misuse of power, all reducing social learning. Government failures. Path dependent institutions.	(Oberlack 2017) (Sánchez et al. 2016; Greiner and Gregg 2011)
Technological	Systems of mixed crop and livestock. Polycultures.	(Nalau and Handmer 2015)

Since AR5 research examining the role of governance, institutions and in particular policy instruments, in creating or overcoming barriers to adaptation to land and climate change in the land use sector is emerging (Foudi and Erdlenbruch 2012; Linnerooth-Bayer and Hochrainer-Stigler 2015). Evidence shows that understanding the local context and targeted approaches are generally most successful (Rauken et al. 2014). Sometimes specific policies including 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. 2015; Baumgart-Getz et al. 2012). Understanding the nature of constraints to adaptation is critical in determining how barriers may be overcome. Formal institutions (rules, laws, policies) and informal institutions (social and cultural norms and shared understandings) can be barriers and enablers of climate adaptation (Jantarasami et al. 2010). Governments play a key role in intervening and confronting existing barriers by changing legislation, adopting policy instruments, providing additional resources, and building institutions and knowledge exchange (Ford and Pearce 2010; Measham et al. 2011; Mozumder et al. 2011; Storbjörk 2010). Understanding institutional barriers is important in addressing barriers (*high confidence, robust evidence*). Institutional barriers may exist due to the path-dependent nature of institutions governing natural resources and public good, bureaucratic structures that undermine horizontal and vertical integration (see 7.7.2), and lack of policy coherence (see 7.5.8).

7.5.9.3 Institutional barriers

Barnett et al. (2015) compared six ecological cases and found that path-dependent nature of the institutions that govern natural resources and public goods is a deep driver of barriers and limits to adaptation (Barnett et al. 2015). 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. 2014). 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). Bureaucratic structures undermine vertical and horizontal policy integration (vertical policy integration in order to mainstream climate change into sectoral policies as well as horizontal policy integration by overarching governance structures for cross-sectoral coordination (Di Gregorio et al. 2017)). 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 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 found conventional, hard to implement adaptation measures are often associated with high costs, inflexibility and conflicting interests in urban areas (Matthews et al. 2015). Perception of barriers to adaptation may be just as important as actual barriers (Adger et al. 2007). A study on smallholder farmers to understand climate adaptation barriers found that the major barriers are personal barriers, institutional and labour barriers, cost of land barriers, facility barriers, and lack of political will barriers (Guodaar and Asante 2018).

Barriers to adaptation also arise from a lack of policy coherence, 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).

7.5.9.4 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. 2014; 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 adapt 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. 2013; Langholtz et al. 2014; Klein et al. 2015).

7.5.9.5 Overcoming Barriers

Policy instruments that strengthen the assets or capitals in Figure 7.6 reduce vulnerability and overcome barriers to adaptation (Hurlbert 2018b) and Hurlbert 2013 Journal of Environmental Planning and Management.

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).

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 Antarctic 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). Fostering equity and participation are correlated with the efficacy of local adaptation to secure food and livelihood security (Laube et al. 2012). In this chapter, the literature surrounding appropriate policy instruments, decision making, and governance practices to overcome limits and barriers to adaptation is proposed.

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).

7.6 Decision-making for Climate Change and Land

The risks posed by climate change generate considerable uncertainty and complexity for decision-makers responsible for land use decisions (*robust evidence, high agreement*). Decision-makers must balance climate ambitions, encapsulated in the 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. 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.

Even in cases where uncertainty exists, there is *medium evidence and high agreement* in the literature that it need not present a barrier to taking action, and there are growing methodological developments and empirical applications to support decision-making. Progress has been made in identifying key source of uncertainty and addressing them (Farber 2015). Many of these approaches involve principles of robustness, diversity, flexibility, learning, or choice editing. In the land sector, the degree of uncertainty varies. Some types of agricultural production decisions can be made in short time-frames as changes are observed, and will provide benefits in the current time period (Dittrich et al. 2017). In other cases, particularly where longer time-frames are involved, uncertainty regarding the future climate can present barriers. For example, the climate suitability in several decades should be considered when selecting sites for new forests or tree-crops such as tea and coffee (Yousefpour et al. 2012). Large, irreversible investments for water management including reservoirs and dams rely on hydrological models which involve considerable uncertainty (Kundzewicz et al. 2018).

Although uncertainty exists across many elements of decision-making, its incorporation and treatment presents a particular challenge for climate change adaptation decisions (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 to taking action. Since the Fifth Assessment Report Chapter on Decision-making (Jones et al. 2014) considerable advances have been made in decision making under uncertainty, both conceptually and in the social/qualitative research areas as well as in economics. Here we focus on emerging approaches of particular relevance to this report.

7.6.1 Formal and Informal decision-making

Formal and informal decision making are key components of formal and informal institutions (see 7.2.2). Formal centers of decision making are those that follow fixed procedures (written down in statues or moulded in an organization backed by the legal system) (Onibon et al. 1999). Formal reasoning is characterized by the formulation of a problem, the design of scientific investigations and evaluation of experimental outcomes while making causal inferences forming and modifying theories all ruled by rules of logic and fixed unchanging premises (Teig and Scherer 2016). Formal decision making is assessed by whether or not conclusions are valid (Teig and Scherer 2016).

Informal centers of decision making are those following customary norms and habits based on conventions (Onibon et al. 1999). In informal decision making, or reasoning, problems without definition solutions are pondered by drawing inferences from uncertain premises. These problems are ill-structured, open-ended, and debatable and the quality of informal decision making is assessed based on the quality of the premises and their potential for strengthening conclusions (Teig and Scherer 2016), akin to complex problems (Waddock 2013). In informal decision making, premises are uncertain and can be questioned and conclusions can be withdrawn or changed in light of new evidence (Evans 2005). Emotions, feelings and social interactions are pivotal in this form of decision making (Verweij et al. 2015). Informal institutions of decision making interact with formal institutions of decision making potentially solving collective action problems (Vandersypen et al. 2007) or allowing formal institutions of decision making to evolve and adapt (Malogdos and Yujuico 2015a). It is not always clear if formal or informal decision making is occurring and the concepts are not mutually exclusive.

7.6.1.1 Formal 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*). These formal decision making processes can occur at all levels including the global, regional, national and sub-national levels (see 7.5.1). 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 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. 2017). 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). These decision making tools are expanded on in 7.6.2.

There are 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 into formal decision making (see 7.6.5) (*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 2015b). The role of informal institutions can be particularly relevant for land use decisions and practices in rural areas (Huisheng 2015).

7.6.1.2 Informal Decision Making

Understanding prevailing formal and informal institutions are crucial for adapting to climate change, especially for the rural poor (Agrawal and Perrin 2008). Informal institutions have been found to be a crucial entry point in dealing with vulnerability of communities and exclusionary tendencies impacting marginalized and vulnerable people (Mubaya and Mafongoya 2017). Informal institutions are also important in advancing adaptive capacity and advancing technological adaptation measures achieving comprehensive disaster management and advancing collective decision making (Karim and Thiel 2017).

Many studies underline the role of local/informal traditional institutions in the management of natural resources in different parts of the world (Yami et al. 2009; Zoogah et al. 2015; Bratton 2007; Mowo et al. 2013; Grzymala-Busse 2010). Social, political and demographic conditions are factors that influence institutions' effectiveness (Yami et al. 2009). Conditions that influence the effectiveness of informal institutions include population growth, population mix or composition (social ethnic, economic), 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.

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).

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 formal institutions including government interventions with implications for the regulation of land use, informal institutional functions, and joint-decision-making (Osei-Tutu et al. 2014). It has been argued that informal institutions can replace, undermine, and reinforce formal institutions irrespective of the 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 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).

Improving the conditions that obstruct the contributions of informal institutions is crucial to enhance effectiveness in sustainable common pool resource management. Furthermore, development interventions and policies should strengthen the involvement of effective informal institutions in decision-making in order to achieve sustainable resource 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). Creating an open platform for local debates in relation to natural resources and allowing these actors their own active formulation of rules and implementation of constitutional rules has advanced the long term sustainable use of resources. Case studies in Zambia, Mali, Indonesia and Bolivia confirmed that enabling factors for advancing the local ownership of resources and crafting this constitutionality of rules required not only this open platform but also recognition in laws, regulations and policies of the state to accommodate this local action (Haller et al. 2016).

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).

7.6.2 Decision Making, Risk, and Uncertainty

7.6.2.1 Structured Problems, Decision Making Tools, and Risk

Structured decision making occurs when there is little uncertainty such that agreement exists on values and norms relating to the issue and there is scientific knowledge about the cause and effect (Hurlbert and Gupta 2016). Examples in the land and climate area include cost benefit analysis surrounding implementation of irrigation projects (Batie 2008) or the choice of adopting soil erosion practices by agricultural producers (Hurlbert 2018b). This decision space is situate within the "known" space where cause and effect is understood and predictable although uncertainty not quite zero (French 2015). Figure 7.7 displays the structured problem area in the bottom left corner corresponding with the Known decision making space. Decision making surrounding risk assessment and risk management (7.5.3.1) occurs within this decision making space.

Climate change increases disaster risk from both extreme events and slow onset events. Therefore, climate change adaptation requires more comprehensive risk management (Papathoma-Köhle et al. 2016). Comprehensive risk management encompasses risk assessment, reduction, transfer, retention, emergency preparedness and response, and disaster recovery (Fra.Paleo 2015) (Fra.Paleo 2015) and includes social protection instruments such as insurance and transformational approaches to build resilience and to strengthen adaptive capacity. Disaster risk management and comprehensive risk management involve an iterative process of threat recognition through risk and vulnerability identification, assessment and analysis of risk, planning, responding, managing knowledge, community participation in building resilience (Ammann 2013) depicted on Figure 7.7.

7.6.2.2 Moderately Structured Problems, Decision Making Tools, and Risk

A moderately structured problem is characterized as one where there is either some disagreement on norms, principles, ends and goals in defining a future state or there is some uncertainty surrounding land and climate including land use, observations of land use changes, early warning and decision support systems, model structures, parameterisations, inputs, or from unknown futures informing integrated assessment models and scenarios (see Chapter 1.3.3.1). 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 individual stakeholders make different decisions on the best future course of action (Waas et al. 2014). Figure 7.7 displays the moderately structured problem space characterized by disagreement surrounding norms on the top left hand side. This corresponds with the complex decision making space, the realm of social sciences and qualitative knowledge where cause and effect is difficult to relate with any confidence (French 2013). 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.

The moderately structured problem space characterized by uncertainty surrounding land and climate on the bottom right hand side of Figure 7.7 corresponds to the knowable decision making space, where the realm of scientific inquiry investigates cause and effects. Here there is sufficient understanding to build models, but not enough understanding to define all parameters (French 2015). The top right hand corner of Figure 7.7 corresponds to the chaotic space where patterns and relationships are difficult to discern and unknown unknowns reside (French 2013). It is in the complex and knowable space that decision making under uncertainty occurs.

A wide range of possible approaches to decision-making under uncertainty exist (Jones et al. 2014). In the climate adaptation literature many build on the principles of adaptive management (see 7.5.4), using 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 2014c), adaptation pathways (Downing 2012), and dynamic adaptation pathways (Haasnoot et al. 2013). Decision making tools can selected and adapted to fit the specific land and climate problem and decision making space. For instance, dynamic adaptation pathways (Haasnoot et al. 2013; Wise et al. 2014) identify and sequence potential actions based on alternative potential futures and are situate within the complex space. Decisions are made at identified decision nodes based on trigger points, linked to scenarios or the changing performance over time (Kwakkel et al. 2016). A key characteristic of these pathways is rather than making irreversible decisions now, decisions evolve over time, accounting for learning (see 7.5.5), knowledge and values. Few applications of dynamic adaptive pathways in the land use sector exist in the literature yet, although Nanda et al. (2018) apply the concept to a wetland in Australia to identify a mix of short and long-term decisions, and Prober et al. (2017) develop adaptation pathways for agricultural landscapes, also in Australia. Both studies identify that longer-term decisions may involve a considerable change to institutional arrangements at different scales. 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 processes that change the very nature of a system may be required (Knight-Lenihan 2016). Scenario analysis is also situate within this space and is important for identifying technology and policy instruments to ensure 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).

Traditional approaches for economic appraisal, including cost benefit analysis and cost effectiveness analysis referred to in 7.6.2.1 do not handle or address uncertainty well (Hallegatte 2009) (Farber 2015) and favour decisions with short term benefits. Alternative economic decision making approaches aim 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 (see Box 7.2) (Lempert and Schlesinger 2000).

