Chapter 1: Framing and Context

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1.1 Executive summary

Today's demand for land resources is unprecedented, both in terms of magnitude but also in terms of the multitude of different ecosystem services required *(robust evidence, high agreement*). The potential for land to continue providing for food, water and other vital ecosystem services under a changing climate and changing socio-economic conditions is fundamentally impacted by land management. In addition to the well-established drivers of land demand such as population growth and changing diets, and economic growth, rapid urbanisation has become an important factor to consider in projections of land use (*high agreement, medium evidence*). The Paris COP21 Agreement to limit warming well below 2^{o}C has placed great prominence on land mitigation (see Chapter 2). Sustainable land management, which seeks an integrated land-water-biodiversity nexus perspective, has the potential to contribute to several Sustainable Development Goals (SDGs) including food, biodiversity, water, as well as the SDG on climate change – if trade-offs are properly considered (*medium evidence, high agreement*) (section 1.3, see also chapter 6). The IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems is, therefore, timely in assessing the various land use challenges, i.e. the trade-offs arising from multiple demands, and in identifying possible solution pathways.

Although land based climate change mitigation (LBM) features in the majority of scenarios of how to keep warming below 2ºC (*robust evidence, high agreement*), climate change mitigation potential of the different LBM measures and their synergies as well as trade-offs with other ecosystem services and biodiversity are not yet well established. Since AR5, the number of studies dealing with LBM efforts have increased significantly. *Low agreement* exists regarding the carbon uptake potential (or the energy that can be supplied as bioenergy) used in climate change mitigation scenarios (*robust evidence*). Future projections show large area requirements for e.g. bioenergy crops or afforestation/reforestation, which competes with area required for food production or biodiversity conservation. Alternatively, smaller areas needs are associated with intensive use of water and fertiliser, and possibly detrimental impacts on local water resources and air quality (ro*bust evidence, high agreement*). Mitigation arising from decreasing greenhouse gas emissions from the AFOLU sector or from restoring soil carbon content and physical structure have received considerable attention in local studies but are not yet part of scenarios that explore climate change mitigation options globally (sections 1.2, 1.3, see also chapters 2 and 6).

Large differences exist between worldregions in terms of degree of desertification and degradation, and recovery from past resource over-use (*robust evidence, high agreement*). Both local action and global trade in agricultural commodities can enhance local food, timber or bioenergy supply and thus contribute to land restoration and maintenance efforts. Trade can also lead to land use displacement (spill-over effects), in that changes in demand in one area are satisfied from altered production elsewhere, with potential of unintended side-effects such as loss of biodiversity and ecosystem services (*robust evidence, high/medium agreement*). Ecosystem services other than agricultural commodities embodied in trade therefore need to be considered in assessment of sustainable land management, including in the design of global scenarios (*medium evidence, high agreement*). Context specific actions at regional and sub-regional levels, can enhance land use in an overall fair and equitable way, with climate change mitigation, or adaptation being positive side-effects (sections 1.4, see also chapters 3-5).

Demand for agricultural commodities is as important as supply for the achievement of sustainable land management, for the reversal of desertification and degradation, the reduction of greenhouse gas emissions and to enhance food security (*robust evidence, high/medium agreement*). Reduction of food waste, shifts of diets by high income population to less animal-sourced protein and increased appreciation of the multiple benefits arising from the protection of biodiversity have all demonstrable positive impacts on land use (*medium/robust evidence, medium/high agreem*ent). Therefore managing land sustainably requires not only shifts in production patterns in response to changes in consumption preferences. Today's scenarios that are applied to assess future climate and global environmental changes include assumptions about such consumption changes, but pathway analysis to support decisions of how these changes can be achieved is lacking. The inhibiting factors preventing the full transition to sustainable land management (SLM) still have to be identified, in order to understand why SLM has not yet been adapted, and pathways to overcome transitional boundaries enabled (sections 1.4, 1.5, see also chapter 5-7).

Decision makers are faced with the task of developing and implementing policies that are based on many knowns but also many unknowns. Climate change exacerbates many of the existing issues and appropriate action requires an integrated system-framework that considers the biophysical, economic, socio-cultural, and institutional dimensions. Land resources are highly susceptible to, and inextricably linked to, conflict over land allocation and use, land rights and land tenure, especially in poor governance regimes which tend to coexist against a socio-economic backdrop of unsustainable land use practices. Climate policy has the option to combine interventions for both adaptation and mitigation, and avoid pursuing single-objective interventions (carbon emission only). Rapid, but flexibly adjustable actions are becoming even more urgent given that population growth, rapid urbanisation, technology use, and intra- and cross-country migration exacerbate negative implications for land use and land use change, atop of climate change, and can also have large negative feed-backs to climate change. The window for reversing current trends to avoid a lock-in of capital and technology is getting smaller (sections 1.2, 1.4, see also chapter 7).

Assessing new knowledge on land and climate change is highly relevant and timely. By 2023, the first evaluation in the form of the global stock take parties to the Paris Agreement will revisit and evaluate progress on Nationally Determined Contributions (NDCs). By requesting this report, governments have recognised the challenges arising from climate change, and the manifold direct and indirect interactions with land use, including land use as part of achieving the NDCs and demonstrating sustained climate action. This report provides the opportunity of updating the scientific knowledge on the issues specified in the report's title that has arisen since AR5, as well as accompanying IPCCs currently finalised report on the 'Global Warming of 1.5°C'. Many of the questions addressed in this report relate also to questions posed in international conventional frameworks such as the United Nations Convention on Biodiversity (UNCBD) and the United Nations Convention to Combat Desertification (UNCCD), but looking here comprehensively at land based solutions and challenges toward climate change mitigation and adaptation efforts. The assessment aims to offer science-based evidence to inform decision making in governments, public and private sectors vis-a-vis options to address challenges in land use change and governance. Governments and their varied institutions are looking for new approaches to support climate resilience and to reduce exposure to hazards and risks that may militate the use of land as an abatement policy tool. As food, energy and water security continue to rank high on the development agenda, the promotion of synergies towards sectoral policies becomes effective adaptation and mitigation set of strategies in order to reduce the risks of anthropogenic climate forcing, and to bring greater collaboration among scientists, policy makers, private sector and land managers to address a global problem (sections 1.2, 1.4, 1.5, and all chapters of this report).

1.2 Part 1 – Vision

1.2.1 Scope and starting

Climate change and land use change are two of the major global challenges that humanity has to address in the foreseeable future in order to transition to a more sustainable pathway. Climate change and its corollaries, land degradation and desertification, together with loss of biodiversity have severe consequences for humans, ecosystems and the planet at large. Societies are witnessing complex and profound changes. Continued population growth and economic development will enhance the general pressure on the biosphere, and the challenges of meeting food and nutritional security and providing basic services for large numbers of populations in regions where such stressors are already experienced today. During the past fifty years, there has been an unsustainable acceleration of wasteful use of natural resources both in terms of production and consumption patterns, resulting in the degradation and depletion of vital natural resources. Recognising these challenges led to the endorsement in the year 2000 of environmental sustainability as one of the Millennium Development Goals (MDGs) to be achieved by 2015. However, by 2003 global rates of consumption and waste production were estimated to be at least 25% higher than the capacity of the planet to provide, replenish, repair resources, and to absorb waste (WWF 2010). With the current state of resources degradation, many of the sustainable development goals, which have been adopted in 2016 (SDGs) will be proving difficult to achieve.

What is required is a transformational change to halt current trends of degradation, and to preserve vital ecosystems linked to land, forests, and oceans. Human societies demand food, feed, fibres, firewood, biofuels, building materials from terrestrial ecosystems, and land for settlements, recreation, spiritual purposes and conservation (Ellis and Ramankutty 2008). Increasing demand for all of these purposes will put greater stress on land management and sustainability.

Previous IPCC reports have made reference to land and its importance in addressing current risks that are accentuated by climate change impacts. This includes risks and threats to agriculture and forestry, but also the role of land and forest management as a contributor to climate change has been documented with increasing focus since IPCC Second Assessment Report. Analyses of land and its links with climate change adaptation and mitigation were also covered in IPCC Special reports, as well as in reports that target other environmental policies than climate change (see Box 1.1 for a brief overview of reports and their main findings).

Box 1.1 Land in previous IPCC and other relevant reports

This box is a placeholder at the moment; to be completed in the next version of the chapter draft.

Consider in particular the AR5, SREX, 1.5 degree report, IPBES reports.

Issues to be covered (not yet complete):

--Role of the AFOLU sector in overall greenhouse gas emissions & biophysical, contribution to regional and global climate change

--Potential for mitigation measures from land and forestry, in particular with respect to. low warming scenarios

--Options for adaptation

--Vulnerability and risk of ecosystem services (other than yield) to climate change

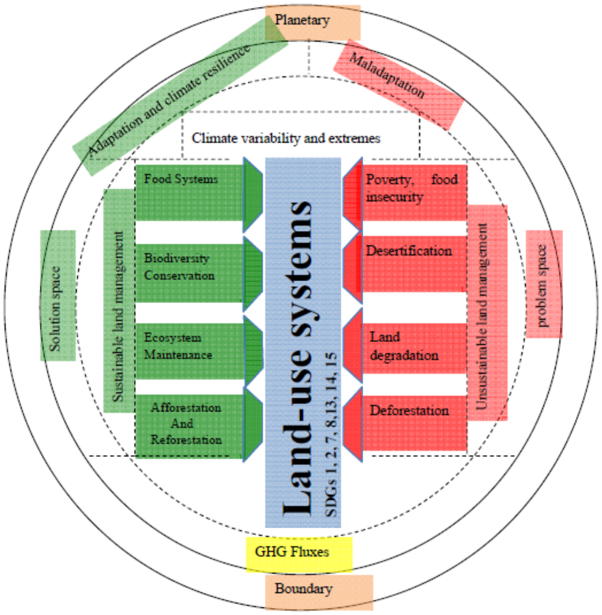
1.2.2 Where are we heading?

