# IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems

## Summary for Policymakers

## Final Draft for Government Review

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# Introduction

This report responds to proposals for Special Reports from governments and observer organisations provided at the start of the IPCC Sixth Assessment cycle.[1] It addresses greenhouse gas (GHG) fluxes in terrestrial ecosystems and sustainable land management in relation to climate adaptation and mitigation, desertification, land degradation and food security. The report sits alongside other IPCC reports, including the *Special Report on Global Warming of 1.5°C*, and related reports from other UN Bodies.[2] It has been produced with careful attention to these other assessments with the aim of achieving coherence and complementarity, as well as providing an updated assessment of the current state of knowledge.[3]

This Summary for Policymakers (SPM) is structured in four parts: A) *People, land and climate in a warming world*; B) *Adaptation and mitigation response options*; C) *Enabling response options*; and D) *Action in the near term.* Confidence in key findings is indicated using the IPCC calibrated language[4]; the underlying scientific basis of each key finding is indicated by references provided to chapter elements.

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[1] FOOTNOTE: Related proposals were: Climate Change and Desertification; Desertification with Regional Aspects; Land Degradation – An Assessment of the Inter-linkages and Integrated Strategies for Mitigation and Adaptation; Agriculture, Forestry and Other Land Use; Climate Change, Food and Agriculture; and Food Security and Climate Change.

[2] FOOTNOTE: Related reports from other UN Bodies include the thematic assessment of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) on *Land Degradation and Restoration* and the *Global Land Outlook* of the UN Convention to Combat Desertification (UNCCD).

[3] FOOTNOTE: The assessment covers literature accepted for publication by 7th April 2019.

[4] FOOTNOTE: Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: *very low, low, medium, high* and *very high*, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: *virtually certain* 99–100% probability, *very likely* 90–100%, *likely* 66–100%, *about as likely as not* 33–66%, *unlikely* 0–33%, *very unlikely* 0–10%, *exceptionally unlikely* 0–1%. Additional terms (*extremely likely* 95–100%, *more likely than not* >50–100%, *more unlikely than likely* 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with IPCC AR5.

# A. People, land and climate in a warming world

**A 1. Land resources provide the basis for human livelihoods via economic, cultural, spiritual, and health benefits. Land contributes to climate regulation through sources and sinks of greenhouse gases, sources of aerosols and sources and sinks of water and energy. Collectively, land ecosystem services, and the biodiversity upon which they depend, support human subsistence and well-being (*high confidence*). {1.2, 2.2, 2.4, 5.1, 5.4, 7.4}**

A1.1. Terrestrial ecosystems and their biodiversity provide food, feed, fibre, fuel and freshwater in addition to many other ecosystem services without which human society, and its economy, could not exist (*high confidence*). Agriculture generates between 1% and 25% of GDP in many countries, with a world average of about 4% in 2016 (*high confidence*). The total economic value of the world's terrestrial ecosystem services has been estimated to exceed annual global GDP by more than 10%, and possibly up to 25% (*medium confidence*). Land and its biodiversity have intrinsic value and also support non-material ecosystem services, such as cognitive and spiritual enrichment, and aesthetic values (*high confidence*). These services have declined at the expense of the increase in material services such as food production (*high confidence*). {1.2, 5.1, 7.4}

A1.2. Through access to ecosystem services, land is an important mediator of human physical and psychological health. Despite increasing food production, an estimated 821 million people are undernourished and 613 million suffer from iron deficiency while 2 billion adults are overweight or obese (*high confidence*). When people living in cities interact with the natural environment, health conditions such as mortality, cardiovascular disease and depression decrease and subjective well-being increases (*medium confidence*). {1.2, 5.1, Cross-Chapter Box 8: 'Ecosystem Services' in Chapter 6, SPM Fig. 1}.

A1.3. Land is both a source and sink for GHGs affecting global climate; climate also affects many land-based ecosystem services. Around 22% of total anthropogenic GHG emissions[5] arise from agriculture, forestry and other land use (AFOLU) (*medium confidence*). Agriculture is responsible for about half of global anthropogenic methane ($CH_4$) emissions, predominantly from ruminant livestock and rice cultivation (*high confidence*), and nearly three quarters of global nitrous oxide ($N_2O$) emissions due to nitrogen fertilisation (*high confidence*). Deforestation and peatland degradation contribute about 10-15% to total anthropogenic carbon dioxide ($CO_2$) emissions (*medium confidence*). Globally, for 2008-2017, land removed nearly 30% of total anthropogenic $CO_2$ emissions through biogeophysical processes (*medium confidence*). In addition, regional climate is affected by biophysical processes, such as exchanges of moisture and energy, and by aerosols from the land, e.g. dust, soot and volatile organic compounds (*high confidence*). {1.2, 2.2, 2.4, 2.6, 5.4, SPM Fig. 1}

**A 2. The rate and geographic extent of global land and freshwater resource exploitation over recent decades is unprecedented in human history (*high confidence*). These area and rate changes together with the intensification of land management have led to the loss of biodiversity and ecosystem services and the acceleration of land degradation and desertification that increasingly affects the livelihoods of people (*high confidence*). {1.2, 1.3, 3.3, 4.2, 4.5, 5.1, 5.5}**

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[5] FOOTNOTE: In this report, aggregated emissions of different GHGs are reported in carbon dioxide ($CO_2$) equivalents based on Global Warming Potentials with a time horizon of 100 years, without climate-carbon feedbacks, using values from the IPCC Fifth Assessment Report

A2.1. Human use affects approximately 72% (*likely* 69-76%) of the global, ice-free land surface, and humans use one quarter to one third of terrestrial potential net primary production for food, fibre and energy (*high confidence*). Wood harvest has increased by about one third since 1970 (*medium confidence*), with more than two-thirds of the global forest area under human use. Since the early 1960s, the supply of global per capita food calories increased by about one third, with the per capita consumption of vegetable oils and meat more than doubling (*high confidence*). Inorganic nitrogen fertiliser use increased by nearly nine-fold globally (*high confidence*) and the area and volume of the world's irrigated cropland roughly doubled (*high confidence*) with irrigation accounting for 70% of global fresh-water use (*medium confidence*). At the same time, global average food waste per capita increased by more than 40% and is now around 25-30% of total food produced (*medium confidence*). {Table 1.1, 1.2, 1.3, 5.1, 5.5, SPM Fig. 1}.

A2.2. About a quarter of the Earth's ice-free land area is subject to degradation (*medium confidence*). Global terrestrial biodiversity loss based on species richness has been estimated to be around 8-14% due to past land-use change (*medium confidence*). Vulnerability to land degradation is particularly high in low-lying coastal areas, river deltas, and in permafrost areas (*high confidence*) with the majority of people affected living in poverty (*medium confidence*). Soil loss from conventionally tilled land is estimated to exceed the rate of soil formation by more than two orders of magnitude (*medium confidence*). In 2015, about 500 (±120) million people lived within areas undergoing desertification; an increase of approximately 300% since 1961 (*low confidence*). {1.3, 3.2, 3.3, 4.2, 4.4, 4.5, 4.8, 4.10, SPM Fig. 1}.