Much of the research for adaptation to climate change has focused around three main economic approaches: Real Options Analysis, Portfolio Analysis, and Robust Decision-Making. Real Options Analysis 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 and sea-level rise (Gersonius et al. 2013; Woodward et al. 2014; Dan 2016), but studies in land use decisions are also emerging, including identifying the optimal time to switch land use in a changing climate (Sanderson et al. 2016) and water storage (Sturm et al. 2017; Kim et al. 2017). Portfolio analysis aims to reduce risk by diversification, by planting multiple species rather than only one, in forestry (Knoke et al. 2017) or crops (Ben-Ari and Makowski 2016), for example, or in multiple locations. There may be a trade-off between robustness to variability and optimality (Yousefpour and Hanewinkel 2016; Ben-Ari and Makowski 2016); but this type of analysis can help identify and quantify trade-offs. Robust Decision Making identifies how different strategies perform under many climate outcomes, also potentially trading off optimality for resilience (Lempert 2013).

While economics is usually based on the idea of a self-interested, rational agent, more recently insights from psychology are being used to understand and explain human behaviour in the field of behavioural economics (Shogren and Taylor 2008; Kesternich et al. 2017), illustrating how a range of cognitive factors and biases can affect choices (Valatin et al. 2016). These insights can be critical in supporting decision-making that will lead to more desirable outcomes relating to land and climate change. Once example of this is in 'policy nudges' (Thaler and Sunstein 2008) which can 'shift choices in socially desirable directions' (Valatin et al. 2016). Tools can include framing tools, binding pre-commitments, default settings, channel factors, or broad choice bracketing (Wilson et al. 2016). Although relatively few empirical examples exist in the land sector, there is evidence that nudges could be applied successfully, for example in woodland creation (Valatin et al. 2016) and agri-environmental schemes (Kuhfuss et al. 2016) (*Medium certainty, low evidence*). Consumers can be 'nudged' to consume less meat (Rozin et al. 2011) or to waste food less (Kallbekken and Sælen 2013).

Programmes supporting and facilitating desired practices can have success at changing behaviour, particularly if they are co-designed by the end-users (farmers, foresters, land-users) (*high agreement,* *medium evidence*). Programmes that focus on demonstration or trials of different adaptation and mitigation measures, and facilitate interaction between farmers, industry specialists are perceived as being successful (Wreford et al. 2017; Hurlbert 2015) but systematic evaluations of their success at changing behaviour are limited (Knook et al. 2018).

Different approaches to decision making 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. 2019), and partly relate to the necessity of assigning probabilities to climate projects, and the complexity of the approaches being a prohibitive factor beyond academic exercises. Formalised expert judgement can improve how uncertainty is characterised (Kunreuther et al. 2014) and these methods have been improved utilising Bayesian belief networks to synthesise 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).

It may also be beneficial to combine decision making approaches with the precautionary principle, or the idea that lack of scientific certainty should not be a means to postpone action when faced with serious threats or irreversible damage to the environment (Farber 2015). The precautionary principle has been recognized in the Rio Declaration and Article 3(3) of the United Nations Framework Convention of Climate Change, and Section I (4) of the Cancun Agreement and requires cost effective measures to address serious but uncertain risks (Farber 2015). The precautionary principle supports a rights based policy instruments choice as consideration is whether actions or inactions harm others moving beyond traditional risk management policy considerations that surround net benefits (Etkin et al. 2012). In assessing case studies of the application of the precautionary principle, Farber (2015) concludes it has been successfully applied in relation to endangered species and successfully identified situation where climate change is a serious enough problem to justify some response (albeit it is unclear how to decide on the magnitude of the response). There is *medium confidence* that combining the precautionary principle with integrated assessment models, risk management, and cost benefit analysis in an integrated, holistic manner, together would be a good combination of decision making tools supporting sustainable development (Farber 2015; Etkin et al. 2012).

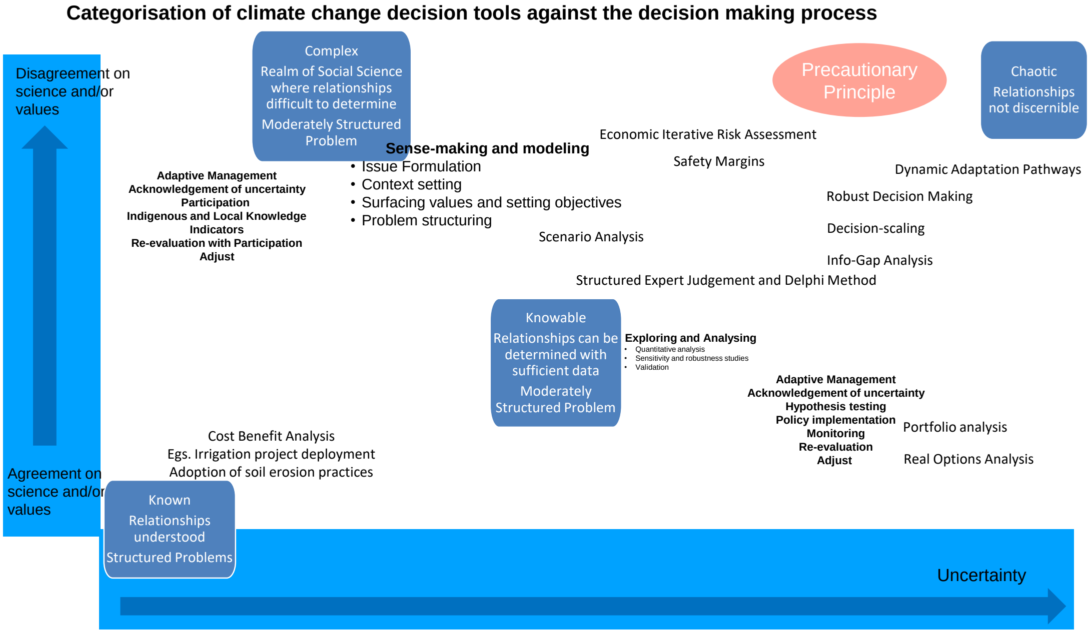

Figure 7.7 Structural and Uncertain Decision Making. Source: Adapted from (Hurlbert 2018b; Hurlbert and Gupta 2016; Hoppe 2011; French 2013, 2015)

7.6.3 Best practices of decision making toward sustainable land management

Sustainable land management is a strategy and also an outcome (Waas et al. 2014) and decision making practices are fundamental in achieving it as an outcome (*medium agreement and medium evidence*). Sustainable land management decision making is improved (*high agreement, and medium evidence*) with ecological service mapping with three characteristics: robustness (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); transparency (to contribute to clear information-sharing and the creation of linkages with decision support processes); and relevancy to stakeholders (people-central in which stakeholders are engaged at different stages) (Willemen et al. 2015; Ashcroft et al. 2016). Practices that advance sustainable land management include remediation practices as well as critical interventions that are reshaping norms and standards: adoption versus adaptation of measures; joint implementation, experimentation, and integration of rural actors' agency in analysis and approaches in decision-making (Hou and Al-Tabbaa 2014).

There is *medium agreement and medium evidence* about what factors consistently determine the adoption of agricultural best management practices (Herendeen and Glazier 2009) and these positively correlate to education levels, income, farm size, capital, diversity, access to information, social network. Attending workshops for information and trust in crop consultants are also important factors in adoption of best management practices (Ulrich-Schad, J.D., Garcia de Jalon, S., Babin, N., Paper, A. 2017; Baumgart-Getz et al. 2012). More research is needed on the sustained adoption of these factors over time (Prokopy et al. 2008).

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 with the participation of stakeholders and social learning (Section 0) (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).

7.6.4 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 decision making (Allen et al. 2011; Williams 2011) that 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 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 that includes stakeholder participation (see 7.6.5) (Foxon et al. 2009). In the adaptive management process the problem and desired goals are identified, evaluation criteria formulated, the system boundaries and context are ascertained, tradeoffs evaluated, decisions are made regarded responses and policy instruments, which are implemented, and monitored, evaluated and adjusted (Allen et al. 2011). 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) as illustrated in Figure 7.8.

Figure 7.8 Adaptive Governance, Management, and Comprehensive Iterative Risk Management. Source: Adapted from (Ammann 2013; Allen et al. 2011)

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) (see 7.6). 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 because of several challenges: lack of clarity in definition and approach, few success stories on which to build an experiential base practitioner knowledge of adaptive management, paradigms surrounding management, policy and funding that favour reactive approaches instead of the proactive adaptive management approach, shifting objectives that do not allow for the application of the approach, and failure to acknowledge social uncertainty (see 7.3.1) (Allen et al. 2011). Adaptive management includes participation (7.5.5), the use of indicators (7.5.6), in order to avoid maladaptation (7.5.7) and trade-offs while maximizing synergies (7.5.8).

7.6.5 Participation

It is recognized that more benefits are derived when citizens actively participate in conservation and management decisions, thus transcending the deficit model (*high confidence*) (Jansujwicz et al. 2013), drawing on local knowledge, challenging external scientists, supported by strong laws, institutions, collaborative platforms, leaders are able to find transparent and effective solutions for conflicts (Couvet and Prevot 2015; Johnson et al. 2017). However, participation and empowerment is constrained by the absence of systematic leadership, the lack of consensus on the place of direct citizen participation, and the limited scope and powers of participatory innovations (Fung 2015).

In terms of participation of decision making, 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 solutions, technology or infrastructure projects, 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, including multi-stakeholder forums, 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 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 uncertainty in respect of science, and/or 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), emphasizing diversity of perceptions to adaptation and mitigation options (Capstick et al. 2015). It is important to consider the method of engaging citizens with climate science, to promote (or encourage) the development of connected trans-local knowledge, prevent techno-scientific closure and encourage reflexive arguments (Blue and Medlock 2014; Voß and Amelung 2016).

Indigenous knowledge, citizen science, participatory modelling, among others, 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.

7.6.5.1 Indigenous and Local knowledge

The importance of indigenous and local 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 in overlapping ways; indigenous, local, traditional and traditional ecological knowledge, standardised for convenience here as indigenous and local knowledge (ILK). ILK.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. 2011b) and (Naess 2013) 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 ILK for adaptation, among farmers, pastoralists and hunter-gatherers. Nyong et al (2007) show the congruence of traditional practices like agroforestry based on ILK with the requirements for climate mitigation. However, (Apraku et al. Submitted) follow another strand in analysis of ILK 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 decision-making and social learning. ILK is context-specific and dynamic in nature, but also embedded in local institutions (Naess 2013). Respect for ILK is both a requirement and an entry strategy for participatory planning of climate action and effective communication of climate action strategies (Nyong et al 2007). 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, and some authors note the limits of ILK in adapting to climate conditions not previously experienced, and to rapid change (Naess 2013; Morton 2017). In many areas inter-generational transfer of local knowledge is weakening, through the decline of direct contact with the environment with livelihood diversification and urbanisation, the modern education system, and the association of modernity with scientific and "western" knowledge (Apraku et al.; Speranza et al. 2010). Attempts to integrate ILK and scientific knowledge may be affected by power relations (Alexander et al. 2011c; Naess 2013), specifically related to climate change, disproportionate impacts on future generations, marginalized groups and poorer citizens and asymmetries in decision-making power undermine proper determine appropriate adaptation responses (Tanner et al. 2015), which include the use of different types of knowledge for adaptation. Apraku et al. (forthcoming) give examples of policy and programming in Kenya to integrate local and scientific knowledge: the Agricultural Sector Development Programme mandates national and county governments in Kenya to use local knowledge in agricultural development, and the Radio Africa Network (RANET) initiative uses the combination of modern science and local knowledge to educate and inform farmers on climate change and agricultural issues, while in their other case-study in the Eastern Cape in South Africa they found an absence of comparable initiatives.

7.6.5.2 Citizen Science

Citizen science is a democratic approach to science involving citizens in collecting, classifying, and interpreting data to influence policy and assist decision processes, including issues relevant to 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 phone-based apps, cloud-based services, ground sensors, drone imagery, and others), 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). On the other hand, there is *limited evidence* of direct conservation impact (Ballard et al. 2017) and improvement of social learning (Loos et al. 2015), and most of the cases derive from rich industrialised countries (Loos et al. 2015). There are many practical challenges to the concept of citizen science at the local level, which includes the lack of universal implementation framework 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, and despite that uncertainty related to citizen science is recognized and managed (Swanson et al. 2016; Bird et al. 2014; Lin et al. 2015), there is *medium agreement* that combining citizen science and participatory modelling has favourable outcomes and improves environmental decision making (Gray et al. 2017).

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 significant potential for combining citizen science and participatory modelling to obtain favourable outcomes and improving environmental decision making (Gray et al. 2017). Citizen participation in land use simulation integrates stakeholders preferences through the generation of parameters in analytical and discursive approaches (Hewitt et al. 2014), supports the translation of narrative scenarios to quantitative outputs (Mallampalli et al. 2016), support the develop digital tools to be used in co-designing decision making participatory structures (Bommel et al. 2014), and use of games to understand the preferences of a local decision making when exploring various (more or less balanced) policies about risks (Adam et al. 2016).