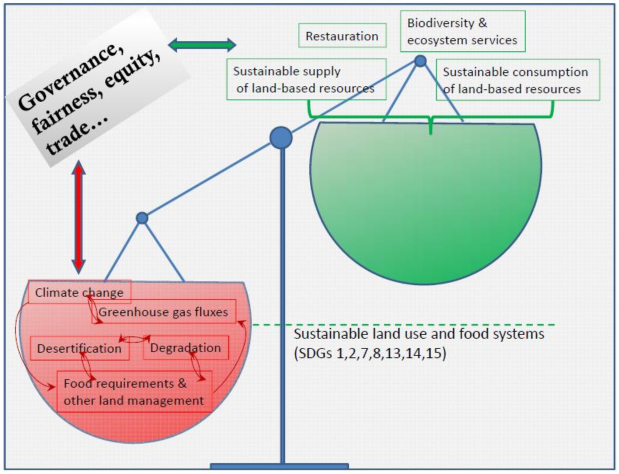
The Paris Agreement was a turning point in its aspiration to bring world economies to a temperature guardrail of below 2ºC –even only 1.5ºC- warming. Achieving such a goal will have tremendous implications on both our consumption and production patterns as well as investments to support a carbon neutral economy. Indeed, NDCs are instruments that will enable a new climate economy and a new world order structured on sustainability and a climate resilient development. Still, there is general concern about the possibility of not meeting goals agreed in Paris (Grassi et al. 2017) and the possibility that this will trigger commensurate problems related to degradation of ecosystems, heightening water and food insecurity (Campbell et al. 2017). Likewise, some of the pathways outlined to achieve the Paris goals, especially related to land-based climate change mitigation efforts such as bioenergy or reforestation will compete with water and food security or biodiversity (Smith et al. 2014b; Creutzig et al., 2015; Popp et al., 2014; Smith et al. 2010a, 2016). Yet, land based mitigation strategies and options have only recently received policy attention in comparison to energy systems, which have been perceived as the main source for mitigation (Rose et al. 2012). As outlined below (and see also chapters 2,6,7) land as a prime sector for mitigation will have to be considered against several development and national priorities, not least energy and food security, conservation, and pollution control (Harvey and Pilgrim 2011).

Meanwhile, the world is already recording a higher number of extreme weather events linked to climate change, in the form of cyclones, heat waves, droughts, and floods, in addition to sea level rise from melting permafrost and glaciers. And the challenges to societies are not confined to living with limited natural resources, but rather to a cascading set of problems related to a higher incidence of poverty as resource-dependent populations become increasingly fragile (Mysiak et al. 2016; FAO 2015; Lesk et al. 2016; Min et al. 2011; Lloret et al. 2011; Warren et al. 2014), with the potential to disrupt livelihoods, economies, infrastructure, and reverse the achievements of the SDGs, progress towards the Paris Agreement and other national, regional and global agreements and frameworks (Fankhauser and Stern 2016).

In the course of the 21st century, land as a global resource will become the subject of increased and amplified competition as various stakeholders compete for its use in various ways. Irrespective of the use of land, be this for food or energy, given the centrality of land as a resource and its considerable abatement potential, both for sustainability and security of supply matter and remain key considerations in land use management (Harvey and Pilgrim 2011). Indeed, land as a non-renewable resource has the potential to destabilise sectors such as agriculture, energy, forestry and in turn affect climate mitigation in significant ways, if land use change and management are not seen as important policy drivers to support climate change mitigation and to do so with human security and ecological considerations (Harahap et al. 2017).

Placeholder Figures and text; to be developed further; aim is to visualise the scope and challenges of the SRCCL





1.2.3 The challenges related to land use, climate change, degradation, desertification and food security

A condensed narrative of the graphical framing of the linkages between climate change, land use, and the food system:

The **land system**, characterised by **land use types (cropping, grazing, forestry, wetlands, reservesand unmanaged)**, and land-based **ecosystem services**, is influenced by several *drivers* **(food demand, demographics, economics, technology, policies and institutions)** and *enabling conditions* (**land competition** and **land intensification**). The land system contributes to global warming by producing **GHG fluxes** and is impacted by **climate change** through several drivers (demographics, economics, technology, and policies). **Land degradation** and **desertification** are two critical outcomes of the human-directed land use systems that are also affected by climate change. The land use and related ecosystem services contribute to several **SDGs**, including **6 (water), 9 (energy), 13 (climate) and 15 (life on earth).**

The food system, linked to land via ecosystem, services, is defined in terms of **food supply (production, storage, processing, and marketing)** and **food demand (consumer behavior and diets)**, both of which are influenced by the **food environment** at that determines the conditions for **availability, access, quality, safety** as well as the equilibrating role of trade. The food environment is affected by several *driviers* **(biophysics, economics, socio-cultural, and demographics)** and *enabling conditions* **(policies, institutions, and governance)**. The *food system* outcomes include **food and nutrition security, health and well-being, and environmental footprints** (including GHGs). Both food production and consumption contribute to **global warming** via **GHG emissions** and are impacted by **climate change** directly (through yields, food quality, increased variability) and indirectly (through the main food drivers). The food system outcomes can also contribute to specific **SDGS** such as **1 (poverty), 2 (hunger), 3(health), 5 (gender), 10 (inequality) and 12 (sustainable production and consumption).**

The aim of this IPCC Special Report is to investigate these linkages and relationships using existing scientific evidence and to propse sustainable solutiosn to ensure that future global warming is capped at or below 2˚C above pre-industrial levels.

Ecosystems are a dynamic complex of natural resources or environmental assets (plant, animal, and micro-organism communities and their non-living environment). The benefits people obtain from these ecosystem functions have been termed ecosystem services (Mace et al. 2012; Millennium Ecosystem Assessment 2005), or nature's contribution to people (Díaz et al. 2018). These provisioning, regulating, supporting, or cultural services are vital for the well-being of all population in the world.

Land use and misuse are strongly correlated to human security and impacts food security, health and resilience of land resources, as well as poverty, migration and conflict (Cordingley et al. 2015). Humanity stands at a crossroads essentially because we are witnessing rapid deterioration, depletion and degradation of the ecosystems and the very services that we have come to rely on at national, regional and global scales (Mace et al. 2012; Newbold et al. 2015). Diminishing resources of land, water, forests, etc. are exacerbating current vulnerabilities, especially in regions where economies are highly dependent on natural resources. Although land degradation is a common risk across the globe, poor countries remain most vulnerable to its impacts. It is estimated that by 2030, the demand for food, energy, and water is expected to increase by at least 50%, 45% and 30%, respectively. Increased competition over land and land use over time and across regions and scales is impacting on land governance, with implications for land acquisition, land tenure and rights, and food security. Meeting food, water and energy needs would require global land use and land cover to be centrally placed within the energy and climate related solutions and for more policy attention to be given to the rehabilitation and maintenance of land.

Sustainable Land Management (SLM) has the potential to bring substantial improvement towards the achievement of three main global sustainability goals; namely food security, energy access, and water availability. Ecosystem-based approaches, including social-ecological system approaches (Ostrom 2009; Sibertin-Blanc et al. 2011; Anderies et al. 2004), have emerged as the potential solutions that can address multiple challenges related to climate change, land degradation and loss of biodiversity (Epple et al. 2016) . Addressing food, energy and water problems in an integrated manner using ecosystem-based tools can alleviate poverty problems and ensure SLM (Rasul and Sharma 2016).

Hence, this report presents an opportunity, from a climate change lens, to reassess the contribution of land and land use as both an opportunity and a threat to multiple vulnerabilities that can conspire to derail sustainable development and the attainment of the SDGs (UN 2015). The window for reversing current trends to avoid a lock-in of capital and technology and to move away from a shrinking carbon budget is getting smaller (The New Climate Economy 2016). The report can help in enabling policy makers and development practitioners to reconfigure potential solutions pathways in which land can be perceived as part of the solution.

1.3 Key issues related to land use, and land cover and land use change

1.3.1 Status of (global) land use

1.3.1.1 Current land use patterns

Today, three quarters of the global 130 Mkm² ice-free land is impacted one way or another by human activities, approximately a quarter remains untouched (Erb et al. 2016a; Luyssaert et al. 2014; Erb et al. 2017; Venter et al. 2016; Ellis et al. 2013); see Table 1.1.1, *robust evidence, high agreement*). The largest area under use is for cropland and pastures. Forests would cover a substantial fraction of the earth surface (55-58 Mkm²) in the absence of land use, but have been reduced by 20%-42% (Erb et al. 2017; Luyssaert et al. 2014). Considerable uncertainties are associated with estimates on the extent of forests (Table 1.1), the range mainly depending on methods or definition thresholds on e.g. minimum tree cover or tree height (Schepaschenko et al. 2015), and the forest area under some form of use or management. Other wooded lands (OWL), i.e. areas with tree cover below e.g. 5% (< 12 Mkm²), are largely included in the 7-28 Mkm² that are identified as untouched, but large knowledge gaps relate to this ecosystem type and its uses (Keenan et al. 2015).

Human societies appropriates one quarter to one third of the total potential net primary production (NPP_{pot}), i.e. the NPP that would prevail in the absence of land use, the range deriving from different definitions and uncertainties in the value of NPP_{pot} (Bajželj et al. 2014; Haberl et al. 2014a; . Cropland processes dominate the associated biomass flows (50%), but around three quarters of these flows are consumed by livestock (Haberl et al. 2014b; Bajželj et al. 2014; Smith et al. 2014b) (*medium evidence, high agreement*). The intensity of land use varies hugely within and among different land use types. At the global level average, around 10% of the total ice-free land surface was estimated to be under intensive management, two thirds under moderate and the remainder under extensive management (Erb et al. 2016a).

Table 1.1 Extent of global land use and management around the year 2000 (placeholder, numbers to be updated in next version)

Global land use and land management in 2000	Mkm^2 Low*	Mkm^2 High*	% of ice-free land surface Low	% of ice-free land surface High	Literature sources
Total ice-free land	130,4	130,4	100%	100%	
Urban / built-up	0,7	3,5	1%	3%	
Cropland, total	15,1	18,8	12%	14%	
on forest	8,7	10,8	7%	8%	
on natural grassland/Savanna	4,7	5,9	4%	5%	
on shrub and tundra	1,7	2,1	1%	2%	
Permanent pastures, total	28,0	34,1	21%	26%	
on forest	3,1	8,3	2%	6%	
on natural grassland/Savanna	18,3	20,5	16%	14%	
on shrub and tundra	4,3	7,5	3%	6%	
Other land affected by management (unforested, productive land), mainly livestock grazing*	7.4	28.1	6%	22%	
Forests under use, total	26,5	29,4	20%	23%	
Planted forests	2,2	2,2	2%	2%	
Human-modified natural forests	24,4	27,3	19%	21%	
Wilderness and non-productive land, total	32,0	37,2	25%	29%	
of w., non-productive, including snow	16,2	16,2	12%	12%	
of w., productive wilderness, forested	6,2	11,4	5%	9%	
of w., productive wilderness, unforested	9,6	9,6	7%	7%	
Summary					
Forests	32,7	40,8	25%	31%	
Agriculture	71,2	60,3	55%	46%	
Wilderness, non-productive	32,0	37,2	25%	29%	
Land cover change	23,2	38,1	18%	29%	
Land management without land cover change	75,2	55,1	58%	42%	

*Calculated as the difference of all land uses plus wilderness to the total ice-free land-surface. **Relates to estimates for infrastructure, cropland, permanent pastures and forests.