A2.3. Socio-economic drivers of land-use change such as technological development, population growth and increasing per capita demand for multiple ecosystem can amplify existing environmental and societal challenges, including the conversion of natural ecosystems into managed land, degradation of land already managed, rapid urbanisation, air and freshwater pollution from the intensification of land management and lack of equitable access to land resources (*high confidence*). Climate change and land degradation act as threat multipliers for already precarious livelihoods (*very high confidence*), leaving them highly sensitive to extreme climatic events, with consequences such as poverty and food insecurity (*high confidence*). {1.2.2, 1.3.1, 1.4.2, 1.43, 1.4.4, 1.4.5, 1.4.6, Cross-Chapter Box 1: 'Scenarios' in Chapter 1, 2.6, 4.2.6, 4.8, 5.2, 7.3, 7.4, SPM Fig. 2}

**A 3. The globally averaged land surface air temperature has risen faster than the global mean surface temperature (GMST)[6] from pre-industrial (1850-1900) to the present day (1999-2018). Impacts are already observed on natural terrestrial ecosystems, permafrost degradation, desertification, land degradation and food security. The frequency and intensity of some extreme events has also increased. (*high confidence*). {2.3, 3.3, 4.3, 4.5, 5.1, 5.2}**

A3.1. According to the single longest and most extensive dataset, the land surface air temperature increase between the period 1850-1900 and the period 1999-2018 was 1.52°C (*very likely* range: 1.39°C to 1.66°C) compared to a global mean increase of 0.86°C over the same period. For the 1880-2018 period covered by four independently produced datasets, the land surface air temperature increase between 1880-1900 and 1999-2018 was 1.41°C (1.31°C to 1.51°C), where the range represents the spread in the datasets' median estimates. {2.3.1, SPM Fig. 1}

A3.2. The frequency and intensity of some extreme events has increased as a consequence of global warming and are projected to continue to increase with the level of warming (*high confidence*). Heat

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[6] FOOTNOTE: Global mean surface temperature (GMST) combines land surface air temperature and sea surface temperature

waves have been more frequent or more intense due to anthropogenic warming in most land regions and are projected to increase in frequency, intensity and duration in most regions of the globe (*high confidence*). The frequency and intensity of drought is projected to increase in the Mediterranean region, central Europe, the southern Amazon and southern Africa (*medium confidence*). Compound extreme events, such as a heat wave within a drought or drought followed by extreme rainfall, will decrease gross primary productivity resulting in reduced terrestrial carbon uptake (*medium confidence*). The frequency and intensity of heavy precipitation events, which is a driver of soil erosion, have increased (*medium confidence*). {2.2.5, 4.3.3, 5.2}.

A3.3. Globally, vegetation greening through enhanced photosynthetic activity has increased over the last three decades (*high confidence*). This results from a combination of changes in human activities, including in land use management, for example irrigation, forest conservation and expansion, and changes in environmental factors, for example $CO_2$ fertilisation, extended growing season, and nitrogen deposition (*high confidence*). Modelled greening trends in high-latitudes are linked to $CO_2$ fertilisation and a longer growing season, while modelled browning trends due to loss of photosynthetic activity in mid- and low-latitudes are linked to regional increases in drought and heat waves (*low confidence*). Increased levels of atmospheric $CO_2$ are improving plant water use efficiency and vegetation productivity in drylands (*high confidence*). The net effect, however, is modulated by soil nutrients and water availability. {2.3.3, Box 2.3, 2.3.4, 3.3.1 3.3.2, 4.4.1, 4.4.2, 4.7.2, 5.2.2}.

A3.4. Warming has resulted in climate zone shifts, which has exposed some biomes to weather and climate variability, including extreme events, beyond their adaptive capacity (*high confidence*). Overall, climate zones have shifted poleward in the mid-to high latitudes and upward in mountainous regions and this is projected to continue under medium and high emission scenarios. In tropical regions warming is projected to result in new, hot climates (*high confidence*). {2.3, 4.5.1}

A3.5. Climate change exacerbates land degradation processes through increases in rainfall intensity, flooding, drought frequency and severity, heat stress, wind, sea-level rise and wave action, with outcomes being modulated by land management (*high confidence*). Coastal erosion is affecting new regions as a result of interacting human drivers and climate change such as sea-level rise (*high confidence*) and impacts of changing cyclone paths (*low confidence*). The areal extent of permafrost and polar climates has decreased (*high confidence*). High-latitude warming is projected to accelerate permafrost thawing and increase disturbance in boreal forests through abiotic agents such as drought and fire, and biotic agents such as pests and disease.-{2.3.4, 4.3.1, 4.3.2, 4.3.3, 4.5.1, 4.5.2, .10.6, Table 4.1, 7.3.1, 7.3.2}

A3.6. Observed climate change is already affecting the four pillars of food security – availability, access, utilisation, and stability – through increasing temperatures, changing precipitation patterns, and greater frequency of some extreme events (*high confidence*). Increasing temperatures are affecting agricultural productivity in higher latitudes, raising yields of some crops such as maize, cotton, wheat, sugar beets, while in lower-latitude regions yields of crops such as maize, wheat and barley are declining. Observed impacts in pastoral systems include pasture declines, lower animal growth rates and productivity, damaged reproductive functions, increased pests and diseases, and loss of biodiversity (*high confidence*). Indigenous and local sources of knowledge also indicate that climate change is affecting food security in drylands, particularly those in Africa, and high mountain regions of Asia and South America. {5.2.1, 5.2.2, 7.3.2}

**A 4. Agriculture forestry and other land use (AFOLU) is a significant net source of GHG emissions (*high confidence*), accounting for around 22% of anthropogenic GHG emissions**

**(expressed as $CO_2$-equivalent) between 2007 and 2016 (*medium confidence*). Half of this contribution arises from $CO_2$ emissions, mostly due to deforestation, and the rest from emissions of methane and nitrous oxide, where AFOLU is the dominant source. {2.4, Table 2.2, 5.4}**

A4.1. Modelled direct anthropogenic fluxes of $CO_2$ from AFOLU were *likely* a net emission of 5.5 ± 2.6 $GtCO_2$ $yr^{-1}$ during 2008 to 2017 driven by land cover change, including emissions from deforestation and removals from afforestation/reforestation, and by wood harvesting. Vegetation models find a net land sink, *likely* 11.7 ± 2.6 $GtCO_2$ $yr^{-1}$, during 2008 to 2017 primarily due to the indirect effects of environmental change, such as climate change, $CO_2$ fertilisation, and nitrogen deposition on all lands. The combined land-atmosphere flux of $CO_2$ on both managed and unmanaged lands *likely* resulted in a net removal of 6.2 ± 3.7 Gt $CO_2$ $yr^{-1}$ from 2008 to 2017 according to the models and corroborated by atmospheric observations. {2.4.1}

A4.2. Anthropogenic $CO_2$ emissions from AFOLU reported in countries' GHG inventories were 0. 1 ± 1.0 Gt $CO_2$ $yr^{-1}$ globally from 2005 to 2014 (*medium confidence*). Estimates from global bookkeeping models were 5.1 ± 2.6 Gt $CO_2$ $yr^{-1}$ over the same period. This discrepancy can primarily be attributed to different approaches for defining anthropogenic fluxes. Inventories consider larger areas of forested lands to be managed and include, as anthropogenic, a large net sink on managed land due to indirect effects of environmental change. In global bookkeeping approaches some of this sink is included in the non-anthropogenic land sink. {2.4.1}

A4.3. Land is a net source of $CH_4$, accounting for 61% of anthropogenic emissions during 2005 to 2015 (*medium confidence*). Net $CH_4$ emissions are increasing and there is a significant increase of $CH_4$ concentration in the atmosphere (*very high confidence*). Biogenic sources such as tropical wetlands and peatlands make up a larger proportion of emissions than they did before year 2000 (*high confidence*). Ruminants and the expansion of rice cultivation are also increasingly important contributors to rising methane emissions (*high confidence*). {2.4.2; 5.4.2; 5.4.3}