7.6.5.3 Participation, Collective Action, and Social Learning

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) when barriers for meaningful participation are surpassed (Clemens et al. 2015). 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). 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 programmes 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 a 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. Moreover, specific cases highlight the inclusion of individuals and communities in land management and climate, which include the successful implementation of national-level land transfer policies (Liu and Ravenscroft 2017), rural development and land sparing (Jelsma et al. 2017), and the development of tools to identify shared objectives, trade-offs and barriers (Nieto-Romero et al. 2016; Nikolakis et al. 2016). While current research recognises the critical importance that 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). Important drivers, include ownership, empowerment or self-reliance, time effectiveness, livelihood security, and plan implementation (Samaddar et al. 2015; Djurfeldt et al. 2018).

In terms of adoption of policies, collective action has been shown to be affected by several 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.

A product of participation, equally important in practical terms, is social learning, which 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 for engaging with uncertainty (Newig et al. 2010) and addressing the increasing unequal geography of food security (Sonnino et al. 2014). 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 the social difference and power (Harvey et al. 2012; Ensor and Harvey 2015).

There are *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).

7.6.5.4 Corruption and elite capture

Climate action is subject to challenges and pressures, at levels from the local to the global, that risk creating inequitable or unjust outcomes (Sovacool 2018). This includes risks of corruption in REDD+ processes (Sheng et al. 2016; Williams and Dupuy 2018) and of corruption or elite capture in broader forest governance (Sundström 2016; Persha and Andersson 2014), as well as elite capture of benefits from planned adaptation at a local level (Sovacool 2018).

Peer-reviewed empirical studies that focus on corruption in climate finance and climate interventions, particularly at a local level, 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, 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. At the country level, historical levels of corruption are shown to affect current climate polices and global cooperation (Fredriksson and Neumayer 2016). Brown (2010) sees three likely inlets of corruption into REDD: in the setting of forest baselines, the reconciliation of project and natural credits, and the implementation of control of illegal logging. The transnational and north-south dimensions of corruption are highlighted by debates on which US legislative instruments (e.g., the Lacey Act, the Foreign Corrupt Practices Act) could be used to prosecute the northern corporations that are involved in illegal logging (Gordon 2016; Waite 2011).

Fadairo et al. (2017) carried out a structured survey of perceptions of households in forest-edge communities served by REDD+, as well as those of local officials, in south eastern Nigeria. 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, national or international, economic or official) can capture the benefits of climate intervention. At the local level, the risks of corruption and elite capture of the benefits of climate action are high in decentralized regimes (Persha and Andersson 2014). Where there are pre-existing inequalities and conflict, participation processes need careful management and firm external agency to achieve genuine transformation and avoid elite capture (Rigon 2014). An illustration of the range of types of such capture is given by Sovacool (2018) for adaptation initiatives including coastal afforestation, combining document review and key informant interviews in Bangladesh, wiinth an analytical approach from political ecology. Four processes are discussed: 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.

7.6.6 Performance indicators

Measuring performance is important in adaptive management 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) focused on reporting the progress of implementing countries' pledges, i.e., 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 the individual sector level, specific key indicators can 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 *high agreement and medium evidence* that indicators for measuring biodiversity and ecosystem services in response to governance at local to international scale 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 be addressed by simple economic instruments and are often unrelated to short-term management or governance scales (Naeem et al. 2015) (Muradian and Rival 2012). Thus, the use of indicators for biodiversity and ecosystem services for monitoring impacts of governance and management regimes on land-climate interfaces needs the participation of relevant stakeholders as well as periodic and effective communication. The adoption of non-economic approaches that are part of the emerging concept of Nature's Contributions to People (NCP) could potentially elicit support for conservation from diverse section of civil society(Pascual et al. 2017).

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 bio energy sustainability (Dale et al. 2015) and vulnerability (Debortoli et al. 2018). 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. Indicators are an important consideration in decision making in relation to synergies and tradeoffs.

7.6.7 Maximizing Synergies and Avoiding Trade-offs

Synergies and trade-offs to address land and climate related measures are identified and discussed in Chapter 6. Here we discuss synergies and trade-offs in policy choices and interactions among policies. Trade-offs will exist between broad policy approaches. For example, while legislative and regulative approaches may be effective at achieving environmental goals, they may be costly and ideologically unattractive in some countries. Market-driven approaches such as Carbon pricing have uncertain effects on emissions but may be favoured politically and economically. Information provision involves little political risk or ideological constraints, but behavioural barriers may mean their effectiveness is limited (Henstra 2016). This level of trade-off is often determined by the prevailing political system.

Box 7.4 Climate and land policy scenarios for climate mitigation and sustainable land management

Future scenario analysis is a powerful tool to explore a range of assumptions about future development including mitigation choices, climate and land policies and behavioural changes (see Cross-Chapter Box 2: Scenarios, Chapter 1). This exploration of future socio-economical pathways is often based on so-called Integrated Assessment Models (IAMs). IAMs can represent the effect of various policies on the economy, energy system, land use and climate with the caveat that these policies are assumed to be effective or in some cases the policy goals (e.g., dietary change) are imposed rather than explicitly modelled (Chapter 2). In the real world, there are various barriers that can make policy implementation more difficult as discussed in section 7.5.9. Nevertheless scenario analysis can provide useful insights with respect to the relative effectiveness of various climate and land use policies and their associated trade-offs and synergies (Calvin et al. 2014).

There is *high confidence* that achieving the goal of the Paris Agreement requires a suite of climate policies, including global mitigation efforts (e.g., global carbon price, emissions constraints). Scenarios lacking such mitigation policies are found to be incompatible with the 2°C climate target (Riahi et al. 2017; Fujimori et al. 2017). Achieving the land-related SDGs may require explicit land policies, including a mix of instruments ranging from ecosystem protection schemes to yield improvement. Scenarios lacking these instruments are incompatible with most SDGs (AR5, WG3, Chapter 6) (van Vuuren et al. 2015). Land use policies strongly influence land, energy, and economics in mitigation scenarios (*high confidence*), with bio energy and BECCS incentives resulting in potentially important trade-offs with SDGs (section 7.3.3.2), while forest and ecosystem protection is likely to foster synergies (Calvin et al. 2014; Harper et al. 2018). Removing fossil fuel subsidies has the potential to reduce GHG-emission but its mitigation effectiveness is debated and possibly low (Jewell et al. 2018). Dietary change has a strong mitigation potential (Bajželj et al. 2014; Erb et al. 2016; Popp et al. 2017a) and can foster synergies with SDGs but the effectiveness of policies targeting behavioural changes remains very uncertain and need more research (IPCC 2018a).

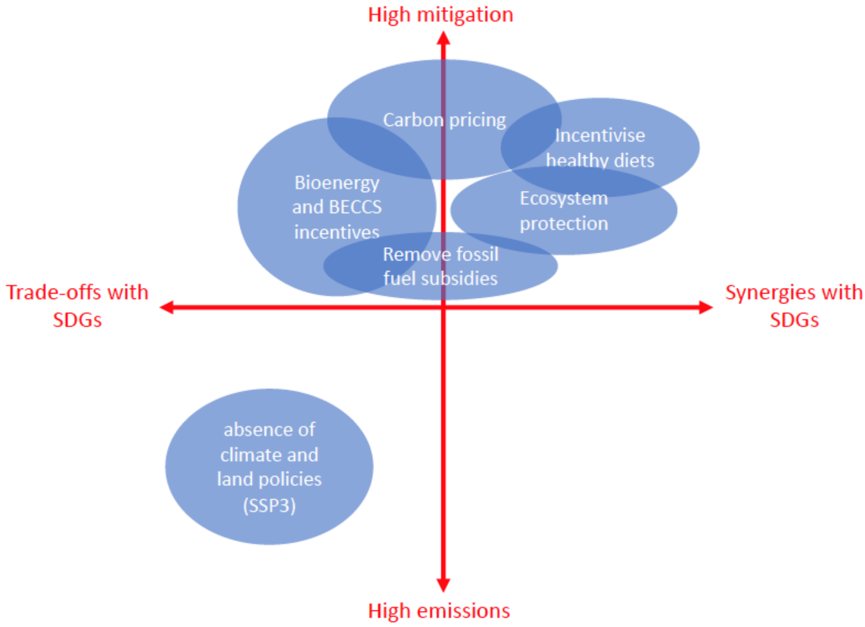

Figure 7.9 Climate mitigation effectiveness of climate and land policies (vertical axis) and associated trade-offs and synergies with SDGs (horizontal axis)

Synergies and trade-offs also result from interaction between policies (policy interplay (Urwin and Jordan 2008)) at different levels of policy (vertical) and across different policies (horizontal) – see also section on policy coherence. If policy mixes are designed appropriately, acknowledging and incorporating trade-offs and synergies, they are more likely to deliver an outcome such as transitioning to sustainability (Howlett and Rayner 2013; Huttunen et al. 2014) (*medium evidence and medium agreement).* 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).

In the agricultural sector, there has been little published empirical work on interactions between adaptation and mitigation policies. Smith and Oleson (2010) describe potential relationships, focussing particularly on the arable sector and predominantly on mitigation efforts and more on measures than policies. The considerable 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.

'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. 2014b). 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).

In the forestry sector, there is evidence that adaptation and mitigation can be fostered in concert. 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). Adaptive forest management focussing on re-introducing native tree species can provide both mitigation and adaptation benefit by reducing fire risk and increasing carbon storage (Astrup et al. 2018).

Land-based mitigation is facing important 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). Synergies between bio energy and food security could be achieved by investing in a combination of instruments 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 dietary change incentives.

7.6.7.1 Considering Synergies and Tradeoffs to Avoid Maladaptation

Coherent policies that consider synergies and tradeoffs can also reduce the likelihood of maladaptation, which is the opposite of sustainable adaptation (Magnan et al. 2016). Sustainable adaptation is 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).

Maladaptations exist across the land sector in developed and developing countries, and some may only begin to be recognised now as we become more aware of the unintended consequences of decisions.

An example prevalent across many countries is irrigation as an adaptation to water scarcity. During a drought from 2007-2009 in California, farmers adapted by using more groundwater. This depleted groundwater elevation by 50 feet. This volume of groundwater depletion is unsustainable environmentally and also emits GHG emissions during the pumping (Christian-Smith et al. 2015). Despite the three years of drought, the agricultural sector performed financially well, due to the groundwater use and crop insurance payments. Drought compensation programmes through crop insurance policies may reduce the incentive to shift to lower water-use crops, thereby perpetuating the maladaptive situation. This example highlights both the potential for maladaptation from farmers' adaptation decisions as well as the unintended consequences of policy choices and illustrates the findings of Barnett and O'Neill (2010) that maladaptation can include high opportunity costs (including economic, environmental, and social); reduced incentives to adapt (adaptation measures that reduce incentives to adapt by not addressing underlying causes); and path dependency or trajectories that are difficult to change.

In practice, maladaptation is a specific instance of policy incoherence, and it may be useful to develop a framework in designing policy to avoid this type of trade-off. This would specify 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 it 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). National level institutions that cover the spectrum of sectors affected, or enhanced collaboration between relevant institutions is likely to increase the effectiveness of policy instruments, as are joint programmes and funds (Morita and Matsumoto 2018).

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). For instance, the biogeophysical co-benefits of reduced deforestation and re/afforestation measures (Chapter 6) are usually not accounted for in current climate policies or in the NDCs, 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).

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

The transformation of river ecosystems for irrigation, hydropower 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 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.

There are however now powerful new analytical approaches, high-resolution data and decision making tools that help to predict cumulative impacts of dams and assess trade-offs between engineering and environmental goals and can help funders and decision makers to compare alternative sites or designs for dam building as well manage flows in regulated rivers based on experimental releases and adaptive learning which could minimise ecological costs and maximise synergies with other development goals under climate change (Poff et al. 2003; Winemiller et al. 2016). Furthermore the adoption of metrics based on the emerging concept of Nature's Contributions to People (NCP) under the IPBES frame-work brings in non-economic instruments and values that in combination with conventional valuation of ecosystem services approaches could elicit greater support for non-consumptive use of rivers for achieving SDG goals (De Groot et al. 2010; Pascual et al. 2017).

7.6.7.3 Sustainable Development Goals (SDGs) Synergies and Trade-offs

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 recognizes 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. 2017; 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. 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. 2017a). 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. 2017a) 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).

7.7 Governance: Governing the land-climate interface

Building on the definition of governance in section 7.2.2, 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. 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 2011). Governance processes determine how people in societies make decisions (Patterson et al. 2017) and involve the interactions among formal and informal institutions (see 7.5.1) through which people articulate their interests, exercise their legal rights, meet their legal obligations, and mediate their differences (Plummer and Baird 2013).

The act of governance "is a social function centred on steering collective behaviour toward desired outcomes and away from undesirable outcomes" (Young 2017a), here sustainable development. 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 2017a) and used to address the interconnected challenges facing food and agriculture (FAO 2017b). These challenges include assessing, combining, and implementing policy instruments at different governance levels in a mutually reinforcing way, managing trade-offs, and capitalizing on synergies and employing experimentalist approaches for improved and effective governance (FAO 2017b). 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). This section will start with describing institutions and institutional arrangements (the core of a governance system (Young 2017)) that build adaptive capacity, modes, levels and scales of governance for sustainable development, describe adaptive governance that responds to uncertainty, explore institutional dimensions of adaptive governance that create an enabling environment for strong institutional capital, discuss land tenure (an important institutional context for effective and appropriate selection of policy instruments), and end with the participation of people in decision making through inclusive governance.