1.3.1.2 Past and ongoing trends

Globally, the area of cropland is estimated to have increased by 70%-85% (Goldewijk et al. 2017; Krausmann et al. 2013) over the last century and is still expanding at a rate of ca. 0.03 Mkm^2 (0,2%) per year (FAOSTAT 2015). Area classified as permanent pasture and grazing land has more or less stabilised if not slightly decreased (FAOSTAT 2015; Alexander et al. 2017a). Recent studies not only agree that global forest loss in the last decades has decreased compared to the 1990s, but forest loss has also partly (approximately 50%) been compensated by forest gains, mainly forest plantations (ca. 1.3-1.9 Mkm^2 yr^{-1} (Keenan et al. 2015; Sloan and Sayer 2015; Hansen et al. 2013; Birdsey and Pan 2015) (*high agreement, robust evidence*). Large regional variability exists, tropical forests still show a clear trend of forest loss, leading to disproportionally high carbon emissions, in contrast to all other forest biomes that show concurrent losses and gains (*medium evidence, high agreement*; (Hansen et al. 2013; Baccini et al. 2017). OWL increased in extent, mainly in subtropical regions (Keenan et al. 2015; Aleman et al. 2016; Searchinger et al. 2015). About 50% of Brazilian Cerrado has been transformed to agriculture and pastures (Lehmann and Parr 2016). Large pressure has also been exerted on the South-American Catinga and Chaco regions (Lehman and Parr 2016; Parr et al. 2014). African savannas have been proposed to follow a similar tropical agricultural revolution pathway in order to enhance agronomical prosperity (Ryan et al. 2016) but with unknown consequences for carbon storage or biodiversity.

1.3.1.3 Future trends in the global land system

Woody and crop biomass commodities are increasingly traded internationally (*high agreement*) leading to large-scale interdependencies of supply and demand between regions (Baldos and Hertel 2015; Kastner et al. 2014; Wood et al. 2018; Krausmann et al. 2013). While there is *high confidence and agreement* that food, fodder and timber demand will increase substantially in the mid-term future due to population and GDP growth and lifestyle changes, there is *low agreement* on the extent of ensuing land use changes, due to uncertainties arising from diets, yield developments as well as dynamics in the livestock sector, conservation or land-based climate change mitigation policies, and spill-over effects (e.g., (Alexander et al. 2015; Muller et al. 2017; Erb et al. 2016b; Billen et al. 2015; Aleksandrowicz et al. 2016; Smith et al. 2014b; Lapola et al. 2010)) (see also section 1.3.2, 1.3.4). Current yield trends have been described to be insufficient to double food production (Ray et al. 2013), which is deemed necessary to feed a growing population, resulting in a high probability for further land expansion in the tropical forests and semi-arid drylands (Laurance et al. 2014). Even for similar scenario archetypes (see section 1.5) future projections of land cover changes are highly variable (Alexander et al. 2017a; Popp et al. 2014) hotspots of uncertainty relate particularly to tropical and boreal regions and forest and grazing land dynamics (Prestele et al. 2016).

Climate change will challenge agriculture and forest production in many regions, thereby accentuating existing development challenges (Lipper et al. 2014; Myers et al. 2017)(see chapter 5). Especially in some developing countries where pressure on land is high, there is growing recognition that climate change impacts will further imperil large populations who rely substantially on agriculture and who have a high prevalence of hunger (Baldos and Hertel 2015) (see also 1.3.5, and chapter 5). Consensus is emerging that climate change will depress global yields in overall terms, but effects show wide ranges with regard to individual cultivars and world regions (Myers et al. 2017; Pugh et al. 2016; Lobell and Tebaldi 2014).

Albeit small in comparison to other land use types (Table 1.1.1), urban and infrastructure areas are key for land use dynamics. The extent of urban areas is projected to increase significantly (up to a factor 2 to 3) until 2030 (Seto et al. 2012; van Vliet et al. 2017; Jiang and O'Neill 2017). Urban expansion is associated with a disproportionally high loss of fertile (crop)land (Bren d'Amour et al. 2016a; Martellozzo et al. 2015; van Vliet et al. 2017) and biodiversity hotspots (Aronson et al. 2014; Güneralp et al. 2013; Seto et al. 2012), particularly important under regional conditions of high population density and an agrarian dominated economy. Due the urban-hinterland teleconnection and the role of cities as hubs of innovation, urbanisation represents a key driver of future changes in global food systems (*high agreement, medium evidence*; (Seto and Ramankutty 2016)).

In addition to urban pressure on land, it is also fairly well documented that climate change will have differential impacts on women and men as a result of disparities in access to productive resources (Omolo 2010; Denton 2002) and women are often not able to draw on social protection opportunities (Cannon 2002)). Gendered divisions of labour in developing countries often tend to perpetuate stereotypes of women as being more suited to caring for the environment, and attending to unpaid labour related to fetching of water and fuel (Denton 2002). Structural challenges related to time, poverty, patriarchy and insufficient participation in key decision making processes related to land, land tenure and rights and overall land governance amplify this situation (Omolo 2010).Women's traditional knowledge can add value to a society's knowledge base and support adaptation practices towards climate change (Lane and McNaught 2009), but this knowledge is also under increasing pressure considering the rate, severity and distribution of climate change impacts.

1.3.2 Competition for land

Competition for land is grounded in the finiteness of the land and the fact that most of highly-productive land is already under some sort of use (Lambin 2012; Lambin and Meyfroidt 2011; Venter et al. 2016). Driven by population, urbanisation, growing food demand, and energy, competition for land is likely to accentuate land scarcity in the future (Tilman et al. 2011; Popp et al. 2016; Foley et al. 2011; Lambin, 2012)(see also 1.3.3; *robust evidence, high agreement*). Competition for land also results from social and power structures as well as economic forces that determine who accesses the land, uses it and transforms it (Meyfroidt 2018). Land competition is either directly competing for space or indirectly for resources produced elsewhere provided by terrestrial ecosystems, many of them ultimately originating in NPP (Running 2014, 2012; Haberl and Erb 2017; Erb et al. 2012a)(*robust evidence, high agreement*). As a planetary boundary, it has been proposed that no more than 15% of the global ice-free land surface should be converted to cropland (Rockström et al. 2009).

Climate change influences land competition both directly (through land productivity and climate-induced changes in land suitability) and indirectly (see chapter 5; and sections 1.3.3; (Schauberger et al. 2017; Pugh et al. 2016; Alexander et al. 2018; Rosenzweig et al. 2014), *robust evidence, high agreement*). Indirect impacts include e.g., degradation of the resource base (reduced water availability; or land quality like increased salinity (Daliakopoulos et al. 2016); decreased biodiversity (Haberl 2015; Coyle et al. 2017; Rolando et al. 2017)). Climate policies can also a play a role in affecting land competition via forest conservation policies or energy crop production (sections 1.3.4.1and 1.3.4.2). Climate change and climate policy responses will therefore accentuate land competition, leading to new patterns of land use, with as yet unpredictable food security implications. Climate change, degradation, desertification and food security are thus tightly linked and must be addressed jointly in terms of achieving sustainable development goals.

1.3.3 Interactions of climate change, land degradation, desertification and food security

1.3.3.1 Land use, greenhouse gas emissions and uptake, and impacts of biophysical surface processes

After the burning of fossil fuels, land use is the largest source of anthropogenic carbon and other greenhouse gases (*robust evidence, high agreement*) (Smith et al. 2014b; Birdsey and Pan 2015; Don et al. 2011; Arneth et al. 2017; Shcherbak et al. 2014; Bodirsky et al. 2012; Le Quéré et al. 2016; Agus et al. 2013; Page et al. 2011; Guillaume et al. 2016; Wandelli and Fearnside 2015; Tadesse et al. 2014, Ciais et al. 2013) (see chapter 2). IPCCs Fifth Assessment Report estimated that annual GHG flux from land use and land use change activities accounted for approximately 4.3 – 5.5 $GtCO_2$-eqyr^{-1}, or about 9%-11 % of total anthropogenic greenhouse gas emissions (Smith et al. 2014b). At the same time, and ecosystems currently also serve as a large carbon sink, due to environmental changes as well as reforestation (Le Quere et al. 2015; Canadell and Schulze 2014; Ciais et al. 2013; Arneth et al. 2017; Erb et al. 2013; Pongratz et al. 2013; Hansis et al. 2015). Whether or not this sink will persist in future is one of the largest uncertainties in carbon cycle and climate modelling (Ciais et al. 2013; Bloom et al. 2016; Friend et al. 2014; Le Quere et al. 2018).

In addition to climate impacts from greenhouse gas emissions and uptake, it has now been consistently demonstrated that biophysical regional climate effects of land cover change, arising from altered energy and momentum transfer between ecosystems and atmosphere can be substantial with the sign of the effect clearly depending on their geographic context (Alexander et al. 2018; Perugini et al. 2017; Quesada et al. 2017)(*robust evidence*; see chapter 2). Differences in future trajectories of land use thus have a large impact on the terrestrial CO_2 (and in general greenhouse gas) balance (*high confidence*), potentially either leading to net emissions or net sequestration. But due to biophysical regional climate impacts, and the overall impact on ecosystem functioning (see 1.3.3, 1.3.4, chapter 6) efforts to manage carbon through land use need to be aware of unintended consequences on ecosystems that could undermine climate regulation or provisioning of a range of important ecosystem services. A broad range of issues must be considered, beyond the carbon-perspective itself.

Global forests are recognised for their pivotal role in terrestrial carbon storage and for biodiversity *(robust evidence*, *high agreement*), (Smith et al. 2014b; Arneth et al. 2017; Newbold et al. 2015; Erb et al. 2017; Ciais et al. 2013; Lehmann and Kleber 2015). Other work has also pointed to high carbon storage in soils of savannas and temperate grasslands, and high levels of biodiversity, ecosystems that are also species rich and that contribute substantially to the world's food production (Lee et al. 2010; Crist et al. 2017; Guo and Gifford 2002)Alkemade et al. 2013; Maestre et al. 2016).