A4.4. AFOLU is the main anthropogenic source of $N_2O$ primarily due to nitrogen application to soils (*high confidence*). Cropland soils have been emitting around 2.5 Mt $N_2O$ $yr^{-1}$ between 2010 and 2016 (*medium confidence*). There has been a disproportionate growth in emissions from managed pastures which contributed more than three-quarters of $N_2O$ emissions from grazing land between 1961 and 2014 (*medium confidence*). Pastures and rangelands are responsible for more than one third of total anthropogenic $N_2O$ emissions (*high confidence*). {2.4.3, 5.4.2; 5.4.3}

A4.5. Future increases in $CO_2$ emissions from vegetation and soils due to climate change are expected to counteract increased sinks due to $CO_2$ fertilisation. Thawing of high-latitude/altitude permafrost will accelerate the loss of soil organic carbon and increase methane emissions relative to $CO_2$ emissions (*medium confidence*). The balance between increased respiration in warmer climates and carbon input from enhanced plant growth is a key uncertainty for the size of the future land carbon sink *(medium confidence*). {Box 2.3, 2.4.1, 2.8.2; 5.4.2}

**A 5. At the global scale, historical and future changes in anthropogenic land cover result in biogeochemical warming that is partially offset by biophysical cooling due to an increased surface albedo (*low confidence*). At the regional scale, land can dampen or accentuate climate change via the redistribution of energy and water vapour between the land and the atmosphere, with the strength and sign depending on location and season (*high confidence*). The likelihood, intensity and duration of many extreme events are also modulated by the land, including heat waves (*high confidence)* and heavy precipitation events (*medium confidence*). {2.1, 2.3, 2.5, 3.4}**

A5.1. The net release of $CO_2$ into the atmosphere from changes in anthropogenic land cover contribute to global warming through biogeochemical effects *(high confidence)*, partly offset by global biophysical cooling, dominated by albedo changes (*medium confidence*). Over historical periods, earth system models do not agree on the magnitude and sign of changes in global temperature from the combined biogeochemical and biophysical effects. The magnitude of such contributions to global temperature change is small compared to that caused by GHG emissions from all sources. Projected changes in land will continue to enhance global warming throughout the 21st century via biogeochemical effects and offset it via biophysical effects under medium and high emission scenarios (*medium confidence*). {2.4, 2.6.1}

A5.2. Desertification exacerbates climate change through changes in vegetation cover, sand and dust aerosols and GHG fluxes (*high confidence*). It also tends to increase albedo, decreasing energy available at the surface and associated surface temperatures (*high confidence*). {3.4}

A5.3. Dry soils can strengthen summer heat wave conditions, and wet soil conditions can dampen extreme warm events, for example from irrigation or crop management practices that maintain a cover crop all year round (*high confidence*). Urbanisation, through the heat island effect, further enhances surface air warming in cities and their surroundings (*high confidence*), intensifying extreme rainfall events over or downwind of urban areas (*medium confidence*). {2.6.1, 2.6.2, 2.6.3, Cross-Chapter Box 4: 'Climate Change and Urbanisation' in Chapter 2}

A5.4. Changes in local land cover or irrigated water availability can affect climate in regions as far as few hundreds of kilometres downwind (*high confidence*). Changes to the land can also affect precipitation through the modification of horizontal and vertical gradients of temperature, pressure and moisture, which in turn alter regional winds (*high confidence*). {2.6.2; 2.6.4; Cross-Chapter Box 4: 'Climate Change and Urbanisation' in Chapter 2}

A5.5. In boreal regions, regional winter warming will be enhanced due to a northward treeline migration, an increased growing season, and permafrost thawing, whereas warming during the growing season will be dampened as a result of greater evapotranspiration (*high confidence*). In the tropics, in areas where increased rainfall is projected, increased vegetation growth will dampen regional warming (*medium confidence*). {2.6.2, 2.6.3}

A5.6. During the growing season, afforestation/reforestation brings cooler days and warmer nights (*high confidence*). Trees locally dampen the amplitude of heat extremes (*medium confidence*). During the growing season, afforestation generally brings cooler days from increased evapotranspiration, and warmer nights from reduced radiative losses (*high confidence*). During the dormant season, especially in snow-covered areas, forests are warmer than any other land cover (*high confidence*). {2.4, 2.6.1, 2.6.2, 2.5.3, 2.6.4}

**A 6. Climate change is projected to create additional stresses on land systems exacerbating existing risks related to desertification, land degradation and food security (*high confidence*).**

A6.1. As global temperatures increase, the potential for adverse impacts on crop yield, food supply stability, vegetation loss, fire damage, permafrost and coastal degradation, soil erosion and water availability become more severe. (*high confidence*). {Cross-Chapter Box 3: 'Fire and Climate Change' in Chapter 2, 2.3, 3.6, 4.3.1.2, 4.5.1.1, 4.5.1.2, 4.6, 5.2.2, 5.2.3, 5.2.4, 5.2.5, 7.3, SPM Fig. 2}.

A6.2. There are increasingly negative effects on GDP from impacts on land-based values and ecosystem service as temperature increases, although the impact varies across regions. Between

1.5ºC - 2ºC of global warming nearly four million people and around 70% of current infrastructure in the Northern Hemisphere permafrost area, including railways, pipelines, buildings and settlements, may be affected by damage from thawing of near surface permafrost. Collapsing infrastructure and livelihoods due to permafrost thaw, disappearance of land due to coastal erosion, and extreme forms of soil erosion are examples of potential limits to adaptation due to climate change induced land degradation. {4.8, 4.9.5, 4.9.6, 4.10.6, 4.10.7, 4.10.8, Cross-chapter Box 10: 'Economic Dimensions' in Chapter 7}

A6.3. In drylands, desertification and climate change are projected to cause reductions in crop and livestock productivity (*high confidence*), modify the composition of plant species and reduce biological diversity (*medium confidence*). At global warming of 2ºC the population of drylands exposed and vulnerable to water stress, increased drought intensity and habitat degradation is projected to range from 35 -522 million. {3.6.2; 3.8.3}

A6.4. Global crop and economic models project a 1-29% increase in cereal prices in 2050 due to climate change under Representative Concentration Pathway (RCP) 6.0, which would impact consumers globally through higher food prices, although regional effects will vary *(high confidence)*. Food quality will also be affected by higher $CO_2$ concentrations through changes to metabolic processes that lead to changes in nutrient composition, for example the amount of protein, or zinc, with impacts on nutritional security (*medium confidence*). The stability of the food supply is expected to decrease as the magnitude and frequency of extreme events increase, disrupting food chains in all areas of the world {4.3.2, 5.2.2, 5.2.4; 5.3.2, 5.3.3, 5.6.2, 5.7.1}.