7.7.1 Institutions Building Adaptive Capacity

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). Institutionalized rule systems that include formal and informal governance structures determine vulnerability as they influence power relations, risk perceptions and establish the context wherein risk reduction, adaptation and vulnerability are managed (Cardona 2012). Institutions contribute to the management of a community's assets, the community members' interrelationship, and their relationships with natural resources (Hurlbert and Diaz 2013). Institutions may also prevent the development of adaptive capacity when they are 'sticky' or characterised by strong path dependence (Mahoney 2000) (North 1991) and prevent changes that are important to address climate change (see Barriers to policy implementation 7.4.9 and Formal and Informal Decision Making 7.5.1 and Barriers of Sustainable Land Management and Overcoming Barriers (7.5.9).

Traditional or locally-evolved institutions, backed by cultural norms, can contribute to resilience and adaptive capacity: Anderson et al. suggest these are particularly a feature of dry land societies that are highly prone to environmental risk and uncertainty (Anderson et al. 2010). Concepts of resilience, and specifically the resilience of socio-ecological systems, have advanced analysis of adaptive institutions and adaptive governance in relation to climate change and land (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" (see 7.5) (Boyd and Folke 2012) (see 7.5). Shortcomings of resilience theory include limits in relation to its conceptualization of social change (Cote and Nightingale 2012), its potential to be used as a normative concept implying politically prescriptive policy solutions (Thorén and Olsson 2017; Weichselgartner and Kelman 2015; Milkoreit et al. 2015), and its potential to hinder evaluation of policy effectiveness (Newton 2016; Olsson et al. 2015). Regardless, concepts of adaptive institutions building adaptive capacity in complex socio-ecological systems governance have progressed (Karpouzoglou et al. 2016; Dwyer and Hodge 2016) in relation to adaptive governance (Koontz et al. 2015).

The study of institutions of governance, levels, modes, and scale of governance, in a multi-level and polycentric fashion is important because of the multi-scale nature of the challenges to resilience, dissemination of ideas, networking and learning.

7.7.2 Levels, Modes, and Scale of Governance for Sustainable Development

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). Implementation of climate change adaptation has been impeded by institutional barriers including multi-level governance and policy integration issues (Biesbroek et al. 2010). To overcome these barriers, 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 been placed in an "earth system" context, showing the existence of complex interactions and governance requirements across different levels and calling for a radical transformation in governance, rather than minor adjustments (Biermann et al. 2012). Climate governance literature has expanded since AR5 in relation to the sub-national and transnational levels.

Sub-national governance efforts for climate policy, especially at the level of cities and communities, have become significant during the past decades (*medium evidence, medium agreement*). A transformation of sorts has been underway through deepening engagement from the private sector and NGOs as well as Government involvement at multiple levels. It is now recognized that business organizations, civil society groups, citizens, and formal governance all have important roles in governance for sustainable development (Kemp et al. 2005).

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).

To address shortcomings of transnational governance, 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).

Sustainable development hinges on the holistic integration of interconnected land and climate issues, sectors, levels of government, and policy instruments (see Policy Coherence 7.5.8), that address the increasing volatility in oscillating systems and weather patterns (Young 2017b; Kemp et al. 2005) 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 polycentric 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 (*medium confidence*). 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). In an assessment of 166 initiatives in 16 countries, integrated landscape initiatives were found to address the drivers of agriculture, ecosystem conservation, livelihood preservation and institutional coordination. However, such initiatives struggled to move from planning to implementation due to lack of government and financial support and powerful stakeholders sidelining the agenda (Zanzanaini et al. 2017). Integrated land use planning coordinated through multiple government levels balances property rights, wildlife and forest conservation, encroachment of settlements and agricultural areas and can reduce conflict (*high confidence*) (Metternicht 2018).
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, for example 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, for example events that occur periodically vs. those that occur infrequently and/or irregularly. In the case of food security abrupt and protracted events of food insecurity might occur. 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.

7.7.3 Adaptive Governance Responding to Uncertainty

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 builds on multi-level and polycentric governance. 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). There is *medium agreement and medium* evidence that 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 allowed 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 (see 7.6.4) (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 the use of scenario planning and reiterative policy review (Boyd et al. 2015). Adaptive governance can be conceptualized as including multilevel governance with a balance between top-down and bottom-up decision making that is performed by many actors (including citizens) in both formal and informal networks, allowing policy measures and governance arrangements to be tailored to local context and matched at the appropriate scale of the problem, allowing for opportunities for experimentation and learning by individuals and social groups (Rouillard et al. 2013; Hurlbert 2018b).

Expert thinking has evolved from implementing good governance at high levels of governance (with governments) to a decentred problem solving approach consistent with adaptive governance. This approach involves iterative bottom up and experimental mechanisms that might entail addressing tenure of land or forest management through a territorial approach to development, thereby supporting multi-sectoral governance in local, municipal, and regional contexts (FAO 2017b).

There is *high agreement and robust evidence* that resource and disaster crises are crises of governance (Pahl-Wostl 2017a; Villagra and Quintana 2017; Gupta et al. 2013). Adaptive governance of risk has emerged in response to these crises and involves four critical pillars including 1) sustainability as a response to environmental degradation, resource depletion and ecosystem service deterioration; 2) recognition that governance is required as government is unable to resolve key societal and environmental problems including climate change and complex problems; 3) mitigation is a means to reduce vulnerability and avoid exposure; and 4) adaptation responds to changes in environmental conditions (Fra.Paleo 2015).

There is *high agreement and medium evidence* that participatory processes in adaptive governance within and across policy regimes overcome limitations of polycentric governance allowing priorities to be set in sustainable development through rural land management and integrated water resource management (Rouillard et al. 2013). Adaptive governance addresses large uncertainties and their social amplification through differing perceptions of risk (Kasperson 2012; Fra.Paleo 2015) offering an approach to co-evolve with risk by implementing policy mixes and assessing effectiveness in an ongoing process, making mid-point corrections when necessary (Fra.Paleo 2015). In respect of climate adaptation to coastal and riverine land erosion due to extreme weather events impacting communities, adaptive governance offers the capacity to monitor local socio-economic processes and implement dynamic locally informed institutional responses. In Alaska adaptive governance responded to the dynamic risk of extreme weather events and issue of climate migration by providing a continuum of policy from protection in place to community relocation, integrating across levels and actors in a more effective and less costly response option than other governance systems (Bronen and Chapin 2013). In comparison to other governance initiatives of ecosystem management aimed at conservation and sustainable use of natural capital, adaptive governance has visible effects on natural capital by monitoring, communicating and responding to ecosystem-wide changes at the landscape level (Schultz et al. 2015). Adaptive governance 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 areas of natural resource management including landscape care and watershed or catchment management groups (Nelson et al. 2008).

There is *high agreement and medium evidence* that transformational change is a necessary societal response option to manage climate risks which is uniquely characterized by the depth of change needed to reframe problems and change dominant mindsets, the scope of change needed (that is larger than just a few people) and the speed of change required to reduce emissions (O' Brien et al. 2012; Termeer et al. 2017). Transformation of governance is required to achieve this, which can happen by intervention strategies that enable small in-depth wins, amplify these small wins through integration into existing practices, and unblock stagnations (locked in structures by advancing learning) preventing transformation by confronting social and cognitive fixations with counterintuitive interventions

(Termeer et al. 2017). Iterative consideration of issues and reformulation of policy instruments and response options facilitates this by allowing experimentation (Monkelbaan 2019).

There is *high agreement and high evidence* that in order to manage uncertainty, natural resource governance systems need to allow agencies and stakeholders to learn and change over time responding to ecosystem changes and new information with different management strategies and practices that involve experimentation (Camacho 2009; Young 2017b). There is an emerging literature on experimentation in governance surrounding climate change and land use (Kivimaa et al. 2017a) including policies such as REDD+ (Kaisa et al. 2017). Governance experiment literature could be in relation to scaling up policies from the local level for greater application, or downscaling policies addressing broad complex issues such as climate change, or addressing necessary change in social processes across sectors (such as water energy and food) (Laakso et al. 2017). Successful development of new policy instruments occurred in a governance experiment relating to coastal policy adapting to rising sea levels and extreme weather events through planned retreat (Rocle and Salles 2018). Experiments in emission trading between 1968 and 2000 in the United States of America helped to realize specific models of governance and material practices through mutually supportive lab experiments and field application that advanced collective knowledge (Voß and Simons 2018).

Box 7.5 Adaptive 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). 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).

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). Integrated governance, policy coherence, and use of multi-functional systems are required to advance synergies across land, water, energy and food sectors (Liu et al. 2017).

Case Study: Flood and Food Security

While floods can sustain riverine ecosystems and flood plain communities, they can also negatively impact food security. Between 2003-2013 floods were the most impacting natural disaster on crop production (FAO 2015b).

In developing countries flood jeopardizes primary access to food. In Bangladesh the 2007 flood is calculated to have reduced average consumption by 103Kcal/cap/day (worsening the existing 19.4% calories deficit) and in Pakistan the 2010 flood resulted in a loss of 205 Kcal/cap/day, or 8.5% of the Pakistan average food supply. The Pakistan 2010 flood affected over 4.5 million workers, two thirds employed in agriculture; 79% of farms lost greater than one half of their expected income (Pacetti et al. 2017). A historical study of Malawi agricultural production failures found flood impacts cascaded through labour, trade and transfer systems. First a harvest failure occurred, followed by the decline of employment opportunities and reduction in real wages, followed by a market failure or decline in trade ultimately followed by a failure in informal safety nets (Devereux 2007). Planned policy responses include those that address the sequential nature of the cascading impacts starting with 'productivity-enhancing safety nets" addressing harvest failure, then public works programmes addressing the decline in employment opportunities, followed by food price subsidies to address the market failure, and finally food aid to address the failure of informal safety nets (Devereux 2007). In range lands of East Africa, flood resulted initially in no sales of livestock, falling food prices, and loss in grain production. Local food shortages couldn't be supplemented with imports due to destruction of transport links, and pastoral incomes were inadequate to purchase food. Livestock diseases became rampant and eventually food shortages led to escalating prices. Due to the contextual nature and timing of events, policy response initially addressed mobility and resource access and eventually longer term issues such as livestock disease (Little et al. 2001).

In North America increasing flood incidence has changed societal expectations from total protection by the state (largely through scientific and engineering developments such as dams) to one of state managed risk (Tarlock 2012). Floods impact agriculture and food production, but are measured by total cost (the 1997 Red River Basin flood cost Manitoba, Canada 1 Billion dollars and the United States of America, 4 Billion dollars (Adaptation to Climate Change Team 2013). In Canada 82% of disaster financial assistance from 2005-2014 was paid in respect to floods (Public Safety Canada 2017). Future climate change may result in a six foot rise in sea level by 2100 costing from USD507 to 882 Billion, affecting 300 American cities (losing one half of their homes) and the wholesale loss of 36 cities (Lemann 2018). Flood control projects are increasingly too expensive and worsening the exposure of people. Historic legal mechanisms for retreating from low lying and coastal areas have failed to encourage relocation of people out of flood plains and areas of high risk (Stoa 2015).

Policy measures are increasingly important as an increasingly warming world may make post disaster assistance and insurance increasingly unsustainable (Surminski et al. 2016). Americans have spent the past Century populating low-lying flood prone and coastal areas. This situation has been exacerbated due to cheap flood insurance and massive federal aid programs (Lemann 2018). Although the state makes disaster assistance payments, it is local governments that determine vulnerability through flood zone mapping, restrictions from building in flood zones, building requirements (Stoa 2015). Integrated planning for flood and a comprehensive policy mix (see 7.4) (implemented through adaptive management as illustrated on Figure 7.9). The local government is required to reduce vulnerability (Hurlbert 2018b) (Hurlbert 2018a). Policy mixes that allow people to respond to disasters including bankruptcy, insolvency rules, house protection, income minimums, and basic agricultural implement protection laws, need to be implemented, reviewed and coordinated to allow people to recover and if necessary migrate to other areas and occupations (Hurlbert 2018b).

At the international level, reactionary disaster response has evolved to proactive risk management that combines adaptation and mitigation responses to ensure effective risk response, build resilient systems and solve issues of structural social inequality (Innocenti and Albrito 2011) and illustrated on Figure 7.10 Ex ante measures of preparedness are the main instruments to reduce fatalities and limit damage. The Sendai Declaration and Framework for Disaster Risk Reduction 2015-2030, is an action plan to reduce mortality, the numbers of affected people and economic losses with four priorities - understanding disaster risk, strengthening its governance to enhance the ability to manage disaster risk, investing in resilience, and enhancing disaster preparedness. There is *high agreement and medium evidence* that the Sendai Framework significantly refers to adaptive governance and could be a window of opportunity to transform disaster risk reduction to address the causes of vulnerability (Munene et al. 2018). Addressing disasters increasingly requires individual, household, community and national planning and commitment to a new path of resilience and shared responsibility through whole community engagement and linking private and public infrastructure interests (Rouillard et al. 2013). It is recommended that a vision and overarching framework of governance be adopted to allow participation and coordination by government, nongovernmental organizations, researchers and the private sector, individuals in the neighbourhood community. Complementary structural and non-structural measures should be implemented together with measurable scorecard indicators (Chen 2011).