1.3.3.2 Land Degradation

Due to loss of productivity but also carbon storage, biodiversity, and other ecosystem services, degradation of soil and land resources is a critical challenge in cropland, pastures, savannas, shrublands and forests around the world (Abu Hammad and Tumeizi 2012; Cerretelli et al. 2018; Mirzabaev et al. 2015; Ravi et al. 2010). Land degradation can be considered in terms of the loss of actual or potential productivity or utility; it results from a mismatch between land productivity and land use, and is driven to a large degree by socioeconomic pressures, such as rapid urbanisation and population growth (Lal 2009; Beinroth et al. 1994; Abu Hammad and Tumeizi 2012; Ferreira et al. 2018; Franco and Giannini 2005; Abahussain et al. 2002). Climate change is one factor contributing to degradation, in addition to inappropriate use of crop, pasture or forest vegetation and soil resources especially in environmentally fragile lands subject to overuse (Field et al. 2014).

Land degradation is in this report defined as a long-term reduction or loss of the biological productivity, and ecological complexity of land, and/or its human values, resulting from a combination of natural and human-induced processes, influenced by climate variability and change (see chapter 4). The definition differs from the one adopted for the recent IPBES report on land degradation and restoration (IPBES 2018) in that the IPBES report did not include explicitly impacts of climate change as a degrading factor (although it can be thought to be included in "human-caused"), and specified decadal time-scales as the time window of recovery.

Global estimates of total degraded area vary from less than 1 billion ha to over 6 billion ha, with equally wide disagreement in their spatial distribution (*medium confidence*; (Gibbs and Salmon 2015)). Increasing at an estimated 5-10 million ha yr^{-1} (Stavi and Lal 2015), the loss of total ecosystem services from degraded lands have been estimated to be equivalent to about 10% of the world's GDP in the year 2010 (Sutton et al. 2016). Soil degradation in particular is of concern, due to the long period necessary to restore soils (Stockmann et al. 2013; Lal 2009; Lal 2015). Land degradation is thus an important one factor contributing to uncertainties of the mitigation potential of land-based ecosystems (Smith et al. 2014b).

1.3.3.3 Desertification (definition, magnitude)

In brief, desertification is "the diminution or destruction of the potential of the land, which can lead ultimately to desert-like conditions". The IPCC has in previous reports adopted the definition of the UNCDD of desertification being land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variations and human activities (see glossary for extended definition; and chapter 3). Desertification results in desert-like conditions that can be non-reversible (Tal 2010). It causes persistent loss of ecosystem function and productivity due to diverse disturbances (e.g., soil fertility loss, soil erosion, vegetation cover loss, and plant species changes) from which the land cannot recover unaided

(Bai et al. 2008). Moreover it is a complex process and can be accelerated and exacerbated by both anthropogenic and natural process of climate variability and climate change (Ravi et al. 2010). However, the term desertification has often been used in the literature in a poorly defined way, and/or different definitions have been applied. For instance, some researchers characterise desertification as a process of change, whereas others define it as an outcome of change (Aggarwal et al. 2010; Bullock and Houérou 1995; Sivakumar 2007; Verón et al. 2006; Verstraete et al. 2008). While climatic variability can change the intensity of desertification process, some authors exclude climate impact, emphasising that desertification is purely human-induced process of land degradation with different severity and consequences (Sivakumar 2007). A critical challenge is also to identify a "non-desertified" reference state (Bestelmeyer et al. 2015).

As a consequence of widely varying definitions, the areal extend of land affected by desertification varies widely (see (Bestelmeyer et al. 2015; D'Odorico et al. 2013), and references therein). Arid regions of the world cover around 40% of the total terrestrial surface (ca. 60 Mkm^2; (Pravalie 2016)). More than two billion people reside in dryland regions (D'Odorico et al. 2013; Maestre et al. 2016). The combination of low rainfall with frequently infertile soils renders these regions, and the people who rely on the land's resources vulnerable to both the climate change, and unsustainable land management. By the end of this century and in spite of the national, regional and international efforts to combat desertification, it is still one of the major environmental problems (Abahussain et al. 2002).

1.3.3.4 Food security (definition, magnitude)

We follow the FAO's High Level Panel of Experts on Food Security and Nutrition (HLPE) definition of food system that "*gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes*" (HLPE 2017) (see chapter 5). HLPE defines a sustainable food system as "a sustainable food system as "a food system that ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised". Food systems are diverse and range from subsistence for self-consumption to modern driven by long-supply chains. Food systems are assessed through a number of outcomes from food and nutrition security, to health as well as sustainability (economic, social and environmental) (HLPE 2017).

In its 2017 Report on the State of Food Insecurity, FAO and its international partners reported that after a prolonged decline, world hunger appears to be on the rise again with the number of undernourished people increased to an estimated 815 million in 2016, up from 777 million in 2015, although still down from about 900 million in 2000 (FAO, IFAD, UNICEF, WFP and WHO, 2017). The same report also states that child undernutrition continues to decline, but levels of overweight and obesity are increasing. The food security situation has worsened in particular in parts of sub-Saharan Africa, South-Eastern Asia and Western Asia, and deteriorations have been observed most notably in situations of conflict and conflict combined with droughts or floods (Cafiero et al. 2018; Smith et al. 2017).

Climate change affects the food system via productivity on land (Lizumi and Ramankutty 2015) (and the ocean), the nutritional quality of food (Loladze 2014; Medek et al., 2017; Myers et al., 2014; Ziska et al. 2016) and water supply availability for crop production (Nkhonjera 2017). These factors impact also on human health and increase morbidity and incidences of diseases which affect human ability to process ingested food (Franchini and Mannucci 2015; Wu et al. 2016; Raiten and Aimone 2017). At the same time, the food system generates environmental footprints (van Noordwijk and Brussaard 2014； Borsato et al. 2018) with direct and indirect impacts on climate change and generate negative externalities in the form of food waste and loss (Kibler et al. 2018; Thyberg and Tonjes 2016) and water consumption (Lovarelli et al.

2016), all of which contribute to degrade the resource base, reduce resilience to climate. As food systems are assessed in relation to their contribution to global warming and/or to land degradation (e.g., livestock systems) it is critical to assess their contribution to food security and livelihoods and to consider alternatives, especially for developing countries where food insecurity is prevalent (Salmon et al. 2018; Röös et al. 2017).

1.3.4 Land-based climate change mitigation and adaptation strategies: trade-off and co-benefits

1.3.4.1 Bioenergy and Bioenergy with carbon capture and storage (BECCS)

Socio-economic pathways (see subsection 1.5) towards achieving a low-end warming goal rely on substantial negative emissions as part of the mitigation portfolio, drawing mostly on bioenergy (with carbon capture and storage) (van Vuuren et al. 2013; Smith et al. 2016; Anderson and Peters 2016). Median BECCS net carbon uptake rates of >3 GtC.yr^{-1} by 2100 (delivering around 150-200 EJ yr^{-1}) have been projected with Integrated Assessment Models in scenarios of achieving a 2°C warming target (Smith et al. 2016; Rogelj et al. 2018), resulting in increases in cropland between ca. 10% and 40%, or even 100% compared to present-day (Smith et al. 2016; Bonsch et al. 2016; Krause et al. 2017; Popp et al. 2016). Robust conclusions are prevented by the large impact different assumptions on land use intensity have on calculations (Smith et al. 2016; Bonsch et al. 2016; Krause et al. 2017).

Confidence in the net BECCS carbon uptake potential calculated with IAMs is low (*medium evidence*), due to: diverging assumptions on bioenergy crop yields, the CCS energy demand and thus the net-GHG-saving of bioenergy systems, and the size of the carbon-debt arising from natural vegetation clearance, as well as from subsequent management regimes (Pingoud et al. 2018; Schlesinger 2018; Krause et al. 2018; Bentsen 2017; Searchinger et al. 2017). Bioenergy provision under politically unstable conditions may also be an issue (Searle and Malins 2015; Erb et al. 2012b). It is virtually certain that growth of bioenergy crops poses large challenges for maintaining food production and avoiding detrimental effects on other important ecosystem services and biodiversity (Smith et al. 2016; Bonsch et al. 2016; Krause et al. 2017; Boysen et al. 2017; Boysen et al. 2016; Santangeli et al. 2016; Heck et al. 2018; Williamson 2016; Henry et al. 2018; Bren d'Amour et al. 2016b; Creutzig et al. 2015; Humpenoeder et al. 2018).

1.3.4.2 Avoided deforestation, reforestation/afforestation

Avoided deforestation, reforestation and afforestation (ADAFF) are frequently discussed as relatively low-technology and cost-efficient land-based mitigation options (Smith et al. 2016; Humpenoder et al. 2014; Popp et al. 2014; Griscom et al. 2017a). Carbon storage potential of ADAFF has been estimated to be principally of similar magnitude than BECCS (Humpenoder et al. 2014; Popp et al. 2014; Krause et al. 2017; Humpenoeder et al. 2018), with caveats being that the Integrated Assessment Models used for these projections typically do not represent the forestry sector explicitly, and poorly (if at all) account for land-management induced changes in carbon stocks (Schmitz et al. 2014; Krause et al. 2017). Similar to BECCS, competition with other land uses and societal needs may result in considerable side-effects that can be beneficial or act as trade-offs. Overall, environmental impacts of afforestation/reforestation depend to a large degree on prior land use and tree species planted (Berthrong et al. 2009; Barcena et al. 2014; Hong et al. 2018; Shi et al. 2013; Graham et al. 2017; Fernandez-Martinez et al. 2014). The biophysical, regional climate impacts (see 1.3.3.1, and chapter 2) of maintaining or increasing forest cover need to be factored in, and can support forest-based mitigation efforts in the tropics (Peng et al. 2014; Perugini et al. 2017; Alkama and Cescatti 2016; Kreidenweis et al. 2016). Some afforestation projections have indicated higher food prices (Stevanovic et al. 2017; Kreidenweis et al. 2016; Humpenoeder et al. 2018). In particular for REDD+, priority regions for carbon sequestration and biodiversity do not automatically overlap (Turnhout et al. 2017; Simonet et al. 2016; Ojea et al. 2016; Magnago et al. 2015; Strassburg et al. 2010, 2012; Visseren-Hamakers et al. 2012). Forests are not the only biodiverse ecosystems, and REDD+-related conservation policies have the potential for a spill-over effect (Popp et al. 2014), in which case land transformation for agriculture may be shifted to carbon-rich ecosystems such as savannahs or temperate grasslands. Thus, incentives towards ADAFF need to address carbon storage potential, as well as biodiversity and other ecosystem services at the same time (*medium evidence, high agreement*).