A6.5. New compound risks to food systems, human and ecosystem health, livelihoods and infrastructure are anticipated (*high confidence*). Increasing human exposure to wildfire is projected as the population in fire-prone regions grows, creating risks to health, including loss of life, increased air pollution, negative mental health impacts, risks to infrastructure and risks to ecosystems, through long-term vegetation changes, accelerated erosion and altered hydrology. (*high confidence*). {2.3; 4.2.6, 4.8, 7.3, 7.4, SPM Fig. 2}

A6.6. Impacts of projected future changes are location-specific with significant regional heterogeneity (*high confidence*). Crop yields and suitability are projected to decline as temperatures increase, especially in tropical and semi-tropical regions. There is also *high confidence* that aridity will increase in some locations with around half of the vulnerable population in South Asia, followed by Central Asia, West Africa and East Asia. Projections, however, provide no evidence for an increasing global trend in dryland aridity (*medium confidence*). {3.6.1, 3.6.2, 5.2.2, 7.3.2.1}

**A 7. The level of risk posed by future climate change will depend not only on the level of warming but also on how future population, consumption, and land management patterns evolve alongside other socio-economic drivers (*high confidence*). Pathways with higher incomes, less resource-intensive consumption, and higher rates of technological change result in lower risks of water scarcity in drylands, land degradation, and food insecurity (*high confidence*). {4.6, 5.1.4, 5.2.3, 6.2.4, 7.3, Cross-Chapter Box 9: 'Illustrative Climate and Land Pathways' in Chapter 6, SPM Fig. 2}**

A7.1. Socio-economic changes can create stresses on land systems (*high confidence*). Increases in population and income, combined with changes in consumption and land management, result in increased demand for food and water, with implications for land use change, food insecurity, water scarcity and terrestrial GHG emissions. Development pathways in which income increases and pressure on land reduces can lead to reductions in food insecurity. All assessed future socio-economic pathways, however, result in increases in water demand and water scarcity (*medium confidence*). {6.2.4}.

**BOX A7: Shared Socioeconomic Pathways (SSPs)**

In this report the implications of future socioeconomic development on climate change mitigation, adaptation and land-use are explored using three illustrative pathways. These scenarios are used extensively by the international modelling community and are known collectively as the shared socio-economic pathways (SSPs).

- SSP1 is a pathway with low population growth (~7 billion in 2100), high income and reduced inequalities, effective land use regulation, less resource intensive consumption, including lower meat consumption and lower food waste, open trade and deployment of environmentally friendly technology.
- SSP2 is a pathway with medium population growth (~9 billion in 2100), medium income; technological progress and consumption patterns are a continuation of past trends, and only gradual improvement in inequality occurs. Compared to SSP 1 changes start later and are less effective.
- SSP3 is a pathway with high population (~13 billion in 2100), low income, material-intensive consumption, barriers to trade, and slow rates of technological change.

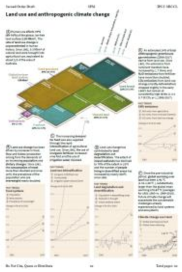
The way in which the risks posed by climate change differ under each pathway is shown in SPM Fig. 2. SPM Fig. 4 provides additional details for quantitative socio-economic indicators corresponding to different SSPs, illustrating the types of outcomes consistent with each SSP and the associated evolution of land-use and land cover.

A7.2. Under current socio-economic conditions, water scarcity in drylands is projected to reach high levels of risk for global warming between 1.5 and 2.5˚C (*medium confidence*). For Shared Socioeconomic Pathways (SSPs – See SPM BOX A7) with low population and less increase in water demand, as in SSP1, there is only a moderate risk related to desertification even at global warming of 3°C. By contrast, in pathways with high population and higher water demand, such as SSP3, the transition from moderate to high risk related to desertification occurs at lower levels of global warming: 1.2°C to 1.5°C. The transition from high to very high risk occurs between 1.5 to 2.8°C (*medium confidence*). {Section 7.3, SPM Fig. 2b, SPM BOX A7}.

A7.3. Risks related to land degradation due to climate change are higher in the SSP3 than in SSP1 as a larger population and increased land use change result in more people exposed to habitat degradation, fire, and coastal flooding (*medium confidence*). The risk transition from moderate to high occurs for global warming between 1.8 and 2.8°C in the SSP1 (*low confidence*) and between 1.4 and 2°C in the SSP3 (*medium confidence*). The transition from high to very high risk occurs between 2.2 and 2.8°C for the SSP3 (*medium confidence*); this latter transition does not occur for the SSP1 in the temperature ranges assessed. A transition to high risk of damage as a result of permafrost thaw is expected to occur by 1.5°C of global warming (*high confidence*). {7.3; SPM Fig. 2b}.

A7.4. Risks related to food security are higher in the SSP3 than in the SSP1, due to increased food prices resulting from land competition, lower income, and more limited trade (*medium confidence*). The risk transition from moderate to high occurs between 2.5 and 3.5°C in the SSP1 (*medium *confidence*) and between 1.3 and 1.7°C in the SSP3 (*medium confidence*). The transition from high to very high risk occurs between 2.2 and 2.7°C for the SSP3 (*medium confidence*); this transition does not occur for the SSP1 in the temperature ranges assessed. {7.3; SPM Fig. 2b}

A7.5. Land-based mitigation and adaptation responses to climate change also affect the risk of desertification, land degradation, and food insecurity by altering land use and land cover, emissions, and regional consequences of biophysical effects (*high confidence*). {2.7, 6.3, 6.4, 6.5}.



[See PDF Figure SPM 1]

**Figure SPM.1 Land use and anthropogenic climate change.**

A representation of the land use and anthropogenic climate change covered in this assessment report. **A:** The central illustration depicts how human use affects 72% (69-76%) of the global, ice-free land area. The surface tiles show the extent of current (in ca. 2015) global land use and management, aggregated into five broad categories and associated uncertainty ranges. "Used land" refers to settlements, managed grassland, forest land and cropland. "Unused land" refers to barren land, unmanaged grassland and forest land. Note that these categories are not intended to be directly relatable to the land cover types used for GHG inventory purposes {1.2, Chapter 1 Table 1.1}[7]. **B:** Agricultural areas have increased to meet the demand arising from population growth, increasing consumption of animal products, growing food waste and overconsumption indicated by the proportion of the global population that is overweight (body mass index > 25 $kg/m^2$) {5.1, 5.2}. **C:** Increasing food production has led to rapid land use intensification, including increases in the use of nitrogen fertiliser and irrigation water that have supported the growth in cereal yields {1.2, Figure 1.1}. The large percentage change in fertiliser use reflects the low level of use in 1961 and relates to both increasing fertiliser input per area as well as the expansion of fertilised cropland and grassland. **D:** Land use change has led to substantial losses in the extent of inland wetlands {4.3.1, 4.7.1}. Dryland areas are under increasing pressures both from the increasing number of people living in these areas and from the increase in droughts {3.2}[8]. **E:** Land use change and intensification has contributed to $CO_2$ emissions, primarily through deforestation, $N_2O$ emissions from agriculture and $CH_4$ emissions from ruminant livestock {2.3}[9]. The various exchanges between the land surface and the atmosphere including the emission and removals of GHG, exchanges related to the land-surface energy balance and aerosols are indicated by arrows {2.4, 2.5}. **F:** Warming over land is more rapid than the global mean temperature change {2.2}[10]. The warming from the late 19th century (1881-1900) to present (1999-2018), was 1.41°C (1.31°C to 1.51°C]) compared to a global mean of 0.86°C {Table 2.1}.

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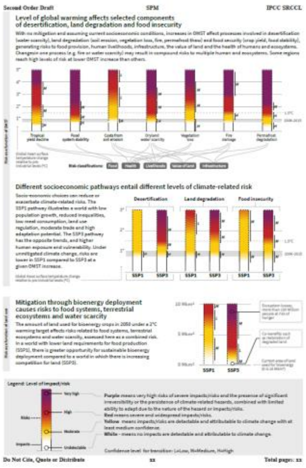
[7] FOOTNOTE: A: Land use and management classification based on the data and approaches described in Chapter 1, Table 1.1. Intensive pasture is defined as having a livestock density greater than 100 animals/$km^2$. Used forest was calculated as total forest area minus unused forest area.