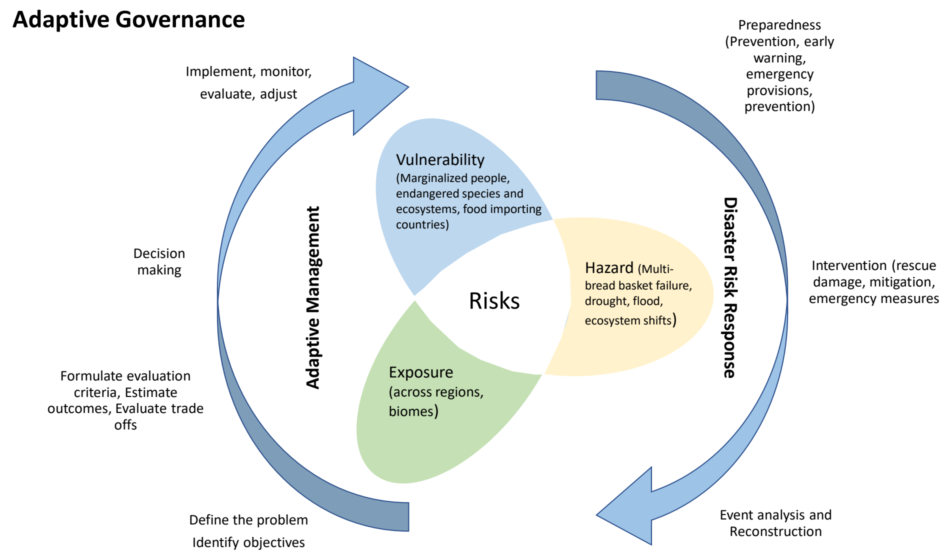

Figure 7.10 Adaptive Governance, Disaster risk response and Adaptive Management

Adaptive management identifies and responds to exposure and vulnerability to land and climate change impacts by identifying problems and objectives, making decisions in relation to response options and instruments advancing response options in the context of uncertainty. These decisions are continuously monitored, evaluated and adjusted to changing conditions. Similarly disaster risk management responds to hazards through preparation, prevention, response, analysis, and reconstruction in an iterative process.

Case Study: Governance of bio fuels and bio energy

Modern bio energy is envisioned to make an increasing contribution to future sustainable energy supply due to its versatility across all energy carriers, although the possible range is quite wide depending on assumptions; for 1.5C-consistent pathways, the bio energy contribution by 2050 ranges from 40-310 EJ (IPCC-1.5°C report). The global technical potential of bioenergy ranges as high as 1700 EJ; the potential that is sustainable and achievable by 2100 is likely to be much lower but estimates are highly context-specific to particular scenarios and vary widely according to the associated assumptions and parameters. It is also important to note that more than 50% of biomass used for energy today is for traditional uses, which contributes 1.9-2.3% of global GHG emissions (Cross-Chapter Box 8: Traditional Biomass).

Tradeoffs can be reduced with analysis of the contribution of bioenergy to climate change mitigation taking into account the interdependencies between different risks and opportunities associated with a large-scale expansion, especially in relation to water resources and food security. (Pahl-Wostl et al. 2018a; Kurian 2017; Franz et al. 2017; Chang et al. 2016; Larcom and van Gevelt 2017; Lubis et al. 2018; Alexander et al. 2015b; Rasul 2014; Bonsch et al. 2016; Karabulut et al. 2018; Mayor et al. 2015) (*high agreement*, *medium evidence*). Opportunities are linked to the broader development of bioeconomy and especially the economic benefits for rural development (Cross-Chapter Box 8: Traditional Biomass).

There is medium agreement and medium evidence that a large-scale expansion of bioenergy and biofuels will increase competition for land and water, potentially including lands with high carbon stocks or high conservation value and biodiversity. (DeCicco 2013; Bárcena et al. 2014; Humpenöder et al. 2017; Harris et al. 2015; Richards et al. 2017a; Ahlgren et al. 2017; Bonsch et al. 2016).

Although carbon-capture technologies (storage or utilization) are considered convenient to enhance the mitigation capacity of bioenergy and biofuels in the case of wide-scale deployment (Yue et al. 2014;

Muratori et al. 2016; Humpenöder et al. 2014; Pour et al. 2017; Venton 2016), it is very likely that a large bioenergy expansion requires substantial land-use change (LUC) at a global scale. (Berndes et al. 2015; Popp et al. 2014a; Chen et al. 2018; Wilson et al. 2014; Behrman et al. 2015; Richards et al. 2017b; Harris et al. 2015). Given the potential environmental and socio-economic risks concerning large-scale bioenergy development, land use change impacts (direct and indirect) are crucial aspects of assessing bioenergy sustainability (S. Ahlgren & Di Lucia, 2014; Don et al., 2012; Popp et al., 2014; Qin, Dunn, Kwon, Mueller, & Wander, 2016). (*high agreement, medium evidence*)

For example, although the direct effects of LUC related to bioenergy expansion could produce alterations of the carbon stock in standing biomass (soil organic carbon), there may also be biodiversity impacts, nutrient leakage, and increase greenhouse gas emissions as N_2O and CH_4 (Harris et al. 2018; Wiloso et al. 2016; Valdez et al. 2017; Behrman et al. 2015) (*medium evidence, high agreement*), these impacts could vary depending on various factors as the starting land use and the type of land, the kind of bioenergy crops, the initial carbon stocks, the climatic region where the land exists, as well as the management regime and the technology used along the value chain. (Qin et al. 2016; Del Grosso et al. 2014; Popp et al. 2017a; Davis et al. 2013; Mello et al. 2014; Hudiburg et al. 2015; Carvalho et al. 2016; Silva-Olaya et al. 2017; Whitaker et al. 2018; Alexander et al. 2015b). (*high agreement, medium evidence)*

Bioenergy may compete in some cases with food, either directly, if food commodities are used as the energy source, or indirectly, if bioenergy crops are cultivated on soil that could be used for food production. If demand for bioenergy crops grows significantly, impacts on food prices could be significant in some cases (Popp et al. 2014b; Bailey 2013; Pahl-Wostl et al. 2018b; Rulli et al. 2016; Yamagata et al. 2018; Kline et al. 2017; Schröder et al. 2018; Franz et al. 2017) (*high agreement, low evidence*). However, the impact on food prices depends on many factors, and the implications for food security can also be positive or negative across various scenarios (Martin Persson 2015; Roberts and Schlenker 2013; Borychowski and Czyżewski 2015) (*medium agreement, medium evidence*). Beyond these uncertainties, it is likely that the use of non-edible crops in degraded and marginal lands for bioenergy expansion could reduce land competition and the associated risk for food security (Manning et al. 2015; Maltsoglou et al. 2014; Zhang et al. 2018; Gu and Wylie 2017; Kline et al. 2017)(*high agreement, low evidence*).

Associated to food security and large-scale bioenergy production, another risk is water availability, insofar as water demand for bioenergy production might place an additional burden on water resources (Rulli et al. 2016; Pahl-Wostl et al. 2018b; Bailey 2013; Bárcena et al. 2014; Chang et al. 2016)(*high agreement, medium evidence*). Although it will depend on what crop is being replaced and how water intensive is the biomass feedstock, it is likely that the competition for water resources could be a limiting factor for large-scale bioenergy expansion under a business as usual scenario (Hamilton et al. 2015; Scarpare et al. 2016; Mathioudakis et al. 2017; Popp et al. 2017a; Bonsch et al. 2016)

Given the complexities associated with large-scale bioenergy and biofuels expansion, governance of these different risks should be addressed in an integrated manner (Weitz et al. 2017b; Pahl-Wostl et al. 2018b) (*high agreement, low evidence*). It is very likely that to maximize the benefits of bioenergy expansion, these risks should be approached from a nexus perspective that links water, energy, and food security in order to deal with complex and interconnected resource management challenges, coordination failures, entrenched domain interests, and power structures, as well to leverage synergies related to systemic governance of risk. (Bizikova et al. 2013; Rouillard et al. 2017; Pahl-Wostl 2017b; Lele et al. 2013; Rodríguez Morales and Rodríguez López 2017; Larcom and van Gevelt 2017; Pahl-Wostl et al. 2018a).

7.7.4 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 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 2008a), 18% of *global* forest area was held under common property systems (Chhatre and Agrawal 2008). Understanding the interactions between land tenure and climate change has to be based on underlying understanding of land tenure and land policy and how they relate to sustainable development, especially in low- and middle-income countries: such understandings have changed considerably over the last three decades , and now show that informal or customary systems can provide secure tenure, but also that where such systems are unrecognised or weakened by governments or the rights from them undocumented or unenforced, tenure insecurity may result (Lane 1998; Toulmin and Quan 2000).

Understanding of land tenure under climate change also has to take account of the growth in large-scale land acquisitions, also referred to as landgrabbing, in developing countries. (Deininger 2011) links the growth in demand for land to the 2007-2008 food price spike, since which it has remained at "extraordinarily high levels"(Deininger 2011, p. 218), especially in Africa, and demonstrates that high levels of demand for land at the country level are statistically associated with weak recognition of land rights. Though data is poor, domestic investment has in fact been more important than foreign investment (Deininger 2011; Cotula et al. 2014). (De Schutter 2011) argues that large-scale land acquisitions will a) result in types of farming less liable to reduce poverty than smallholder systems, b) increase local vulnerability to food price shocks by favouring export agriculture and c) accelerate the development of a market for land with detrimental impacts on smallholders and those depending on common property resources. (Cotula et al. 2014) note the extremely poor quality of data on such acquisitions but are able to present cross-checked data for completed lease agreements in Ethiopia, Ghana and Tanzania. In the three countries 174, 28 and 64 deals had been completed respectively, with mean sizes of 4516 ha, 9374 ha and 7262 ha, representing 1.9%, 1.9% and 1.1% of each country's total land suitable for agriculture.

Table 7.5 sets out, in highly summarised form, some key findings on the multi-directional inter-relations between land tenure and climate change, with particular reference to developing countries. The rows represent different categories of landscape or resource systems. For each system the second column summarises current understandings on land tenure and sustainable development, in many case predating concerns over climate change. The third column summarises the most important implications of land tenure systems, policy about land tenure, and the implementation of that policy, for vulnerability and adaptation to climate change, and the fourth gives a similar summary for mitigation of climate change. The fifth column summarises key findings on how climate change and climate action (both adaptation and mitigation) will impact land tenure, and the final column findings on implications of climate change for evolving land policy.

Table 7.5 Major Findings on the Interactions between Land Tenure and Climate Change

Landscape or natural resource system	State of understanding of land tenure, land policy and sustainable development	Implications of land tenure for vulnerability and adaptation to climate change	Implications of land tenure for mitigation of climate change	Impacts of climate change and climate action on land tenure	Implications of climate change and climate action for land policy
Smallholder cropland	In South Asia and Latin America the poor suffer from limited access including insecure tenancies, though this has been partially alleviated by land reform.[a] In Africa informal/customary systems may provide considerable land tenure security and enable long-term investment in land management, but are increasingly weakened by demographic pressures on available land resources increase. Creation of freehold rights through conventional land titling is not a necessary condition for tenure security and may be cost-ineffective or counter-productive.[b,c,d,e] Alternative approaches utilising low cost technologies and participatory methods are available.[f]	Insecure land rights are one factor deterring adaptation and accentuating vulnerability.[g,h] Specific dimensions of inequity in customary systems may act as constraints on adaptation in different contexts.[i]	Secure land rights, including through customary systems, can incentivise farmers to adopt climate-smart practices,[j] e.g., planting trees in mixed cropland/forest systems.[k]	Increased frequency and intensity of extreme weather can lead to displacement and effective loss of land rights.[l] REDD+ programmes tend slightly to increase land tenure insecurity on agricultural (but not on forest) lands.[m]	Landscape governance and resource tenure reforms at farm and community levels can facilitate and incentivize planning for landscape management and enable the integration of adaptation and mitigation strategies.[h]
Rangelands	Communal management of rangelands in pastoral systems is a rational and internally sustainable response to climate variability and the need for mobility. Policies favouring individual or small group land-tenure may have negative impacts on both ecosystems and livelihoods.[n,o,p]	Erosion of traditional communal rangeland tenure has been identified as a determinant of increasing vulnerability to drought and climate change and as a driver of dryland degradation.[q,r,s,t,u]	Where pastoralists' traditional land use does not have legal recognition, or where pastoralists are unable to exclude others from land use, this presents significant challenges for carbon sequestration initiatives.[v,w]	Increasing conflict on rangelands is a possible result of climate change and environmental pressures, but depends on local institutions.[x] Where land use rights for pastoralists are absent or unenforced, demonstrated potential for carbon	Carbon sequestration initiatives on rangelands may require clarification and maintenance of land rights.[v,w]