Placeholder, cross-chapter text box on afforestation/reforestation, to be developed.

Reforestation and afforestation have been put forward as cost-effective climate change mitigation mechanisms. A number of such efforts already exists, arising mostly from efforts to curb erosion and support restauration of land. Based on these existing studies this cross chapter box will assess

- Capacity to store carbon (in relation to storage potential proposed in future climate-mitigation scenarios)
- Impacts on important ecosystem services such as erosion and flood control, water and air quality, as biodiversity

Risks, associated e.g., from risks to the forests per se, but also unintended side effects such as impacts on regional and local climate.

1.3.4.3 Wood products

Closely related to afforestation/reforestation is the ultimate use of wood products. The use of wood in the building sector could not only provide a potentially long-term carbon sink but also reduce emissions from cement production, which currently contributes about 6% of total fossil and industry emissions (Le Quere et al. 2018; Bergman et al. 2014). These developments are supported by technological advances that make wood suitable for high-strength applications (Song et al. 2018).

1.3.4.4 Biochar and soil carbon sequestration

Enhancing the carbon content of soil and/or use of biochar has increasingly moved into focus in recent years as climate change mitigation option with large co-benefits for other ecosystem services, but are not yet included in global land-based mitigation scenarios computed with IAMs (Smith 2016; Paustian et al. 2016). Recent estimates have placed the carbon uptake potential around 0.7 GtC_{eq} a^{-1}, approximately 20% of BECCS (see 1.3.3.1) at relatively low cost (Smith 2016; Woolf et al. 2016). Enhancing soil carbon or adding biochar has been found to be beneficial for soil properties (pH, soil water storage capacity, nutrient availability) and yields, but generalisation overall is difficult since these impacts appear to be site- and/or biochar-specific (Jeffery et al. 2017; Lorenz and Lal 2014; Stavi 2013).

Enhancing soil carbon storage and addition of biochar can be practised without competition for land area but evidence is limited and impacts of large scale application of biochar on the full greenhouse gas balance of soils, or human health are yet to be explored (Smith 2016; Gurwick et al. 2013; Lorenz and Lal 2014).

1.3.4.5 Limits to adaptation, maladaptation and malmitigation

Climate change adaptation involves actions aimed at achieving higher resilience to a changing climate (IPCC 2014a). Both mitigation and adaptation actions are said to be required to respond effectively to climate change (IPCC 2014b). Mitigation and adaptation measures tend to differ in both sector and scale of implementation, as well as in metric systems and assessment periods. There are cases where adaptation measures can indirectly foster mitigation, or vice versa, resulting in positive outcomes regarding both objectives and contributing to climate resilient pathways (Fleurbaey et al. 2014; Denton et al. 2014).

Previous IPCC reports have so far concentrated to a large degree on risks associated with lack of mitigation, but only recently have the risks of mitigation moved into focus (see previous sub-sections; chapters 6 and 7). In addition, while maladaptation has been a well-coined term, mal-mitigation –arising from unintended consequences of mitigation efforts- so far has not yet been discussed (Hallegatte and Mach 2016). In particular in developing regions, land-based climate mitigation might have severe consequences that are in conflict with the achievement of sustainable development goals such as no poverty, zero hunger and life on land (UN 2015). Therefore, large-scale land-based mitigation will have to be accompanied by additional policies to reduce or avoid trade-offs, especially in the food system (Doelman et al. 2018).

1.3.4.6 Co-benefits and feedbacks

Costs of mitigation need to be interpreted in light of costs of inaction (costs of restoring the equivalent of a damaged ecosystem-based resource, the diminution in value of ecosystem services, and damage assessments) (Rodriguez-Labajos 2013). A combination of multiple, cost-effective nature-based actions, was found to contribute until 2015 to 20% of necessary emissions reduction of a 2ºC pathway (and beginning to decline from then on; (Griscom et al. 2017b)). Regional contexts are decisive for the performance of individual mitigation options (Albanito et al. 2016). Some of these actions can also benefit societies to adapt to climate change, and enhance other ecosystem services including reduced land degradation and desertification, and enhanced food security (*medium agreement, robust evidence*) (Locatelli et al. 2015; Thornton and Comberti 2013; Thierfelder et al. 2017; Hof et al. 2017; Di Gregorio et al. 2017; Altieri and Nicholls 2017) and biodiversity protection (Tilman et al. 2017)(see also 1.3.5.2-1.3.5.4, and chapter 6).

Cost efficiency depends to a large degree on the speed of implementation of mitigation (or combined mitigation/adaptation) measures. Many assessments on the potential of climate mitigation measures rely on near-immediate implementation (Griscom et al. 2017a) and do not account for known lags in decision making, which have been demonstrated by the uptake of land use policies (Hull et al. 2015a; Alexander et al. 2013). Likewise, feedbacks in the coupled human and natural system have been explored so far chiefly on site scale (Hull et al. 2015b; Meyfroidt 2013; Robinson et al. 2017), but recent advances towards alternative approaches of process-based coupled human-environment models have begun to recognise feedbacks that notably reinforce or dampen the original stimulus for land use change (*high agreement, low evidence*) (Alexander et al. 2018; Verburg et al. 2015; Robinson et al. 2017).

1.3.5 Systemic links between production and consumption (supply and demand) of land resources, this is where solutions have to be found

The complexity of climate change and changes in the global socio-economic environment requires a systemic link between food production and consumption. Moreover, food, water, and energy are inextricably linked, and actions in one sector influence the others. Food production requires water and energy; water extraction, treatment, and redistribution require energy; and energy production requires water (Bazilian et al. 2011; Hussey and Pittock 2012). The 'Nexus thinking' emerged as an alternative to sector-specific governance of natural resource use to achieve global securities like water, food and energy (Hoff 2011), but will also have to include biodiversity concerns. Yet to date there is no agreed upon definition of "nexus" nor a uniform framework to approach the concept. Various combinations are considerations depending on the primary concern- some are land-focused (Howells et al. 2013), water-focused (Hoff 2011) or food-centred (Biggs et al. 2015; Ringler and Lawford 2013) nexus assessments. Despite recent improvements to water-energy-food nexus approaches, significant barriers remain, including challenges to cross-disciplinary collaboration, complexity, political economy and incompatibility of current institutional structures (Hayley et al. 2015). However, the momentum for recognising interdependencies across state and non-state actors, more sophisticated modelling systems to assess and quantify water-energy-food linkages are set to establish nexus approaches as part of a wider repertoire of responses to global environmental change.

1.4 Sustainable Land Management for adaptation and climate resilience

1.4.1 What comprises Sustainable Land Management, and what are the specific options with respect to degradation, desertification, food?

Clearly, land degradation, desertification, and climate change pose significant adverse consequences to critical ecosystem functions and services (*robust evidence, high agreement*). Regional detection and attribution of land degradation and desertification to climate change is not trivial, as it remains difficult to disaggregate other anthropogenic influences such as intensive agriculture, land use change and population pressure occurring at multiple scales ((Borrelli et al. 2017), see also chapter 2). Despite these challenges, there is also strong scientific evidence supporting the implementation of sustainable land management (SLM) technologies and practices as tangible solutions to, among other things, achieving land degradation neutrality and food security, while simultaneously contributing to climate change mitigation and adaptation options at varying scales (Altieri and Nicholls 2017); *medium evidence, high agreement*). Sustainable land management describes “the use of land resources . for the production of goods to meet changing human needs while assuring the long-term productive potential of these resources and the maintenance of their environmental functions” (see chapter 6; (Alemu 2016), and conceptually includes ecological, technological and governance aspects.

The choice of SLM strategy employed is a function of regional context and land use types, with *high agreement* on (a combination of) choices such as agroforestry, conservation agriculture practices, organic farming, integrated pest management, soil fertility management, rain water harvesting, range and pasture management, and precision agriculture systems (Zhang et al. 2015; Agus et al. 2015). Conservation agriculture is typified by agricultural systems with minimal soil disturbance with no tillage or minimum tillage, permanent soil cover with mulch combined with rotations to ensure permanent soil surface cover aiming at a more sustainable cultivation system for the future (Hobbs et al. 2008; Friedrich et al. 2012). Whereas precision agriculture is characterised by “management system that is information and technology based, is site specific and uses one or more of the following sources of data: soils, crops, nutrients, pests, moisture, or yield, for optimum profitability, sustainability, and protection of the environment” (USDA 2007).

1.4.2 Consumption/demand needs to be an integral part of SLM

Under climate and socio-economic changes, sustainable land management measures responsive to food security is best addressed from a holistic food system approach, covering both supply and demand drivers and encompassing production, transformation (transport, storage, processing and packaging), and consumption.

On the supply side, improving land productivity implies agricultural intensification; but the latter may force trade-offs with other SLM objectives leading either to higher or lower deforestation. Increased climate variability requires tackling greater fluctuations in world food supply and price variability (Warren 2014; Challinor et al. 2015; Elbehri et al. 2017). Analysing the impacts of climate change requires grappling with the climate-induced risks, or “food shocks” and their transmission across various sectors, and assessing how they interact with specific vulnerabilities, especially for the poor and the food insecure (Lehmann et al. 2013; LE 2016; FAO 2015).

Land productivity can be enhanced in several ways including the promotion of crop genetic diversity (Abberton et al. 2016; Ebert and W. 2014; Sunil and Pandravada 2015), the preservation and protection of pollination services under climate change, soil management (including water and nutrients) and conservation agriculture, especially in dry lands (Poeplau and Don 2015; Schulte et al. 2014; Stockmann et al. 2013). Water harvesting techniques are critical in the restoration of rangelands and for improving land productivity (Bakali et al. 2016).

On the demand side, changing dietary and consumption habits may fall beyond economic incentives (through prices) since diets are also rooted in culture and traditions but also responses to changing lifestyles driven by urbanisation, changing income and gender empowerment. There are a number of common sustainable dietary patterns around the world with significant savings in land and water and GHG emissions. (Aleksandrowicz et al. 2016). To change diet, price incentives (e.g., discounts or subsidies) can influence a shift to a healthier diet (Juhl and Jensen 2014).