[8] FOOTNOTE: D: Areas undergoing human caused desertification, after accounting for precipitation variability and $CO_2$ fertilisation, are identified in (Le et al. 2016). Population data for these areas are from HYDE3.2 (Goldewijk et al. 2017). The 12-month accumulation Global Precipitation Climatology Centre Drought Index (Ziese et al. 2014) was extracted for drylands. The area in drought was calculated for each month (Drought Index below -1), and the mean over the year was used to calculate the percentage of drylands in drought that year. The inland wetland extent trends (WET) index was developed by aggregating data from 2130 time series that report changes in local wetland area over time. Dryland areas were defined using TerraClimate precipitation and potential evapotranspiration (1980-2015) to identify areas where the Aridity Index is below 0.65.

[9] FOOTNOTE: E: Sources: $N_2O$ from agricultural activities and $CH_4$ from enteric fermentation: Net-land use change emissions of $CO_2$ are from the annual Global Carbon Budget, using the mean of two bookkeeping models (Le Quéré et al. 2018). See Section 2.3 for a discussion of uncertainties and other emissions estimates.

[10] FOOTNOTE: F: The warming curves are averages of four historical estimates (1881-1900) to present (1999-2018). Note that Figure 2.2 depicts the change of land-surface air temperature (LSAT) and global mean surface temperature (GMST) since the preindustrial period 1850–1900 and for the entire 1850-2018 period. The thickness of lines in Figure 2.2 represents the spread between the annual median estimates from the respective datasets and panel F of SPM1 depicts the mean values of those medians.



Second Order Draft SPM IPCC SRCCL

Level of global warming affects selected components of desertification, land degradation and food insecurity

Different socioeconomic pathways entail different levels of climate-related risk

Mitigation through bioenergy deployment causes risks to food systems, terrestrial ecosystems and water scarcity

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2 [See PDF Figure SPM 2]

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**Figure SPM. 2 Risks to land-related human systems and ecosystems from global climate change, socio-economic development and mitigation choices.**

**Panel A**: Risks to selected elements of the land system as a function of global mean surface temperature, and their interconnection to broader human and ecological systems (food supply, human and ecosystem health, livelihoods, value of land, and infrastructure). {2.2; Box 2.1; 3.6; 3.8.1.1; 4.5.1.1; 4.5.1.2; 4.5.1.3; 5.2.2; 5.2.3; 5.2.4; 5.2.5; 7.3;7.4}. The land elements shown and their links to broader systems are illustrative of interconnected systems and risks and not intended to be comprehensive. **Panel B**: Risks associated with desertification, land degradation and food security as a function of climate change and patterns of socio-economic development. Increasing risks associated with desertification include a growing fraction of population exposed and vulnerable to water scarcity and changes in irrigation supply and demand. Risks related to land degradation include increased vegetation loss, population exposed to fire and floods, costs of floods, extent of deforestation, and ecosystem services including the ability of land to sequester carbon. Risks to food security include population at risk of hunger, food price increases, and increases in disability adjusted life years. The risks are assessed for two contrasted socio-economic pathways (SSP1 and SSP3 {SPM Fig. 4}) under unmitigated climate change {3.6; 4.3.1.2; 5.2.2; 5.2.3; 5.2.4; 5.2.5; 6.2.4; 7.3}. **Panel C:** Risks associated with bioenergy crop deployment in 2050 as a land-based mitigation strategy under two socio-economic pathways (SSP1 and SSP3). Risk includes consequences of bioenergy expansion for food security, ecosystem loss and water scarcity. Very high risk indicates that adverse consequences are expected for all three {2.6; 4.6; 5.6.2; 7.3}. The climate scenario considered in Panel C is a mitigation scenario consistent with limiting global warming at 2°C (RCP2.6). For all: As in IPCC SR1.5, AR5 and O'Neill et al. (2017), literature was compiled, and data extracted into a summary table. A formal expert elicitation protocol, based on the modified-Delphi technique and the Sheffield Elicitation Framework, was followed to develop threshold judgments on risk transitions. {7.3, Chapter 7 Supplementary Material}

# B. Adaptation and mitigation response options

**B 1. Numerous options exist to address five land challenges: climate change adaptation, climate change mitigation, combating desertification, reversing land degradation, and enhancing food security. Response options can be grouped into those based on land management, on value chain management, and on risk management. Response options tend to be region- and context-specific and many take time to be effective. Many mitigation and adaptation options are synergistic and can provide co-benefits and reduce costs (*high confidence*). { 2.7, 6.2, 6.4, 6.5, SPM Fig.3}**

B1.1. A number of mitigation and adaptation measures, including avoided deforestation, afforestation/reforestation, soil carbon management and land-based renewable energy, are already being implemented (*high confidence*). Land-based mitigation options cover up to a quarter of the total mitigation proposed by countries in Nationally Determined Contributions submitted under the Paris Agreement (*medium confidence*). {2.7.3, 4.6.3; 6.4.4}

B1.2. Land management practices relating to organic soils, peatlands and wetlands are subject to specific biophysical conditions and some, like fire management and soil carbon management, cut-across land use types. Food value chain and risk management are also context and region specific. Land management responses linked to freshwater resources are location and scale-specific. (*high confidence*){6.3, 6.4, 6.5.4}

B1.3. Most adaptation and mitigation options, such as agroforestry, soil management, increased productivity and reducing food loss, generate synergies across all land challenges. Others, such as fire management, may have adverse side-effects. Achieving land degradation neutrality depends on the integration of multiple responses across local, regional and national scales, multiple sectors including agriculture, water and energy, and types of use including food, feed, shelter and industry. Supply side responses, such as productivity gains and crop diversification, along with demand side measures such as nutritionally balanced diets and reduced food waste and loss, and trade, can support sustainable food systems (*high confidence*). {5.7, 6.3, 6.4, 6.5, SPM Fig. 3}

B1.4. Many response options take time to deliver impacts. These include those which address biological-dependent processes such as afforestation and reforestation, systemic changes affecting food and land systems, and social transitions such as dietary change. Some actions can avoid the loss of high-carbon ecosystems, such as peatlands, wetlands, mangroves and forests, which provide multiple services that are difficult to replace. Scaling up responses quickly and expanding their scope to include, for example, soil carbon management and land degradation neutrality, would allow current and future ambition to be met. (*high confidence*). {6.5.5; Cross-Chapter Box 10: ‘Economic Dimensions’ in Chapter 7}

**B 2. Many activities and measures for combating desertification can contribute to climate change adaptation and mitigation, with further sustainable development co-benefits (*high confidence*). Integrating strategies to combat desertification with those that address climate change adaptation can increase resilience to environmental change in dry regions, but the potential for residual risks and maladaptive outcomes is high (*high confidence*). {3.7.1, 3.7.2, 3.7.3, 3.7.4, 3.8.1, 3.8.2}**

B2.1. Site-specific technological solutions that help adapt to climate change at the same time as combating desertification include: adaptive restoration to improve techniques for optimising rain use efficiency in plantations; adjusting land use by using natural vegetation and exploring native plant species’ drought resilience; agroforestry; ecosystem-based adaptation; incorporating conservation tillage; and using modern information and communication technologies for monitoring and early warning systems (*high confidence*). {3.7.1, 3.8.2; 3.8.5}