				sequestration may assist advocacy.[w]	
Forests	Historical injustices towards forest dwellers can be ameliorated with appropriate policy, e.g., 2006 Forest Rights Act in India.[y] Land tenure systems have complex interactions with deforestation processes. Land tenure security is generally associated with less deforestation, regardless of whether the tenure form is private, customary or communal.[z]	Land tenure policy for forests that focuses narrowly on cultivation has limited ability to reduce ecological vulnerability or enhance adaptation.[y] Secure rights to land and forest resources can facilitate efforts to stabilise shifting cultivation and promote more sustainable resource use if appropriate technical and market support are available.[aa]	Land tenure systems interact with REDD+ and other land-based mitigation actions in complex ways.[z] Communal tenure systems may lower transaction costs for REDD+ schemes, though with risk of elite capture of payments. Perceived tenure insecurity may incentivise short term resource exploitation.[k]	Findings on both direction of change in tenure security and extent to which this has been influenced by REDD+ are very diverse.[m]	Forest tenure policies under climate change need to accommodate and enable evolving and shifting boundaries linked to changing forest livelihoods.[g] REDD+ programmes need to be integrated with national-level forest tenure reform.[m]
Poor and informal urban settlements	Residents of poor and informal urban settlements enjoy varying degrees of tenure security from different forms of tenure. Security will be increased by building on de facto rights rather than through abrupt changes in tenure systems.[ab]	Public land on the outskirts of urban areas can be used to adapt to increasing flood risks by protecting natural assets.[ac] Secure land titles in hazardous locations may make occupants reluctant to move and raise the costs of compensation and resettlement.[l]	Urban land use strategies such as tree planting, establishing public parks, can save energy usage by moderating urban temperature and protect human settlement from natural disaster such as flooding or heatwaves.[ad]	Without proper planning, climate hazards can undermine efforts to recognise and strengthen informal tenure rights without proper planning.[ae,af]	Climate risks increase the requirements for land use planning and settlement planning and settlement that increases tenure security, with direct involvement of residents, improved use of public land, and innovative collaboration with private and traditional land owners.[af,ag]
Riverscapes and riparian fringes	Well-defined but spatially flexible community tenure can support regulated and sustainable artisanal capture fisheries and biodiversity.[ah,ai,aj,ak,al,am]	Unequal land rights and absence of land management arrangements in floodplains increases	Mitigation measures such as protection of riparian forests and grasslands can potentially play a major role, provided rights to		Secured but spatially flexible tenure will enable climate change mitigation in riverscapes to be synergized with local

		vulnerability and constrains adaptation.[an] Marginalized or landless fisherfolk will be empowered by tenurial rights and associated identity to respond more effectively to ecological changes in riverscapes including riparian zones.[ao,ap,aq,ar]	land and trees are sufficiently clear.[as,at]		livelihoods and ecological security.[ap,au]

Sources: a) Binswanger et al. 1995 b) Schlager and Ostrom 1992 c) Toulmin and Quan 2000 d) Bruce and Migot-Adholla 1994 e) Easterly 2008 f) McCall and Dunn 2012 g) Quan et al. 2017 h) Harvey et al. 2014 i) Antwi-Agyei et al. 2015 j) Scherr et al. 2012 k) Barbier and Tesfaw 2012 l) Mitchell 2010 m) Sunderlin et al. 2018 n) Behnke 1994) o) Lane and Moorehead 1995 p) Davies et al. 2015 q) Morton 2007 r)López-i-Gelats et al. 2016 s) Oba 1994 t) Fraser et al. 2011 u) Dougill et al. 2011 v) Roncoli et al. 2007. w) Tennigkeit and Wilkes 2008 x) Adano et al. 2012 y) Ramnath 2008 z) Robinson et al. 2014 aa) Garnett et al. 2013 ab) Payne 2001 ac) Barbedo et al. 2015 ad) Zhao et al. 2018 ae) Satterthwaite et al. 2018 af) Mitchell et al. 2015 ag) Satterthwaite 2007 ah) Thomas 1996 ai) Welcomme et al. 2010 aj) Silvano and Valbo-Jørgensen 2008 ak) Biermann et al. 2012; Abbott et al. 2007 al) Béné et al. 2011 am) McGrath et al. 1993 an) Barkat et al. 2001 ao) FAO 2015 ap) Hall et al. 2013 aq) Berkes 2001 ar) ISO 2017 as) Rocheleau and Edmunds 1997 at) Baird and Dearden 2003 au) Béné et al. 2010.

The clearest findings on land tenure and climate change relate primarily to drylands where weak land tenure security, either for households disadvantages within a customary tenure system or more widely as such a system is eroded, can be associated with increased vulnerability and decreased adaptive capacity (*limited evidence, high agreement*). For forest systems, land tenure interacts in complex ways with deforestation processes and with REDD+ and other land-based mitigation actions (*moderate evidence, high agreement*). For all the systems, an important finding is that land policies can provide both security and flexibility in the face of climate change, but through a diversity of forms (recognition of customary tenure, redistribution, regulation of rental markets, strengthening the negotiating position of the poor) rather than sole focus on freehold title (Quan and Dyer 2008) (*moderate evidence*, *high agreement*). Land policy can be climate-proofed and integrated with national policies such as NAPAs (Quan and Dyer 2008). Land administration systems have a vital role in providing land tenure security, especially for the poor, especially when linked to an expanded range of information relevant to mitigation and adaptation (Quan and Dyer 2008; van der Molen and Mitchell 2016).

A separate but related issue is that of Free Prior Informed Consent (FPIC), which as mandated by the United Nations Declaration on the Rights of Indigenous People, crucial part of self-determination, has been used as a means to ensure that people´s rights are respected when mitigating climate change, especially when using mitigation options like REDD+. Currently FPIC is applied to implementation of strategies (Kane et al. 2018) and research (Fernández-Llamazares et al. 2017). There is *strong agreement and low evidence* that FPIC is an effective tool if used correctly. Indigenous groups through FPIC are demanding proper representation of communities, including marginalized groups and true power-sharing (Sovacool et al. 2016). However, FPIC concept becomes ambiguous when it no longer refers to consent, but consultation instead, which may facilitate the widespread violation of indigenous peoples' rights (Prior and Heinämäki 2017). In terms, of implementation, FPIC is hampered by a number of legal and institutional barriers, including the non-binding nature of the FPIC guidelines and the challenges facing governments (Carodenuto and Fobissie 2015) but it is likely to be more accepted by the government if it is built upon the national legal framework on citizen rights (Pham et al. 2015).

7.7.5 Institutional dimensions of adaptive governance

The characteristics of governance systems in Table 7.6 facilitate adaptation and enhance the adaptive capacity of institutions but the governance processes and policy instruments supporting these characteristics are context specific (*high agreement, medium evidence*). The table represents a summary of characteristics, evaluative criteria, elements, or institutional design principles of institutions that advance adaptive governance.

An assessment of community forest management cases in Cameroon found that 70% of cases did not meet standards of inclusive participation. To address weak indicators, policy instruments can be implemented such as favourable loans, tax measures, and financial support to catalyze entrepreneurial leadership, and building awards for supportive and innovative elites to reduce elite capture and ensure more inclusive participation (Duguma et al. 2018). An additional study of community forest management literature concerning Cameroon determined key enablers included benefit generation, partnership, monitoring and policy support (Duguma et al. 2018). A study of adaptive governance of disaster in Canada and South America determined more focus on learning that changed underlying assumptions of institutional patterns was required (Hurlbert 2018b).

Consideration of the institutional dimension of adaptive governance is also important when implementing climate change mitigation instruments. A 'Variety,' redundancy, or duplication of climate mitigation policy instruments is an important consideration for meeting Paris Commitments. Given 58% of EU emissions are outside of the EU Emissions Trading system, implementation of a carbon tax, a redundant instrument may add co-benefits (Baranzini et al. 2017). A carbon tax phased in over time through a schedule of increases would allow for ‘Learning.’ The tax revenues could be earmarked to finance additional climate change mitigation and or redistributed to achieve ‘Equity’. It is recommended that the measure be implemented using information sharing and communication devices to enable public acceptance, openness, provide measurement and accountability, or “Fair governance’ (Baranzini et al. 2017).

Table 7.6 Institutional Dimensions or Indicators of Adaptive Governance

Characteristics	Description	References
Variety	• Room for a variety of problem frames reflecting different opinions and problem definitions • Participation. 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. 2017a; 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 inTable 7.6, 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).

7.7.6 Inclusive governance for Sustainable Development

Many sustainable development efforts fail because of lack of attention to societal issues including inequality, discrimination, social exclusion and marginalization (see Cross-Chapter Box 6: Gender) (Arts 2017a). The human rights based approach of the 2030 Agenda and Sustainable Development Goals commits to leaving no one behind (Arts 2017b). Inclusive governance for development includes social, ecological and relational components used for assessing access to, as well as the allocations of rights, responsibilities and risks with respect to social and ecological resources (Gupta and Pouw 2017).

Citizen engagement is important in enhancing natural resource service delivery by including them in management and governance decisions (see 7.6.5). In governing natural resources, focus is now not only on rights of citizens in relation to natural resources, but also on citizen obligations and responsibilities (Karar and Jacobs-Mata 2016; Chaney and Fevre 2001). This citizen engagement is also imperative for analysing and understanding pressures caused by aggregated informal coping strategies of local residents, which are important drivers of natural resource depletions particularly in developing countries, often lost in a conventional policy development processes in natural resource management (Ehara et al. 2018).

Inclusive adaptive 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 values 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).

7.8 Key uncertainties and knowledge gaps

Uncertainties in land, society and climate change processes are outlined in 7.3 and Chapter 1. This chapter has reviewed literature on risks arising from GHG Fluxes, climate change, land degradation, desertification and food security, policy instruments responding to these risks, as well as decision making and adaptive governance in the face of uncertainty.

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

- New models that allow incorporation of considerations of inequality and human agency in socio-environmental systems;
- Understanding of how policy instruments and responses can augment or reduce risks in relation to 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 knowledge considering trade-offs in climate, land, ecosystem services and food policies and an urgent need to evaluate and mitigate risks;
- The impacts of increasing use of land due to climate mitigation measures such as BECCS, carbon centric afforestation/REDD+ and their impacts on human conflict, livelihoods and displacement.

- Understanding the full cost of climate change in the context of disagreement on accounting for climate change interactions and their impact on society, as well as issues of valuation, and attribution uncertainties;
- New models and Earth observation to understand complex interactions described in this section.

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

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. Better understanding is needed of the triggers and leveraging actions that build sustainable development as well as the effective organization of the science and society interaction and in joint shaping of policies in the future. What societal interaction in the future will form inclusive and equitable governance processes and achieve inclusive just governance institutions?

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 (7.6). More inter and transdisciplinary research is required 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. 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. 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.

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. 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. More research is required to understand the interconnections of land with water, food and energy.

Cross-Chapter Box 7: Ecosystem services and their relation to the land-climate system

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This Cross-Chapter Box describes the concept of *ecosystem services (ES)*, and discusses the importance of ES in relation to climate-land interactions. ES have become an important concept since the 1990s to describe the benefits that humans obtain from ecosystems, and have strong relevance to sustainable land management (SLM) decisions and their outcomes. It is timely that the SRCCL report includes attention to ES, as the previous IPCC Special Report on Land-Use, Land-Use Change and Forestry (LULUCF) did not make use of the ES concept and focused mostly on carbon fluxes in land-climate interactions (IPCC 2000). The broader mandate of SRCCL is to address not just climate but land degradation, desertification and food security issues, all of which are closely linked to the provisioning of various ES, and the Decision and Outline for SRCCL explicitly requests an examination of how desertification and degradation "impacts on ecosystem services (e.g. water, soil and soil carbon and biodiversity that underpins them)" among other issues. Attention to ES is particularly important in discussing co-benefits, trade-offs and adverse side effects of potential climate change mitigation, land management, or food security response options, as many actions may have positive impacts on climate mitigation or food production, but may also come with a decline in ES provisioning or adversely impact biodiversity. This box considers the importance of the ES concept, how definitions have changed over time, continuing debates over operationalization and use of ES concepts, and finally concludes with how ES are treated in various chapters in this report.

The concept of ES extends back to the late 1960s and the extinction crisis, with concern that species decline might cause loss of valuable benefits to humankind (King 1966; Helliwell 1969; Westman 1977) (Helliwell 1969; Westman 1977). The first uses of the term appeared in the 1980s (Lele et al. 2013; Monney and Ehrlich 1997). A seminal paper by Costanza et al. (1997) attempted to put an economic value on the stocks of global ES and natural capital on which humanity relied. Attention to ES expanded rapidly after the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005), and the linkages between ES and economic valuation of these functions were addressed by the Economics of Ecosystems and Biodiversity study (TEEB 2009). The ES approach is increasingly used in global and national environmental assessments, including the United Kingdom National Ecosystem Assessment (Watson 2012), and recent and ongoing regional and global assessments organized by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al. 2015). IPBES has recently completed an assessment on land degradation and restoration that addresses a number of ES issues of relevance to the SRCCL report (IPBES 2018).