Solutions to food waste and loss (FWL) need to tackle not only technical solutions but also the economics of food since FWL arises as an unintended side effect of supply chain efficiency and low cost food (in part due to subsidies and unaccounted for externalities). A more sustainable solution requires internalising the cost of food waste reduction into the product price to induce a shift in consumer behaviour towards less waste and perhaps even more nutritious, or alternative, food intake (FAO 2015)(Alexander et al. 2017b). Sustainable solutions affecting both demand and supply should rely on more than the carbon footprint and should be extended to other vital ecosystems like water, nutrients, and biodiversity footprints (Cremasch 2016) (van Noordwijk and Brussaard 2014).

Climate mitigation policies might create new trade opportunities (e.g., biomass) (Favero and Massetti 2014) or impede existing trade patterns (e.g., eco-labels like “mile food”; “local food”; carbon footprints). Food trade can either increase or reduce the overall environmental impacts of agriculture, depending on whether or not the impact is greater in the exporting region (Dalin and Rodríguez-Iturbe 2016). Countries where trade dependency may accentuate the risk of food shortages from foreign production shocks; such risk could be reduced by increasing domestic reserves or importing food from a diversity of suppliers that possess their own reserves (Gilmont 2015; Marchand et al. 2016).

However, trade is not a panacea and may also create its own instability as price or supply shocks can propagate across regions. Moreover, in the absence of sustainable practices and when the ecological footprint falls outside the market system, trade can also exacerbate over resource exploitation and environmental leakages, thus weakening trade mitigation contribution (Mosnier et al. 2014; Elbehri et al. 2017). It is important to ensure that future trade rules are both non-distorting to trade as well as being more aligned with climate objectives. In the longer term, trade rules should evolve to allow internalisation of the cost of carbon (and possibly other vital resources such as water) to avoid negatively affecting climate change mitigation. Likewise, future climate change mitigation policies should include measures designed to internalise the environmental costs of resources (Elbehri et al. 2017).

1.4.3 Actors in the solution space

Policies tend to often discount the environment's natural strengths and vulnerabilities when proposing alternative livelihood options and strategies towards climate resilient development. Local people are invariably endowed with ingenuity and local knowledge to manage land degradation and risks, but stronger links therefore need to be made between scientific and policymaking communities, to value the knowledge base of land users on issues that are intimately linked with soil conservation and degradation (Johnston and Soulsby 2006).

The dominance of governance arrangements anchored on particular flows of resources has material effects on the provision of other resources or ecosystem services (Sikor 2003; DeFries et al. 2010).

In Latin America, the overall gender disparity between rights and actual rural land ownership between men and women continues to have implications for land use and land use change (Deere and León de Leal 2014). For instance, in spite of the legal reforms adopted in the region, rural and indigenous women continue to have limited access and property rights to forests and agriculture land (Bose et al. 2017). Bose et al., 2017 in their Latin America study place a great deal of emphasis on the importance of addressing gender related asymmetries to create a level playing field amongst social groups and to reduce the tendencies of unequal societies and entrenched incidences of poverty. This would mean the need to appreciate countries with unique social values, cultures and institutional mechanisms and, in turn, identify the ways in which these social norms play a role in women's social and economic empowerment, including entrepreneurship.

1.4.4 Market-based solutions

Successful and large-scale sustainable land management requires policy-directed and market-based solutions and the synergistic contribution of public, private sector as well civil society organisations. Market-based solutions for climate-compatible development requiree a paradigm shift in business models to fully integrate the value associated with managing climate risks (Biagini and Miller 2013; Loch et al. 2010). With private sector engagement in adaptation, assures greater investments can be catalysed enabling the replication of climate-resilient technologies and services in core development sectors (Biagini and Miller 2013). Private sector and community action can also encourage sustainable production codes (Chartres and Noble 2015). Private-public partnerships can be effective mechanisms for deploying infrastructure to cope with climatic events (floods) and for climate-indexed insurance (Kunreuther 2015).

Payments for environmental services (PES) have worked well in forest recovery when combined with regulatory enforcement, market incentives and participatory approaches (Jadin et al. 2016). PES could be better designed and expanded to encourage integrated soil-water-nutrient management packages (Stavi et al. 2016), services for pollinator protection (Nicole 2015), water governance use under scarcity and combine public and private actors' engagement (Loch et al. 2013). Effective PES also require better economic metrics to account for human-directed losses in terrestrial ecosystems and to food potential, and to address market failures or externalities unaccounted for in market valuation of ecosystem services.

Market-based instruments (eco-labels) (Appleton 2009) and institutions (agricultural commodity roundtables; social networks) (Nepstad et al. 2013) (Gautier et al. 2016) are also expanding the scope of private sector participation in climate mitigation. Footprint labels can be effective means to induce behavioural change from consumers. However, private labels focusing on a single metric (e.g., carbon) may give misleading signals if they target a portion of the life cycle (e.g., transport) (Appleton 2009) or ignore other ecological indicators (water, nutrients, biodiversity)(van Noordwijk and Brussaard 2014). Commodity roundtables seek to exclude unsustainable farmers from commodity markets through international social and environmental standards (Nepstad et al. 2013). Adaptive strategies can also rely on the social construction of markets through which market access is based on social networks as in the case of livestock systems (Gautier D, Locatelli B 2016).

However sustainable market-based solutions must be integrated within enabling policy and regulatory frameworks. PES in forestry were shown to be most effective when coupled with appropriate regulatory measures (Alix-Garcia and Wolff 2014). Effective application of water markets depend on local governance conditions and supporting water policies (Loch et al. 2010). Market-based solutions based on narrow economic criteria will be inadequate to ensure sustainable land management options. Adequate policy support must complement economic mechanisms for effective solutions to restore degraded lands (Reed et al. 2015), or build farming-livestock resilience (Gautier D, Locatelli B 2016). Private investments also require appropriate public policy to mitigate against risk and to avoid shifting risks to the public (Biagini and Miller 2013).

Market-based options (including private carbon footprints and associated standards) to climate mitigation depend on the reliability of the global trading system and the underlying trade rules, especially within the World Trade Organization (WTO) (Elbehri et al. 2015). Domestic trade measures to facilitate private carbon footprints and standards must be accommodated by WTO rules. More generally, the case for reconciliation between the United Nations Framework Convention on Climate Change (UNFCCC) and WTO is more critical now than before and calls for specific steps to enable trade to accommodate climate-compatible private sector business models (Mathews 2017).

1.4.5 Socio-ecological systems thinking

Sustainable land use management options in the context of climate resilience are by nature complex, multi-variable, cross-scale and dynamics, and require a social-ecological system (SES) framing (source). Overcoming the constraints associated with common-pool resources (forestry, fisheries, water) are often of economic and institutional nature (Hinkel et al. 2014) and require tackling the absence or poor functioning of institutions such as policies and markets (Schut et al. 2016).

Ostrom and colleagues developed a useful SES framework built on the foundations of the institutional analysis and development (IAD) framework applied for analyses on how institutions affect human incentives, actions and outcomes (Ostrom and Cox 2010). The Ostrom SES framework is commonly applied to common-pool resource problems (water, forestry, fisheries). The SES framework analyses a resource system (fishery, forest, lake, grazing area) and its related resource units (fish, water, fodder) and examines the institutional and governance system and how they affect and are affected by interactions and outcomes achieved at a particular time and space (Ostrom 2009). The framework investigates the interactions between the social and ecological attributes and how they may affect and be affected by larger socioeconomic, political, and ecological settings in which they are embedded (Ostrom 2009; Veldkamp et al. 2011).

Designing interventions in social-ecological systems to build climate resilience requires confronting the issue of governance (Lebel et al. 2006) and addressing the scale concordance between the social and ecological dimensions (Veldkamp et al. 2011; Myers et al. 2016). Linking scaling to governance is an important issue for the improvement of current environmental management and policies (Azizi et al. 2017; Veldkamp et al. 2011). In building sustainable arrangements for land use along the SES framework principals, several attributes are essential: including knowledge and trust building for effective collective action, polycentric and multi-layered institutions and responsible authorities that pursue just distributions of benefits to enhance the adaptive capacity of vulnerable groups and communities (Lebel et al. 2006).

Application of SES framework requires deploying diagnostic tools to facilitate the analysis of options and to derive policy outcomes. One prominent approach applicable to a wide range of land-based management scenarios is the Multiple Criteria Decision Analysis (MCDA) (Favretto et al. 2016) - a useful tool to operationalise participatory decision-making and scenario design (Turner et al. 2016). Agent-based modeling (ABM) is a powerful diagnostic tool that can elucidate household agent behaviour through a spatially explicit and agent-specific assessment of the trade-offs and can help refine the design of interventions in a wide range of situations including agricultural intensification, conservation initiatives, and payments for ecosystem services (Villamor et al. 2014).

Food systems can be conceptualised as social-ecological systems (Ericksen 2008) for vulnerability assessment, understanding the particular difficulty owing to the multiple objectives of different actors within the food systems and the inevitable trade-offs that result (Ericksen 2008). For example, a study by Crona et al. (2015) shows that integrating small-scale fisheries within global markets via trade, produces different outcomes for local fisheries-based social-ecological systems with either positive and negative impacts on livelihoods, economics, and ecology, depending on the local context. In the presence of strong and well-enforced institutions, you can engage in trade and maintain sustained fish stocks, while a combination of weak institutions, patron-client relationships, high external demand and highly vulnerable target species result in declining stocks, conflict and debt among fishers (Crona et al. 2015).

The nature, source, and mode of knowledge generation are also critical in ensuring that sustainable solutions are community-owned and fully integrated within the local context (Mistry and Berardi 2016). Integrating local and indigenous knowledge with scientific information is a prerequisite for such community-owned solutions. Local Indigenous Knowledge (LIK) is local and context-specific, transmitted orally or through imitation and demonstration, adaptive to changing environments, collectivised through a shared social memory, and situated within (Mistry and Berardi 2016). LIK is also holistic since indigenous people do not seek solutions aimed at adapting to climate change alone, but instead look for solutions to increase their resilience to a wide range of shocks and stresses (Mistry and Berardi 2016). LIK can be deployed in the practice of climate governance especially at the local level where actions are informed by the principles of decentralisation and autonomy (Chanza and de Wit 2016). LIK need not be viewed as needing confirmation or disproval by formal science, but rather LIK can advance science and serve to complement scientific knowledge (Klein et al. 2014).

1.4.6 Regional complexity and contextualisation

Section to be developed in the next version of the report.