B2.2. Measures combating desertification by limiting dust and sand storms and sand dune movement can reduce the negative socioeconomic effects of wind erosion, improving capacity to combat desertification (*high confidence*). Afforestation programs for the creation of windbreaks can reduce sand storms, avert desertification, and increase carbon sinks (*high confidence*). {3.4, 3.7.1, 3.8.2}

B2.3. Measures that sequester soil carbon also contribute to climate change mitigation and biodiversity conservation (*high confidence*). For example, expected rates of carbon sequestration following changes to conservation agriculture practices in drylands range between 0.04-0.4 tC $ha^{-1}$ (*medium confidence*). Natural vegetation restoration and tree plantation in degraded land enables organic carbon in the topsoil and subsoil to accumulate (*medium confidence*). Avoiding, reducing and reversing desertification would enhance soil fertility, increase carbon storage in soils and biomass, thus reducing carbon emissions from soils to the atmosphere, and would enhance productivity and food security (*high confidence*). {3.2.4, 3.4, 3.7.1, 3.7.2, 3.7.3, 3.8.1, 3.8.2}

B2.4. Sustainable land management solutions, such as controlled grazing and the management of forest land and cropland, contribute to addressing desertification as well as mitigating and adapting to climate change. These have co-benefits for poverty reduction and food security among dryland populations (*medium confidence*), as well as sustainable development co-benefits (*high confidence*). Adoption of land degradation neutrality measures in dryland areas can contribute to climate change adaptation with mitigation co-benefits (*high confidence*). {3.5.2, 3.7.1, 3.7.2, 3.7.3}

B2.5. Limits to adaptation and avoiding maladaptive outcomes in vulnerable communities are considerations in adaptation and climate risk management. Empirical evidence on the limits to adaptation in dryland areas is limited. Potential limits to adaptation include losses of land productivity due to irreversible forms of desertification. Residual risks can emerge from the inability of sustainable land management measures to fully compensate for yield losses due to climate change impacts, as well as foregone reductions in ecosystem services due to soil fertility loss even when applying sustainable land management measures could revert land to initial productivity after some time. Some activities favouring agricultural intensification in dryland areas can become maladaptive due to their negative impacts on the environment. (*medium confidence*). {3.7.4}

B2.6. Developing renewable energy resources, such as bioenergy, hydro-energy, solar and wind energy, can contribute to mitigating climate change and combating desertification through decreasing use of fuelwood and crop residues for energy while increasing the diversity of energy supply (*medium confidence*). {3.7.3, 3.7.4}

**B 3. Reducing and reversing land degradation provides cost effective and immediate benefits to communities by enhancing ecosystem services. Sustainable land and forest management encompasses practices, technologies, and enabling socio-economic conditions that can address land degradation at any scale from individual farms (*very high confidence*) to entire watersheds (*medium confidence*). Implementing sustainable land management supports adaptation to climate change (*very high confidence*) and mitigation of climate change (*high confidence*). {4.2.5, 4.9, Table 4.2}**

B3.1. For sustainable land management to be successful, it must be implemented in a way that is appropriate for local biophysical and social conditions. Compatibility between specific land management practices and socio-economic conditions, including land tenure and gender, is essential (*very high confidence*) {4.10.4, 4.2.6, 4.8,1, 4.9.1, 4.9.2, 4.9.7}.

B3.2. Proven agronomic measures, such as cover crops, intercropping, and reduced tillage, can prevent and reduce soil erosion and nutrient leakage (*very high confidence*), as well as increasing soil carbon stocks (*very high confidence*). Adding biochar to soil sequesters carbon (*very high confidence*) and can improve soil conditions in some locations (*medium confidence*). Changing from annual crops to deep rooted perennial cropping systems has the potential to substantially reducing erosion and nutrient leakage while building soil carbon (*high confidence*). {4.9.1.1, 4.9.1.3, 4.10.2, 4.10.5}

B3.3. Avoiding deforestation and forest degradation can help to meet short term goals, while sustainable forest management and agroforestry aimed at providing timber, fibre, biomass, non-timber resources and other ecosystem services can provide long-term livelihoods for communities (*high confidence*). {4.2.5, 4.4.2, 4.6.3, 4.9.1.3, 4.9.3, 4.9.4}

B3.4. Sustainable forest management, including agroforestry, can maintain land productivity, thus preventing land degradation, and reducing the propensity for conversion to non-forest uses (e.g. cropland or settlements) (*high confidence*). {4.2.5, 4.6.4, 4.9.1, 4.9.3, 4.9.4}.

B3.5. Residual degradation such as coastal erosion and degradation of permafrost regions will occur in some situation even with measures to address land degradation) (*high confidence*) which may pose limits to adaptation {4.9.5.1, 4.10.6, 4.10.7, 4.10.8}.

B3.6. Achieving land degradation neutrality will require a balance of measures that avoid and reduce land degradation, through adoption of sustainable land management, and measures to reverse degradation through rehabilitation and restoration of degraded land. Many interventions to achieve land degradation neutrality commonly also deliver climate change mitigation benefits. The pursuit of land degradation neutrality provides impetus to address land degradation and climate change simultaneously (*high confidence*). {4.6.3, 4.9.5, 4.9.7}.

**B 4. The global food system contributes to approximately 25-30% of total GHG emissions, attributable to agriculture practices, land use and land use change, storage, transport, packaging, processing, retail, and consumption (*medium confidence*). Within the food system, the major sources of emissions from the supply side are agricultural production (5.0-5.5 GtCO2eq.yr$^{-1}$) and associated land use change (4.5-5.0 GtCO2eq.yr$^{-1}$) (*high confidence*). Supply chain activities and food loss and waste contribute to 5-10% of total food system GHG emissions (*medium confidence*). Integrated supply- and demand-side options can be scaled up in all segments of the food system to advance adaptation and mitigation climate responses (*high confidence*). {5.3, 5.4, 5.6}**

B4.1. Supply-side practices that contribute to climate change adaptation and mitigation in cropland include increased soil organic matter and erosion control, reductions in $N_2O$ emissions from fertilisers, reductions in $CH_4$ emissions from paddy rice, improved cropland management, and genetic improvements for heat and drought tolerance; in livestock, options include better grazing land management, improved manure management, and higher-quality feed. Reductions in GHG emissions intensity from livestock can support absolute reductions in emissions, provided there is appropriate governance for total production (*medium confidence*). Diversification in the food system is a key strategy to reduce risks from climate change (*medium confidence*). Total potential of mitigation from crop and livestock activities is estimated as 1.5–4.0 GtCO2eq.yr$^{-1}$ by 2030 at prices ranging from 20-100 USD/tCO2eq (*high confidence*). Significant synergies exist between adaptation and mitigation, for example through sustainable land management approaches (*high confidence*). {5.3.3, 5.5.1, 5.6}

B4.2. Diversification of diets can simultaneously reduce GHG emissions and increase resilience to climate change. Consumption of healthy and sustainable diets, such as those based on coarse grains, pulses, fruits and vegetables, nuts and seeds, and animal-sourced produces produced in low-energy intensive systems, presents major opportunities for reducing GHG emissions from food systems and improving health outcomes (*high confidence*). The total economic mitigation potential of dietary changes is estimated as 1.8-3.4 GtCO2eq.yr$^{-1}$ by 2050 at prices ranging from 20-100 USD/tCO2eq (*medium confidence*). {5.3, 5.5.2, 5.6}