Although a number of policymakers have embraced the ES concept, it is unevenly applied in policy formulation worldwide. Some countries, especially in Europe, have now incorporated ES explicitly into many policy frameworks, while other countries, like the US, have not used the term as extensively. ES concepts have been incorporated into some specific national-level policies like natural capital accounting and payments for ecosystem services (PES) in over a dozen countries, including Costa Rica, Ecuador, and Vietnam (Salzman et al. 2018).

The MA defined ES as "the benefits that ecosystems provide to people," and identified four broad groupings of ES: *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling (Millennium Ecosystem Assessment 2005). The MA emphasized that people are components of ecosystems engaged in dynamic interactions, and particularly assessed how changes in ES might impact human well-being, such as access to basic materials for living (shelter, clothing, energy); health (such as access to clean air and water); social relations (including community cohesion); security (freedom from natural disasters and access to natural resources); and freedom of choice (the opportunity to achieve) (Millennium Ecosystem Assessment 2005). Upon publication of the MA, incorporation of ES into land use change assessments increased, including studies on how to maximize provisioning of ES alongside human well-being (Carpenter et al. 2009); how intensive food production to feed growing populations required trading off a number of important ES (Foley et al. 2005); and how including ES in GCMs indicated increasing vulnerability to ES change or loss in future climate scenarios (Schröter et al. 2005).

Cross-Chapter Box 7, Table 1 Comparison of MA and IPBES categories and types of ES and NCPs

MA category	MA: Ecosystem Services	IPBES category	IPBES: Nature's Contributions to People
Supporting services	Soil formation		
	Nutrient cycling		
	Primary production		
Regulating services		**Regulating Contributions**	Habitat creation and maintenance
	Pollination		Pollination and dispersal of seeds and other propagules
	Air quality regulation		Regulation of air quality
	Climate regulation		Regulation of climate
	Water regulation		Regulation of ocean acidification
	See above		Regulation of freshwater quantity, flow and timing
	Water purification and waste treatment		Regulation of freshwater and coastal water quality
	Erosion regulation		Formation, protection and decontamination of soils and sediments
	Natural hazard regulation		Regulation of hazards and extreme events
	Pest regulation and disease regulation		Regulation of organisms detrimental to humans
Provisioning Services	Fresh water	**Material Contributions**	Energy
	Food		Food and feed
	Fiber		Materials and assistance
	Medicinal and biochemical and genetic		Medicinal, biochemical and genetic resources
Cultural Services	Aesthetic values	**Nonmaterial Contributions**	Learning and inspiration
	Recreation and ecotourism		Physical and psychological experiences
	Spiritual and religious values		Supporting identities
			Maintenance of options

Starting in 2015, IPBES has introduced a new related concept to ES, that of Nature's Contributions to People (NCP), which are defined as "all the contributions, both positive and negative, of living nature (i.e., diversity of organisms, ecosystems and their associated ecological and evolutionary processes) to the quality of life of people" (Díaz et al. 2018). NCPs are divided into regulating NCPs, non-material NCPs, and material NCPs, a different approach that used by the MA (see Cross-Chapter Box 7, Figure 1). However, IPBES has stressed NCP are a particular *way to think* of ES, rather than a replacement for ES. Rather, the concept of NCP is proposed to be broader umbrella to engage a wider range of scholarship, particularly from the social sciences and humanities, and a wider range of values, from intrinsic to instrumental to relational, particularly those held by indigenous and other peoples (Redford and Adams 2009; Schröter et al. 2014; Pascual et al. 2017). Further, unlike the MA, the IPBES approach recognizes that all ES are filtered through cultural perceptions and values, which need to be acknowledged beyond a singular category of "cultural ES" (Díaz et al. 2018). The differences between the MA and IPBES approaches can be seen in Cross-Chapter Box 7, Table 1.

While there are in fact many similarities between ES and NCPs as seen above, the IPBES decision to use the NCP concept has been controversial, with some people arguing that an additional term is superfluous, that it incorrectly associates ES with economic valuation, and that the NCP concept is not useful for policy uptake (Braat 2018; Peterson et al. 2018). Others have argued that the MA approach to ES is outdated, did not explicitly address biodiversity, and confused different concepts, like economic goods (timber), ecosystem functions (detoxification), and general benefits (aesthetic enjoyment of landscapes) (Boyd and Banzhaf 2006). Moreover, for both ES and NCP approaches, it has been difficult to make complex ecological processes and functions amenable to assessments that can be used and compared across wider landscapes, different policy actors, and multiple stakeholders (Groot et al. 2002; Naaem 2015; Seppelt et al. 2011). There remain competing categorization schemes for ES, including those of the MA, IPBES, TEEB, the Common International Classification for Ecosystem Services (CICES), and the US Environmental Protection Agency's (EPA) Final Ecosystem Services and Goods Classification System (FEGS-CS) (Wallace 2007; Potschin and Haines-Young 2011). There are also competing metrics on how most ES might be measured (Danley and Widmark 2016; Nahlik et al. 2012). Ecologists particularly attribute the lack of clear ES metrics to incomplete understanding of the underlying ecological production functions that go into services and which can be used to assess how any change in an ecosystem's condition, structure, or function will result in related impacts on ES (Nelson et al. 2009; Tallis and Polasky 2009). The implications of these discussions for this SRCCL report is that there remain many areas of uncertainty with regard to much ES measurement and valuation, which will have ramifications for choosing options for SLM.

This report addresses ES/NCP in multiple ways. Individual chapters have used the term ES in most cases, especially since the preponderance of existing literature uses the ES terminology. For example, Chapter 2 discusses CO2 fluxes, nutrients, and water budgets as important ES deriving from land-climate interactions. Chapters 3 and 4 discuss issues such as biomass production, soil erosion, biodiversity loss, and other ES affected by land use change. Chapter 5 discusses both ES and NCP issues surrounding food system provisioning and tradeoffs.

In Chapters 6 and 7 that are focused on integrated response options and policies, the concept of NCPs is used. For example, in Chapter 6 Tables 6.22 to 6.24, possible response options to respond to climate change, to address land degradation or desertification, and to ensure food security are cross-referenced against the 18 NCPs identified by Díaz et al. (2018) (see Cross-Chapter Box 7, Figure 1) to see where there are tradeoffs and synergies. For instance, while BECCS may deliver on climate mitigation, it has a number of tradeoffs that are significant with regard to water provisioning, food and feed availability, and loss of supporting identities if BECCS competes against local land uses of cultural importance.

Chapter 7 has an explicit section 7.3.2.2 that covers risks due to loss of biodiversity and ES and a Table 7.1 that includes policy responses to various land-climate-society hazards, some of which are likely to enhance risk of loss of biodiversity and ES. A case-study on the impact of renewable energy on biodiversity and ES is also included. Chapter 7 also notes that because there is no SDG covering fresh-water biodiversity and aquatic ecosystems, this policy gap may have adverse consequences for the future of rivers and associated ES.

Cross Chapter Box 7, Figure 1 List of NCPs used by IPBES and intersections with SRCCL report (red boxes). Source: Díaz et al. 2018

Cross-Chapter Box 8: Land-climate implications of traditional biomass use

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Introduction and significance

Nearly 75% of biomass used for energy today is still traditional use of fuelwood, agricultural residues, animal dung and charcoal, for cooking and heating, by some 3 billion persons worldwide (IEA 2017). In spite of the fact that traditional biomass accounts for a similar amount of energy use as all modern renewables combined, scholarly analysis, statistics and publications are still limited compared to other important land-climate interactions due to the non-commercial nature of traditional biomass, the transaction costs of transforming the sector and its prevalence among marginalised people in developing countries .

In rural areas, fuelwood is often gathered at no cost to the user and is burned directly whereas in urban areas, traditional biomass use is more likely to involve semi-processed fuels such as charcoal, particularly in sub-Saharan Africa where charcoal is the primary urban fuel for cooking outside of South Africa. In South Asia and other regions where woody biomass is scarce, animal dung and agricultural residues are more common. The fraction of biomass harvest that is not "demonstrably renewable" is known as the fractionation of non-renewable biomass (fNRB). Default values for fNRB have been determined by the UNFCCC for least developed countries and small island developing states. Several global hotspots for NRB have been identified, particularly in East Africa and South Asia (Bailis et al. 2015).

Food security and other SDGs

The population of the world that is food insecure intersects significantly with the population relying heavily on traditional biomass. Poor and vulnerable populations often expend considerable time (gathering fuel) or use a significant share of household income (on purchased fuel such as charcoal) for low quality energy services that also have considerable negative ecological, environmental and health impacts, the latter due largely to poor indoor air quality and especially particulates (Masera et al. 2015; Rao and Pachauri 2017; Pachauri et al. 2018). Climate mitigation policies can result in trade-offs between climate goals and energy access goals in that the associated higher energy costs can lead to increased reliance on traditional biomass for the urban poor and rural users that purchase fuels (Cameron et al. 2016).

More generally, there is a trade-off between minimising costs for energy services and meeting household priorities (Fuso Nerini et al. 2017). Limited biomass availability, potential shifting of impacts and rebound effects may jeopardise the achievement of interlinked SDGs such as when households switch back to biomass due to price increases . The negative effects on adaptive capacity and GHG emissions of unsustainable traditional biomass use means that improved access to modern energy services can simultaneously promote adaptation, mitigation and development goals (Suckall et al. 2015). The scarcity of woody biomass can affect nutrition as rural populations are more likely in such cases to cook foods inadequately, which is often less healthy according to traditional diets. Cross-Chapter Box 8, Table 1 summarises some of the broader development benefits of replacing traditional biomass with modern fuels and electricity.

Cross-Chapter Box 8, Table 1 Broad development benefits and reduced risks from replacing traditional biomass

Impacted aspect	Impact pathway
Health	Reduced risk of indoor air pollution related diseases from use of biomass for cooking, and kerosene for cooking and lighting
Climate change mitigation	Reduced GHG emissions from deforestation and forest degradation for woodfuel extraction. Reduced emission of black carbon, a short-lived climate forcer.
Climate change adaptation	Less depletion of local ecosystems that are utilized by households (e.g. assistance in water recharge, locally forest resources) to cope with climatic events . Energy availability for income diversification e.g. lighting for operating small businesses Provision of energy requirements for adaptation measures e.g. water pumping (drinking & irrigation), food processing and storage, medicine storage.
Rural development	Employment and income opportunities from feedstock production, transport, processing and sales. Diversification of income base for rural households Jos creation in the fuel/stove sectors, forest management and allied services More time available for women to engage in income generating activities, and development initiatives (e.g. self-help groups)
Protection of local ecosystems	Healthier ecosystems offer more ecosystem services. Wildlife protection, a key source of revenue, especially in Africa.
Gender empowerment	Less time spent by women and girls on collecting fuelwood, leaving time for education and other gainful ventures

Land degradation and deforestation related to traditional biomass use

Woody biomass can be a sustainable energy source if harvest does not exceed growth rate, and measures are in place to protect sensitive areas and species. However, reliance on traditional biomass is quite land-intensive: supplying one household sustainably for a year can require more than half a hectare of land, which, in dryland countries such as Kenya, can result in substantial percentage of total tree cover (Fuso Nerini et al. 2017). It has been found that 27 to 34 % of global woodfuel was harvested unsustainably in 2009 (Bailis et al. 2015). Charcoal production is often environmentally detrimental, as traditional charcoal-making produces particulate and GHG emissions, and it tends to involve large quantities of biomass from large forest areas, when targeting urban markets. In sub-Saharan Africa and in some other regions, land degradation is widely associated with charcoal production. The links between charcoal and forest and land degradation are complex, with charcoal production often a by-product of other activities, such as clearing land for agriculture (Kiruki et al. 2017; Ndegwa et al. 2016). However, criminalisation of charcoal production has often been unsuccessful due to the lack of alternatives or affordability (Smith et al. 2015).

Through selective tree logging, charcoal production contributes to forest degradation. In addition to loss of biomass carbon, logging causes environmental degradation and reduction of ecosystem services resulting in lower agricultural productivity (Ndegwa et al. 2016). In Uganda, the National Forestry Authority estimates that 80,000 hectares of private and protected forests are being cleared annually for the unsustainable production of charcoal. Land degradation from unsustainable charcoal production in dryland countries such as Kenya adds to its GHG emissions, and threatens future livelihoods due to declining forest productivity, decreased biodiversity and other impacts (Kiruki et al. 2017).