Will contain: Regional priorities, regional SLM approach, policy options and uptake, knowledge systems (LIK), bring a wide set of local stakeholders into the process, co-design.

1.5 Uncertainties

1.5.1 Nature and scope of uncertainties related to land use

Identification and communication of uncertainties is crucial to support decision making towards sustainable land management. Yet providing a robust and comprehensive understanding of uncertainties in observations, models, and scenarios is challenging. The identification of anthropogenically forced changes in climate (or other environmental) records (detection), and the assessment of the roles various contributors play (attribution) remains a challenging aspect in both observations and models (Lean 2018; Gillett et al. 2016; Rosenzweig and Neofotis 2013) (see chapter 2). Decision makers are thus faced with the task of developing and implementing policies that are based to varying degrees on many knowns but also many unknowns (*e.g.*, (Rosenzweig and Neofotis 2013; Anav et al. 2013; Ciais et al. 2013; Stocker et al. 2013), see 1.5.4, chapter 7).

1.5.1.1 Uncertainties in observations

There is *robust evidence and high agreement* that detection of land cover change, as a fundamental requirement to assess land use change impacts, has benefited from improved space observation over recent years (He et al. 2018; Ardö et al. 2018; Martin-Guay et al. 2018; Spennemann et al. 2018; Hansen et al. 2013). Lack of spatial resolution, the relative shortness of the satellite record, data gaps, and differences in the definitions of major land cover classes still provide major obstacles (Alexander et al. 2017a; Chen et al. 2014; Yu et al. 2014; Lacaze et al. 2015).

Likewise, ground-based measurements of key variables related to land use change and SLM are affected by spatial and temporal scale limitations, instrumentation resolution and data treatment algorithms (Song 2018; Peterson et al. 2017; Smith and Gregory 2013) (see Table 1.2 for examples). But jointly with new inter-comparisons and uncertainty analysis (Desjardins et al. 2018; Brown and Wagner-Riddle 2017; Levy et al. 2017) the picture of the response of soil organic carbon, and greenhouse gas and water fluxes in response to land use change continues to improve, caused to a large degree by advances in methodologies and sensors (Kostyanovsky et al. 2018; Rosenstock et al. 2016; Brümmer et al. 2017; Iwata et al. 2017; Valayamkunnath et al. 2018).

To overcome the time and scale mismatch between different observation methods, and the typically larger-scale gridded, continuous simulations of land use change impacts on global and regional carbon and other greenhouse gases budgets, and water cycling, a combination of different observations across scales and models is necessary (Wang et al. 2017a; Smith et al. 2010b; Scholze et al. 2017; Kaushal et al. 2017; Karthikeyan et al. 2017; Zhang and Zhou 2016). Integration of multiple data sources in model and data assimilation schemes constrains budget estimates and reduces uncertainties, as for example in estimates of land use change carbon fluxes improved by biomass observations (Li et al. 2017), land use in tropics (Clark et al. 2017) and remote sensing data for peatlands (Lees et al. 2018).

Table 1.2 Observations related to variables indicative of land management, and their uncertainties (possible table/box to be placed in the chapter)

LM-related process	Observations methodology	Scale of observations (space and time)	Uncertainties[1]	Pros and cons	Select literature
GHG emissions	Micrometeorological fluxes (CO_2)	1-10 ha 0.5hr- >10 y	10-30%	<u>Pros</u> Larger footprints Continuous monitoring Less disturbance on monitored system Detailed protocols <u>Cons</u> Limitations by fetch and turbulence scale Not all trace gases	(Wang et al. 2017a) (Luyssaert et al. 2007) (Campioli et al. 2016)(Rannik et al. 2016)
	Micrometeorological fluxes (CH_4)		8-24%		
	Micrometeorological fluxes (N_2O)		3-5%		(Peltola et al. 2014) (Desjardins et al. 2018) (Brown and Wagner-Riddle 2017)(Rannik et al. 2015)
	Soil chambers(CO_2)	0.01-1 ha 0.5hr - 1 y	15%-50%	<u>Pros</u> Relatively unexpensive Possibility of manipulation experiments Large range of trace gases <u>Cons</u> Smaller footprint Complicate upscaling Static pressure interference	(Vargas and Allen 2008)(Ogle et al. 2016)(Dossa et al. 2015)(Lavoie et al. 2015)
	Soil chambers(CH_4)		3%- 31%		(Pirk et al. 2016)(Morin et al. 2017)
	Soil chambers(N_2O)		53%- 100%[2]		(Lammirato et al. 2018) (Barton et al. 2015)
	Atmospheric inversions (CO_2)	Regional 1->10 y	50%	<u>Pros</u> Integration on large scale Attribution detection (with 14C) Rigourously derived uncertainty <u>Cons</u> Not suited at farm scale Large high precision observation network required	(Wang et al. 2017b)
	Atmospheric inversions (CH_4)		3-8%		(Pison et al. 2018)
Carbon balance	Soil carbon point measurements	0.01ha-1ha >5 y	5-20%	<u>Pros</u> Easy protocol	(Chiti et al. 2018) (Castaldi et al. 2018)

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[1] Footnote: Uncertainty here is defined as the coefficient of variation CV

[2] Footnote: > 100 for fluxes less than 5g N_2O-N ha^{-1} d^{-1}

				Well established analytics Cons Need high number of samples for upscaling Detection limit is high	(Chen et al. 2018) (Deng et al. 2018)
	Biomass measurements	0.01ha – 1ha 1-5 y	2-8%	Pros Well established allometric equations High accuracy at plot level Cons Difficult to scale up Labour intensive	(Disney et al. 2018; Urbazaev et al. 2018; Clark et al. 2017; Paul et al. 2018; Vanguelova et al. 2016; Djomo et al. 2016; Pelletier et al. 2012; Forrester et al. 2017; Marziliano et al. 2017) (Henry et al. 2015)(Xu et al. 2017)
Water balance	Soil moisture (IoT sensors, Cosmic rays, Thermo-optical sensing etc.)	0.01ha – regional 0.5hr-<1y	3-5% vol	Pros New technology Big data analytics Relatively unexpensive Cons Scaling problems	(Cao et al. 2018)(Iwata et al. 2017)(McJannet et al. 2017; Karthikeyan et al. 2017; Zhang and Zhou 2016; Iwata et al. 2017)(Yu et al. 2013)(Amaral et al. 2018; Moradizadeh and Saradjian 2018; Strati et al. 2018)
	Evapotranspiration	0.01ha – Regional 0.5hr->10y	10-20%	Pros Well established methods Easy integration in models and DSS Cons Partition of fluxes need additional measurements	(Valayamkunnath et al. 2018)(Zhang et al. 2017; Papadimitriou et al. 2017; Kaushal et al. 2017; Valayamkunnath et al. 2018)(Tie et al. 2018)(Wang et al. 2018)
Soil Erosion	Sediment transport	1 ha – Regional 1d - >10y	-21-34%	Pros Long history of methods Integrative tools Cons Validation is lacking Labour intensive	(Efthimiou 2018; García-Barrón et al. 2018)(Fiener et al. 2018)
Land cover	Satellite	0.01ha – Regional 1d - >10y	16 - >100%	Pros Increasing platforms available Consolidated algorithms Cons Need validation Lack of common Land Use definitions	(Liu et al. 2018)(Yang et al. 2018)(Olofsson et al. 2014)

1.5.1.2 Uncertainties in early warning systems

Early warning systems (EWSs) are a key feature of decision support systems (DSSs) and are becoming increasingly important for sustainable land management and food security (Shtienberg 2013; Jarroudi et al. 2015). EWSs can help to optimize fertiliser and water use, aid disease suppression, and/or increase the economic benefit by enabling strategic decisions on when and what to plant (Jarroudi et al. 2015; Caffi et al. 2012; Watmuff et al. 2013; Chipanshi et al. 2015). The accuracy of EWSs depend on the capability of the methods to predict phenological crop or pest developments, which in turn depends on expert agricultural knowledge, and the accuracy of the weather data used to run the phenological models (Shtienberg 2013; Caffi et al. 2012). Overall, DSSs with an EWS include a wide range of both extensive crops (corps that require low financial investment and returns low profit) and intensive crops (high financial investments and profit), the former being the most commonly used systems, suggesting their acceptance depending on how the farmers perceive the risk (Shtienberg 2013).

1.5.1.3 Uncertainties in model structures, parameterisations and inputs

The absence of important process representations and the lack of understanding how a process should best be described through algorithms are chief sources of model uncertainty. Quantifying model skill in benchmarking exercises, the repeated confrontation of models by a range of observations to establish a track-record of model developments and performance, is an important development to support the design and the interpretation of the outcomes of model ensemble studies (Randerson et al. 2009; Kelley et al. 2013; Luo et al. 2012)(*medium evidence, high agreement*). Since observational data sets in themselves are uncertain (1.5.1.1), benchmarking benefits from transparent information on the observations that were used, and the inclusion of multiple, regularly updated data sources (Luo et al. 2012; Kelley et al. 2013).

The currently most widely used approaches to quantify model uncertainty in climate change, land use change and ecosystem modelling are intercomparisons and the calculation of model-ensemble means. The latter implies that the mean across a range of models "averages-out" some of the structural and parameter-related uncertainties and yields more robust results (*high agreement, medium evidence*). But the use of ensembles might unintentionally also lead to models being "re-tuned" to fit better to the average model response results (Parker 2013; Prestele et al. 2016; Buisson et al. 2009). Although methods to also quantify impacts of within-model structural characteristics and choice of parameterisations on simulation results are available, they are computationally costly (Xia et al. 2013; Arora and Matthews 2009; Ahlström et al. 2015; Booth et al. 2012; Wramneby et al. 2008; Zaehle et al. 2005). In view of the often still untested model structural and parameter uncertainties, deriving estimates of uncertainty from model intercomparison must be interpreted with caution (Parker 2013).

1.5.1.4 Uncertainties arising from unknown futures

The work assessed in the IPCC reports is based on exploratory scenarios of the future that cover a range of projections of indirect and direct drivers, deemed plausible within diverging overarching storylines. Within and since AR5, the four Representative Concentration Pathways (RCPs) have provided emission scenarios for climate change projections. The RCPs were more recently complemented by five Shared Socio-economic Pathways that seek to describe different socio-economic challenges for mitigation and adaptation that arise from assumptions on demographic trends, economic development and degree of interconnectedness of world regions (van Vuuren and Carter 2014; van Vuuren et al. 2014; O'Neill et al. 2014). Based on some similarities in these assumptions, SSPs and other, previously used global or regional scale scenarios, have been grouped into scenario archetypes (IPBES 2016; van Vuuren et al. 2012).