B4.3. Reduction of food loss and waste can lower GHG emissions and contribute to adaptation through reduction in additional land area needed for food production and associated food system vulnerabilities (*medium confidence*). Combined food loss and waste amount to a third of global food production (*high confidence*), contributing to 8–10% of total food system emissions (*medium confidence*). Technical options for reduction of food loss and waste include improved harvesting techniques, on-farm storage, infrastructure, and packaging. Causes of food loss, for example due to lack of refrigeration, and waste differ substantially in developed and developing countries, as well as across regions (*medium confidence*). {5.5.2}

**B 5. Some response options, when applied at scales necessary to remove $CO_2$ from the atmosphere at the scale of several Gt $CO_2$ yr$^{-1}$, lead to land use change and increase pressure on land (*high confidence*). This increased pressure can lead to adverse side-effects for adaptation, land degradation and food security (*high confidence*). {6.3, 6.5; Cross-Chapter Box 7: ‘Bioenergy and BECCS’ in Chapter 6; SPM Fig. 3}**

B5.1. When applied at large scale, afforestation, reforestation, the use of land to provide feedstock for bioenergy with or without carbon capture and storage, and biochar could greatly increase pressure on land. Reduced grassland conversion to croplands, restoration and reduced conversion of peatlands, and restoration and reduced conversion of coastal wetlands affect smaller land areas, so the impacts of these options would be smaller or more variable (*high confidence*). {Cross-Chapter Box 7: ‘Bioenergy and BECCS’ in Chapter 6, 6.5; SPM Fig. 3}

B5.2. There are limits to the deployment of land-based mitigation measures such as bioenergy crops. Widespread use at the scale of several millions of km$^2$ globally could compromise sustainable development with increased risks, and potentially irreversible consequences, for food security, desertification and land degradation. Applied over smaller areas, land-based mitigation measures that displace other land uses have fewer adverse side-effects and can even have some positive co-benefits for some land challenges (*high confidence*). The amount of area for bioenergy, with low to moderate risks to food security, land degradation and desertification, depends on patterns of socioeconomic developments, reaching limits between 2 and 6 million km$^2$. {4.3, 6.5; Cross-Chapter Box 7: ‘Bioenergy and BECCS’ in Chapter 6; SPM Fig. 2c}

B5.3. Increasing the extent and intensity of biomass production, for example through fertiliser additions, irrigation or monoculture energy plantations can result in local land degradation. Poorly implemented intensification of land management contributes to land degradation, for example through salinisation from irrigation, and disrupted livelihoods (*high confidence*). The global extent of degraded lands suitable for dedicated biomass production is not known (*high confidence*) and cannot be established without due consideration of current land tenure arrangements. Increasing the spatial extent of dedicated biomass production can lead to land degradation elsewhere through indirect land-use change (*medium confidence*). {4.2.6, 4.5.2, 4.6, 4.8.1, 4.9.1, 4.9.4}

B5.4. Large-scale afforestation measures in arid areas with tree species which are not suited to local soil and climatic conditions can reduce water availability for other uses, exacerbating water scarcity (*medium confidence*). In areas where afforestation and reforestation occur on previously degraded lands, opportunities exist to restore and rehabilitate lands with potential significant co-benefits (*high confidence*). {3.8.2, 4.10.3}

B5.5. Food security may be threatened if land-based mitigation displaces crops and livestock to regions with lower productivity potential, higher climatic risk and higher vulnerability. Effects are mediated mainly by increase in food prices and reducing land available for food production. The highest increases in the population at risk of hunger are likely to occur in Sub-Saharan Africa and South Asia (*medium confidence*). {5.6.1}

**B 6. Most response options can be applied without competing for available land and have the potential to provide multiple co-benefits across the whole range of land challenges (*high confidence*). A further set of options have the potential to reduce pressure on land, thereby enhancing the potential for other response options to deliver across the range of land challenges (*high confidence*). Many response options contribute positively to sustainable development and other societal goals (*high confidence*). {6.3; 6.4.6; 6.5.3; SPM Fig. 3}**

B6.1. A number of land management options such as improved cropland management, improved forest management, and increased soil organic carbon content, do not require land use change and so do not increase pressure on land. Further, a number of response options such as increased food productivity, and value chain responses including dietary change and food waste reduction, can reduce pressure on the land, thereby potentially freeing land and creating opportunities for enhanced implementation of other response options (*high confidence*). Response options that reduce competition for land can contribute to portfolios of response options applied at different scales by different stakeholders from farm to international scales (*high confidence*). {6.4.6, 6.5, SPM Fig. 3}

B6.2. A wide range of adaptation and mitigation responses have the potential to make positive contributions to sustainable development and other societal goals (*high confidence*). Preserving natural resources such as peatland, coastal and forest restoration, options that reduce competition for land, those applied across all ecosystems, such as fire management and soil management options, and most risk management options, provide almost exclusively positive impacts on sustainable development (*medium confidence*). {6.5.3}

B6.3. Most of the land management-based response options that do not increase competition for land, and almost all options based on value change management and risk management, can contribute to eradicating poverty and eliminating hunger, while promoting good health and wellbeing, clean water and sanitation, climate action, and life on land (*medium confidence*). Eradicating poverty and eliminating hunger can be adversely affected by land management-based options that require land use change (*medium confidence*). {6.5.3}

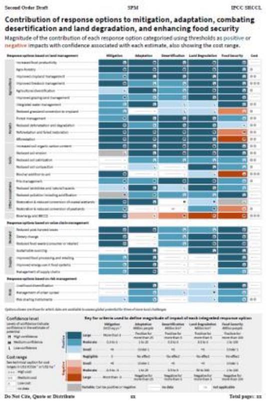
**B 7. Delivering climate mitigation and adaptation while at the same time addressing desertification, land degradation, and enhancing food security necessitates the selection and deployment of location specific response options (*high confidence*). Depending on the desired climate outcome, the portfolio of options chosen, and the policies developed to support their implementation, different land-use pathways can arise with large differences in the projected 2100 agricultural and forest area (*high confidence*). Projections range from minus 5.2 million km$^2$ to plus 3.4 million km$^2$ in the case of agricultural area, and minus 3.1 million km$^2$ to plus 7.5 million km$^2$) for the forest area (*medium confidence*). {2.7, 5.5, 5.6, 6.2, 6.5, 7.5, Cross-Chapter Box 9: 'Illustrative Climate and Land Pathways' in Chapter 6, SPM Fig. 4}**

B7.1. All assessed pathways that limit warming to 1.5ºC require extensive land-based mitigation, with most including reforestation/afforestation, large-scale bioenergy, and in the majority of cases bioenergy with carbon capture and storage (BECCS) (*high confidence*). {Section 2.7, 6.5, 7.5, 7.7, Cross-Chapter Box 9: 'Illustrative Climate and Land Pathways' in Chapter 6, SPM Fig. 4}

B7.2. Pathways in which warming exceeds 1.5ºC require less land-based mitigation (*high confidence*), but the impacts of higher temperatures on regional climate and land, including land degradation, desertification, and food insecurity, become more severe, especially in pathway SSP3 (*medium confidence*). { 2.7, 6.5, 7.5, Cross-Chapter Box 8: 'Ecosystem Services' in Chapter 6, SPM Fig. 2, SPM Fig. 4}