GHG emissions and traditional biomass

The use of traditional woodfuels (fuelwood and charcoal) contributes 1.9-2.3% of global GHG emissions due to the effects of overharvesting along with the effects of short-lived climate pollutants (Bailis et al. 2015). This estimate is conservative for traditional biomass overall, as it only includes woody biomass and does not account for losses in soil carbon or the effects of nutrient losses from use of animal dung. Of particular interest among short-lived climate pollutants that have near-term scope for mitigation are emissions of black carbon, which not only contributes to climate forcing but is also correlated with negative health impacts that affect especially women and children (Shindell et al. 2012). Interaction between high woodfuel dependence and subsistence farming, which is also land-intensive (in relation to output) can create further climate risks as soil fertility becomes depleted and landscapes degraded. The use of biochar can offer a climate-smart approach to address agricultural productivity (Solomon and Lehmann 2017).

Although it is normally preferable from climate economics perspective to improve efficiency and switch to modern energy (including modern bioenergy), switching to LPG brings health benefits and can reduce emissions on balance even though it is a fossil fuel as the emissions non-renewable biomass outweigh the emissions from LPG (Cutz et al. 2017). Unlike modern energy sources, scientific assessments on traditional biomass use are complicated by its informal nature and the difficulty of tracing data and impacts; more systematic analytical efforts are needed to address this research gap (Cerutti et al. 2015). The traditional biomass sector thus remains under-researched and under-exploited in terms of cost-effective emissions reductions as well as for synergies between climate stabilisation goals and other SDGs.

Frequently Asked Questions

FAQ 7.1 How can indigenous knowledge and local knowledge inform land-based mitigation and adaptation options?

Indigenous knowledge (IK) refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. Local knowledge (LK) refers to the understandings and skills developed by individuals and populations, specific to the place where they live. These forms of knowledge are often highly context-specific and embedded in local institutions, providing biological and ecosystem knowledge with landscape information. This means they can contribute to effective land management, predictions of natural disasters and identification of longer-term climate changes, for example, and IK can be particularly useful where formal data collection on environmental conditions may be sparse. IK and LK are often dynamic, with knowledge holders often experimenting with mixes of local and scientific approaches. Water management, soil fertility practices, grazing systems, restoration and sustainable harvesting of forests, and ecosystem based-adaptation are many of the land management practices often informed by IK and LK. LK can also be used as an entry point for climate adaptation by balancing past experiences with new ways to cope. To be effective, initiatives need to take into account the differences in power between the holders of different types of knowledge. For example, including indigenous and/or local people in programmes related to environmental conservation, formal education, land management planning and security tenure rights is key to facilitate climate change adaptation. Formal education is necessary to enhance adaptive capacity of IK and LK since some researchers have suggested these knowledge systems may become less relevant in certain areas where the rate of environmental change is rapid and the transmission of IK and LK between generations is becoming weaker.

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SUPPLEMENTARY MATERIAL

Figure S. 1. Standard Burning Embers figure for land associated risks

Component	**Risks included**	**Risk transition**	**GMT increase since pre-industrial**		**Confidence level**	**Rational**
			Begin	End		
Desertification	Water scarcity, soil erosion, vegetation changes (in arid climates only)	Undetectable to moderate	0.8	1.0	Medium	In some regions, the role of climate change on recent desertification trends can be detected [Chapter 3]
		Moderate to high	1.5	2.0	Medium	Water scarcity in dry areas is expected to increase substantially above 1.5 degree [Chapter 3; SM table]
		High to very high	3.5	4.0	Medium	In addition to water scarcity, soil erosion and vegetation loss in dry areas will worsen under high emission scenarios [Chapter 3; ref to SM table]
Land degradation	soil erosion, fire, vegetation changes, coastal erosion, permafrost degradation (in non-arid climates only)	Undetectable to moderate	0.8	1.0	Low	Land degradation has been widely recorded across many regions of the world, and several of the recorded changes have been attributed to climate change [Chapter 4]
		Moderate to high	1.3	3.6	Medium	The transition from moderate to high is considered to be wide as some risks associated with land degradation are diverse and will become high at various warming levels. Moreover, for some aspects of land degradation little is known about the sensitivity to projected GMT [Chapter 4]
		High to very high	3.8	4.2	High	At high warming levels, risks associated with land degradation (e.g., permafrost degradation, coastal erosion, vegetation changes) are projected to become very high
Food insecurity	Yield, nutrition	Undetectable to moderate	0.5	0.8	High	Impacts on yields are both detectable and attributable to climate change [SR1.5] See also: Asseng et al. 2015; Leng and Huang 2017

		Moderate to high	1.5	2	Medium	SR 1.5 notes increasing impacts. But literature also makes clear that direction of impacts are mixed and largest negative impacts are in low latitudes. Impacts on nutrition also become increasingly evident. Protein content decreases with higher eCO_2, associated with higher temperature.
		High to very high	3.5	4	Medium	Catastrophic declines in yield at low latitudes and increasing declines in mid to high latitudes.. See Rosenzweig et al. 2014; Bahrami et al. 2017; Xie et al., 2018; Medek et al. 2017; etc.

Risk	**Risk transition**	**GMT increase since pre-industrial**		**Confidence level**	**Rational**
		Begin	End		
Water scarcity	Undetectable to moderate	0.8	1	Medium	CC effect already detectable in many regions [SR1.5]
	Moderate to high	1.8	2	Medium	Sharp increase in drought and water stress at 2 degree [SR1.5]
	High to very high	3	4	Medium	AR5, SM table
Soil erosion	Undetectable to moderate	0.8	1.5	Low	Changes in soil erosion have been recorded, yet so far there are only few studies attributing observed changes to either climate change influences from land cover and land management changes. Moreover, there are only very few studies scaling soil erosion risks against global mean temperature [Chapter 4]
	Moderate to high	2.5	3.8	Low	Increases in intense precipitation will lead to enhanced water erosion in several regions, whereas warming reduces soil organic matter and hence resistance against erosion. Substantial uncertainty regarding warming level at which risks become high [Chapter 4]
	High to very high	4.0	4.8	Low	Substantial uncertainty regarding warming level at which risks become very high [Chapter 4]

Fire	Undetectable to moderate	0.8	1	High	Already detected [SR1.5]
	Moderate to high	1.4	1.6	Medium	Risk is high at 1.5 degree and above [SR1.5]
	High to very high	2.5	3	Low	AR5?
Coastal erosion	Undetectable to moderate	0.5	1.0	High	Already detected [SR1.5?]
	Moderate to high	1.5	2.0	Medium	Flood costs under 1.5°C and 2.00°C warming by 2100 amount up to 0.25% of global GDP per year (Jevrejeva et al., 2018).
	High to very high	3.5	4.0	Medium	Flood costs under RCP8.5 amount up to 2.8% of global GDP per year (Jevrejeva et al., 2018).
Vegetation changes	Undetectable to moderate	0.5	1.0	Medium	Negative impacts on e.g. forests have already been documented (Bonan et al., 2008) [Chapter 4]
	Moderate to high	1.6	1.8	Medium	Moderate risk at 1.5, high at 2 degrees [SR1.5]
	High to very high	2.5	3.5	Medium	Increase in tree mortality due to climate-induced physiological stress and interactions with other stressors such as insect outbreaks, drought, storms, floods and wildfires [Chapter 4]
Permafrost degradation	Undetectable to moderate	0.8	1.0	High	Permafrost degradation in the Arctic Tundra is already detected (Bring et al., 2016; DeBeer et al., 2016; Jiang et al., 2016; Yang et al., 2016) [AR5: 12.4.6; SR1.5 Chapter 2]
	Moderate to high	2.0	2.5	Medium	Reduction of the diagnosed 2080–2099 near-surface permafrost area (continuous plus discontinuous near-surface permafrost) by 37 ± 11% (RCP2.6) [AR5 12.4.6]

	High to very high	3.0	3.2	Medium	Reduction of the diagnosed 2080–2099 near-surface permafrost area (continuous plus discontinuous near-surface permafrost) by 51 ± 13% (RCP4.5), 58 ± 13% (RCP6.0), and 81±12% (RCP8.5) [AR5 12.4.6]
Yield	Undetectable to moderate	0.5	0.8	High	See SR 1.5. Different impacts between low and mid to high latitudes..
	Moderate to high	1.5	2	High	See SR 1.5 Chapter 3: "Generally, vulnerability to decreases in water and food availability is reduced at 1.5°C versus 2°C (Cheung et al., 2016a; Betts et al., 32 2018) , whilst at 2°C these are expected to be exacerbated especially in regions such as the African Sahel, the Mediterranean, central Europe, the Amazon, and western and southern Africa (Sultan and Gaetani, 2016; Lehner et al., 2017; Betts et al., 2018; Byers et al., 2018; Rosenzweig et al., 2018).". See also, Su, B. et al. (2018).
	High to very high	4	4.3	Medium	Rosenzweig et al. 2014; Asseng et al 2015 and others. Impacts now negative across many regions.
Nutrition	Undetectable to moderate	0.5	0.8	High	See SR 1.5. Note different impacts on C3 and C4 plants.
	Moderate to high	1.3	2.0	Medium	See SR. 1.5 as well as Myers et al. 2017; Medek et al. 2017: decreases in protein in rice, wheat, barley and potato, CO_2 concentrations of 550 ppm can lead to 3–11% decreases of zinc and iron concentrations in cereal grains and legumes and 5–10% reductions in the concentration of phosphorus, potassium, calcium, sulfur, magnesium, iron, zinc, copper, and manganese across a wide range of crops under more extreme conditions of 690 ppm CO_2.
	High to very high	3.0	3.5	Low	To be completed

Figure S. 2. Risks under Different Socio-economic pathways

Risk	**Socio-economic pathway**	**Risk transition points**	**GMT increase since pre-industrial**		**Confidence level**	**Rational**
			Begin	End		
Coastal Erosion (land degradation	SSP1	Undetectable to moderate (0 to 100 million people flooded per year)	0.8	1.5	Medium	See Figure 1. Hinkel et al. 2017. Using GLOBDEM, RCP 8.5. Constant Protection
		moderate to high (150 to 250 million people flooded per year)	2.0	3	Medium	See Figure 1. Hinkel et al. 2017. Using
		High to very high (400 to 500 million people flooded per year)	/	/		Does not reach that level
	SSP2	Undetectable to moderate (0 to 100 million people flooded per year)	0.8	1.5	Medium	See Figure 1. Hinkel et al. 2017. Using GLOBDEM, RCP 8.5. Constant Protection
		moderate to high (150 to 250 million people flooded per year)	2.0	2.7	Medium	
		High to very high (400 to 500	4	4.2	Low	Significant variation under different RCP scenarios. Under

		million people flooded per year)				
	SSP3	Undetectable to moderate (0 to 100 million people flooded per year)	0.8	1.5	Medium	See Figure 1. Hinkel et al. 2017. Using GLOBDEM, RCP 8.5. Constant Protection
		moderate to high (150 to 250 million people flooded per year)	2.0	2.5	Medium	
		High to very high (400 to 500 million people flooded per year)	3.1	4.1	Low	A higher number of people are flooded at lower temperatures compared to other socio-economic pathways.
Increase in Food Prices (Food insecurity)	SSP1	Undetectable to Moderate (1 to 1.2 increase in price compared to 2005)	0.8	1	High	Figure 8. Popp et al. 2017. Change in world market prices [2005 = 1] aggregated across all crop and livestock commodities RCP 4.5.
		Moderate to High (1.3 to 1.5 increase compared to 2005)	/	/	High	Does not reach as declines in price possible. Remains at same risk level.
		High to very high (1.7 to 2 increase compared to 2005)	/	/	High	Does not reach as declines in price possible. Remains at same risk level.
	SSP2	Undetectable to Moderate	0.8	1	High	Figure 8. Popp et al. 2017. Change in world market prices [2005 = 1] aggregated across all crop and livestock commodities RCP 4.5.

		(1 to 1.2 increase in price compared to 2005)				
		Moderate to High (1.3 to 1.5 increase compared to 2005)	1.9	2.0	Medium	Figure 8. Popp et al. 2017. Change in world market prices [2005 = 1] aggregated across all crop and livestock commodities RCP 4.5
		High to very high (1.7 to 2 increase compared to 2005)	2.3	2.4	Low	Figure 8. Popp et al. 2017. Change in world market prices [2005 = 1] aggregated across all crop and livestock commodities RCP 4.5
	SSP3	Undetectable to Moderate (1 to 1.2 increase in price compared to 2005)	0.8	1	High	Figure 8. Popp et al. 2017. Change in world market prices [2005 = 1] aggregated across all crop and livestock commodities RCP 4.5
		Moderate to High (1.3 to 1.5 increase compared to 2005)	1.5	1.6	Medium	
		High to very high (1.7 to 2 increase compared to 2005)	2.4	2.5	Low	

Figure 3. Risk from Land based mitigation

Component	**Risk transition**	**Share of land-based mitigation in 2100 under a 2-degree compatible scenario**		**Confidence level**	**Rational**
		Begin	End		
Food insecurity	Undetectable to moderate	2%	5%	Medium	Impact on cropland area and food prices [ref, 7.3]
	Moderate to high	10%	15%	Medium	[ref]
	High to very high	35%	40%	Medium	Above 35% a large portion of land area is devoted to land-based mitigation with strong restrictions for food production [ref]