Since AR5, an increasing number of studies have begun to explore uncertainty in global or regional land cover and land use projections computed by Integrated Assessment models and land use change models (Alexander et al. 2017a; Popp et al. 2016; Prestele et al. 2016; Krause et al. 2017; Eitelberg et al. 2016; Fuchs et al. 2015; Rogelj et al. 2018). These studies agree that large differences exist in the extend and location of future cropland, pasture and forest, both between scenarios, but also even within a single scenario (*high agreement*, *high/medium evidence*). Recently it was also shown that differences in projected land cover changes caused by different model structure is similar in magnitude to differences attributable to scenarios (Alexander et al. 2017a; Prestele et al. 2016)(*high agreement, limited evidence*). This raises concerns, considering that in AR5 only one IAM provided the realisation of projected land cover change for a given RCP (Hurtt et al. 2011).

Placeholder: cross-chapter box on scenarios, to be developed.

In face of an unknown future scenarios are indispensable to examine how differences in socio-economic conditions, environmental changes and political decisions will affect future societies and their interactions with the environment. This cross-chapter text box will explore

- different approaches to scenarios and their advantages and disadvantages,
- will highlight the enhanced need to combine scenarios with pathway analysis,
- and identify important uncertainties that exist both in the existing future socio-economic scenarios as well as the challenges arising for studies that explore impacts of these scenarios on land ecosystems and climate.

The uncertainty in ecosystem responses that arises from past land cover and land use estimates is at least of equal magnitude to that caused by different climate change projections (hi*gh agreement*, *high/medium evidence*) (Bayer et al. 2017; Arneth et al. 2017; Fuchs et al. 2016; Krause et al. 2017, 2018; Ahlstrom et al. 2013, 2012; Wu et al. 2017; Blanke et al. 2016). A broader range of harmonised scenarios available to the climate change and ecosystem modelling community is therefore needed but will only partially be achieved in AR6.

Scenarios as used in IPCC assessments are exploratory in the sense that they are based on a number of alternative, possible storylines and assumptions about how drivers might interact. However, for questions of sustainable land management, or other questions of sustainable development, futures that achieve a number of set targets need to be explored more explicitly (Reilly and Willenbockel 2010; Le Mouel and Forslund 2017). Therefore, normative (or solution-orientated) scenario approaches, targets representing a desired situation at some point in the future are first defined and pathways to achieve these targets are derived from model simulations (Reilly and Willenbockel 2010). For instance, Erb et al. (2016b) and Henry et al. (2018), using different scenario approaches, found it possible to meet global food demand under the constraint of only little (or no) deforestation by 2050, contingent to decreasing meat consumption or increasing yields (Erb et al. 2016b). However, it was not possible to stay within a global crop-area planetary boundary when in addition also adding a third, bioenergy-demand related target (Henry et al. 2018). As normative scenarios are designed to support sustainable visions their increasing use offers a useful way forward.

1.5.2 Uncertainties in decision making

1.5.2.1 Types and classifications of uncertainties

Standard decision theory focuses mostly on the *uncertainty of consequences*. Here *risk* refers to situation where all possible outcomes are known and can be assigned meaningful probabilities (see also chapter 7, for more detailed discussion); *(non-probabilistic) uncertainty* refers to a lack of probability estimates[3], while for *ignorance* one also does not know the full space of possible outcomes (sometimes referred to as `black swans' or `unknown unknowns'). How to discuss (and deal with) more information-poor decisions that go beyond the uncertainty of consequences is much less clear (see also **Error! Reference source not found.**). Several research fields introduced different terms that are not mutually exclusive, but put a different focus on the multifaceted aspects of uncertainties decision making faces, given multiple futures that cannot be easily differentiated regarding their plausibility or probability. In context of climate change projections, the term *deep uncertainty* is frequently used to denote situations where either the analysis of a situation is inconclusive, or parties to a decision cannot agree on a number of criteria that would help to rank model results in terms of likelihood (e.g. Lempert et al. 2004; Hallegatte and Mach 2016; Maier et al. 2016). Part of deep uncertainty are *uncertainty of demarcation,* meaning that it may not be that clear what the decision is all about or how far in time and space its consequences are to be considered, or *moral uncertainty*, i.e. uncertainty about the values or the moral principle to act on (Maier et al. 2016). Whether to act trading off the various consequences (e.g. via risk minimisation, consequentialist approach) or whether to act on basis of deontological reasoning and go for a precautionary approach may be far from clear. Resolving these issues is further complicated as it may not be apparent how to identify the most relevant experts and how to judge conflicting evidence (*uncertainty of reliability)*. (see chapter 7 for more details on methods in decision making).

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[3] Footnote: Probabilities in this terminology refer to objective probabilities.

Table 1.3 Possible uncertainties decision making faces (following (Hansson and Hadorn 2016)

Type	Knowledge gaps	Understanding the uncertainties
Uncertainty of consequences	Do the model(s) adequately represent the target system? What are the numerical values of input parameters, boundary conditions, or initial conditions? What are all potential events that we would take into account if we were aware of them? Will future events relevant for our decisions, including expected impacts from these decisions, in fact take place?	Ensemble approaches; downscaling Benchmarking, sensitivity analyses Scenario approaches
Moral uncertainty	How to (ethically) evaluate the decisions? What values to base the decision on (→ often unreliable ranking of values not doing justice to the range of values at stake, cp. Sen 1992), including choice of discount rate, risk attitude (risk aversion, risk neutral, …) Which ethical principles? (i.e. utilitarian, deontic, virtue, or other?)	Possibly scenario analysis Identification of lock-in effects and path-dependency (e.g. Kinsley et al 2016)
Uncertainty of demarcation	What are the options that we can actually choose between? (not fully known because "decision costs" may be high, or certain options are not „seen" as they are outside current ideologies). How can the mass of decisions divided into individual decisions? e.g. how this influences international negotiations and the question who does what and when (cp. Hammond et al. 1999).	Possibly scenario analysis
Uncertainty of consequences & uncertainty of demarcation	What effects does a decision have when combined with the decision of others? (e.g. other countries may follow the inspiring example in climate reduction of country X, or they use it solely in their own economic interest)	Games
Uncertainty of demarcation & moral uncertainty	How would we decide in the future? (Spohn 1977; Rabinowicz 2002)	

1.5.2.2 Decision making in the face of uncertainty

The spectrum of the multitude of ways to deal with uncertain consequences can be spanned by two extreme decision approaches (see also chapter 7): cost-benefit analysis (CBA) and a precautionary approach. A typical variant of cost benefit analysis is risk minimisation: the focus is on the negative outcomes only and one aims at minimising the expected harm. This approach needs reliable probability estimates (Gleckler et al. 2016; Parker 2013) (*robust agreement, medium evidence*). Subjective probability estimates may provide a possibility to apply risk analysis or cost benefit analysis also in cases where so-called "objective" probability estimates are not available. The other end of the spectrum of decision approaches, the precautionary approach provides a decision method that does not take into account probability estimates (cf. Raffensperger and Tickner 1999):[4] In a nutshell, the focus here is on the worst outcome only and it is to be avoided at any cost (Gardiner 2006).

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[4] Footnote: Note that there are different versions of the precautionary approach. This is sometimes referred to as strong formulation of the precautionary principle in order to distinguish it from meta-decision criteria, so called weal formulations, as given, for example in the Rio Declaration on Environment and Development 1992.

In between these two extreme cases, various decision approaches are suggested that try to not only avoid the deficits of CBA and a precautionary approach, but also address some of the other uncertainties in a more reflective manner. Climate informed decision analysis may combine various approaches that can be considered more bottom-up, as they start with exploring real options and the vulnerabilities and sensitivities of certain decisions. Such an approach includes stakeholder involvement, and can be combined with e.g., analysis of climate modelling (Hallegatte and Rentschler 2015)(see chapter 7). Generally, different approaches to decide in the light of complex uncertainties are not considered mutually exclusive (Walker et al. 2013).

Though current decision making, despite faced with various uncertainties, often assumes that the future can be predicted and thus develop optimal plans for some probable or likely future, given "deep uncertainty" flexibility in decision making requires that decisions are not set in stone and can change over time (Hallegatte and Rentschler 2015; Walker et al. 2013). As such, monitoring of the impacts of the decision becomes necessary. As regards COP21, one may argue that the breakthrough in agreeing on a temperature threshold was made possible, amongst many other things, by a shift towards a "reasonable pluralism" (e.g. Boran 2014) since the Durham platform (County Durham Climate Change Delivery Plan 2015), by starting to address various types of uncertainties. For example it was claimed that the launch of various small-scale mitigation projects had a positive influence on the discussions (cf**.** Tavoni 2015). Generally, within the deep uncertainty community a paradigm is emerging that requires from decision making to develop a strategic vision of the long- or mid-term future, while committing to short-term actions and establishing a framework to guide future actions (Haasnoot 2013).

1.6 Introduction of the remaining chapters & story of the report

Land use is an environmental challenge but can also contribute to address climate change, hence, land gives us an opportunity to maximise the several solutions that exist, beyond energy based solutions. This report should help us to assess how land can be used in a way to contribute to achieving the SDGs. Chapter 2 concentrates on the natural system dynamics, assessing recent progress that has been made towards understanding impacts of climate change on land, and feedbacks arising from altered biogeochemical and biophysical exchange fluxes. Chapters 3 to 5 concentrate on the report's key terms "desertification", "degradation" and "food security.

Chapter 3 examines in particular how the world's dryland populations are uniquely vulnerable to desertification and climate change, but also have significant knowledge in adapting to climate variability and addressing desertification. Chapter 4 assesses the urgency of addressing land degradation. Despite accelerating trends of land degradation, reversing these trends seems attainable through proper implementation of SLM, which is expected to improve resilience to climate change, mitigate climate change, and ensure food security for generations to come. Food security is then picked up in Chapter 5, in an assessment of the risks and opportunities that climate change presents to food systems, focusing on how mitigation and adaptation can contribute to both human and planetary health.

Chapters 6 and 7 then are faced with the challenge to take up the issues identified in Chapter 1 and to provide a cross-chapter synthesis which brings out the key messages related to the manifold interlinkages, and to identify integrative (win:win) response options, in light of the SDGs. Chapter 7, highlights these aspects further, especially regarding the challenges and opportunities that arise in the broader climate land interactions.

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