B7.3. Pathways that include large increases in area for bioenergy crops may result in increased competition for land and can have adverse side-effects for water scarcity, biodiversity, land degradation, desertification, and food insecurity. The amount of land needed for bioenergy and BECCS ranges from nearly 0.8 to 6.6 million km$^2$, depending on the socioeconomic pathway and the warming level. The effects of bioenergy production on land degradation, water scarcity, biodiversity loss, and food insecurity are scale and context specific (*high confidence*). Large areas of monoculture bioenergy crops that displace other land uses can exacerbate these challenges, while integration into sustainably managed agricultural landscapes can alleviate them (*medium confidence*). {6.2, 6.5, Cross-Chapter Box 7: 'Bioenergy and BECCS' in Chapter 6}

B7.4. A small number of modelled pathways achieve 1.5ºC with limited carbon dioxide removal (CDR) or without BECCS. These pathways rely on behavioural and lifestyle changes, including less resource intensive diets and reduction of food waste, agricultural intensification, and rapid reduction of GHG emissions in other sectors (*high confidence*). {2.7.2, 5.5.1, 6.5}



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Contribution of response options to mitigation, adaptation, combating desertification and land degradation, and enhancing food security

Magnitude of the contribution of each response option categorised using thresholds as positive or negative impacts with confidence associated with each estimate, also showing the cost range.

**[See figure SPM 3]**

**Figure SPM.3 Contribution of response options to mitigation, adaptation, combating desertification and land degradation, and enhancing food security.**

**Magnitude of potential:**
Magnitudes are for the technical potential of response options globally. For each land challenge, magnitudes are set relative to a marker level. For mitigation, potentials are set relative to the approximate potentials for the mitigation options with the largest individual impacts (~3 $GtCO_2$-eq $yr^{-1}$) (Pacala and Socolow 2004). The threshold for the "large" category is set at this level. For adaptation, magnitudes are set relative to the 100 million lives predicted to be lost due to climate change between 2010 and 2030 (DARA 2012). The threshold for the "large" category represents 25% of this total. For desertification and land degradation, magnitudes are set relative to the lower end of current estimates of degraded land, 10-60 million $km^2$ (Gibbs and Salmon 2015). The threshold for the "large" category represents 30% of the lower estimate. For food security, magnitudes are set relative to the approximately 800 million people who are currently undernourished (HLPE 2017). The threshold for the "large" category" represents 12.5% of this total. Magnitudes are based on the assumption that large land areas are required for afforestation and reforestation, and for feedstock production for large-scale bioenergy and BECCS and for biochar. Increased food production is assumed to be achieved through sustainable intensification rather than through application of additional external inputs such as mineral fertilizers and other agrochemicals.

**Levels of confidence:** Levels of confidence indicate confidence in the estimate of potential being in the high, medium or low categories for each land challenge (mitigation, adaptation, combating desertification and land degradation, and enhancing food security) shown in the magnitude of contribution key. *High confidence* means that there is a high level of agreement and evidence in the literature to support the categorisation as high, medium or low magnitude. *Low confidence* denotes that the categorisation of magnitude is based on few studies. *Medium confidence* reflects medium evidence and agreement in the magnitude of response. **Cost ranges:** One coin indicates low cost (<\$10 $tCO_2$-$eq^{-1}$ or <\$20 $ha^{-1}$), two coins indicate medium cost (\$10-\$100 $tCO_2$-$eq^{-1}$ or \$20-\$100 $ha^{-1}$), and three coins indicate high cost (>\$100 $tCO_2$-$eq^{-1}$ or \$200 $ha^{-1}$). The cost thresholds in \$t/$CO_2$-eq are from Griscom et al. (2017); thresholds in \$ $ha^{-1}$ are chosen to be comparable, but precise conversions will depend on the response option. **Supporting evidence:** Supporting evidence for the magnitude of the potential and the evidence base for land management-based response options can be found as follows: for mitigation tables 6.13 to 6.20, with further evidence in Section 2.7.1; for adaptation tables 6.21 to 6.28; for combating desertification tables 6.29 to 6.36, with further evidence in chapter 3; for combating degradation tables 6.37 to 6.44, with further evidence in chapter 4; for enhancing food security tables 6.29 to 6.36, with further evidence in chapter 5. Other synergies and trade-offs not shown here are discussed in chapter 6.

# C. Enabling Response Options

**C 1. The design of policies, institutions, and governance systems can enable opportunities available in the land sector for adaptation and mitigation while providing the basis for sustainable and climate-resilient low-carbon development. Coherent climate and land policy portfolios have the potential to save resources and also amplify social resilience, ecological restoration, and local stakeholder engagement and collaboration between multiple stakeholders (*high confidence*). (SPM Fig. 1, SPM Fig. 2, SPM Fig. 3) {3.7.2, 3.7.3, 4.10.4, 5.7, 6.4, 6.5, 7.3.2, 7.4, 7.5.7, 7.5.8, 7.5, 7.6, 7.6.5, 7.6.6, 7.7.6, Cross-Chapter Box 10: 'Economic Dimensions' in Chapter 7}**

C1.1. The combination of pressures coming from climate variability, anthropogenic climate change and land changes pose sustained risks to those living in poverty, and contributes to food insecurity and increased disease burden (*high confidence*). Regulations can protect people and land, as well as create revenue and investment to rehabilitate degraded lands and invest in net-zero-carbon energy sources. Institutions and policies which ensure dignified livelihoods and shore people up against instability and poverty can manage the trade-offs in a just transition. Policies promoting the target of land degradation neutrality can also support food security, human wellbeing and mitigation. (*high confidence*). {3.5.2, 4.2.6, 4.8, 5.1.2, 5.7.3, 7.4, 7.5.6, 7.5.7, 7.6, SPM.Fig.2}

C1.2. Land tenure systems operate within specific socio-economic and legal contexts. They have implications for both adaptation and mitigation, and may themselves be impacted by climate change and climate action (*medium confidence*). Land policies affect land tenure security and thus the range of options and incentives available for mitigation and adaptation, especially for the poor. {3.7.1, 3.7.2, 7.7.4, Cross-Chapter Box 6: 'Agricultural Intensification' in Chapter 5}

C1.3. Policy packages, rather than single policy approaches, can deliver superior results in addressing the complex challenges of sustainable land management and climate change (*high confidence*). Purposefully designed policy can provide stability that helps reduce disruptions to people's food and livelihood security (*high confidence*). Policies promoting sustainable land management provide significant co-benefits for food and livelihood security, conserve biodiversity and ecosystem services, contribute to addressing desertification, land degradation, mitigation and adaptation (*medium confidence*). {4.10, 4.10.2, 5.6, 7.4.2, 7.5.2, 7.5.6, 7.5.7, 7.5.8, 7.7.4}

C1.4. Policies such as financial inclusion, flexible carbon credits, disaster risk and health insurance, social protection and adaptive safety nets, contingent finance and reserve funds, and universal access to early warning systems can enable the rapid adoption of sustainable development principles and can strongly reduce vulnerability and exposure of human and natural systems to climate change, and ameliorate risks of desertification, land degradation and food insecurity (*high confidence*). Adaptive climate governance, adaptive management and decision support tools assist with decision making in the face of uncertainty, by incorporating principles of flexibility, iteration, and consultation (*medium confidence*). {1.3, 5.6.6, 7.6.2, 7.6.5, 7.73}

**C 2. More sustainable land use, enhanced food security and low-emissions trajectories are enabled by incentivising efficient food production, consumption of healthy and sustainable diets, and reduction of food loss and waste (*high confidence*). Enabling policies, such as improving access to markets and securing land tenure, have the potential to increase adoption of sustainable land management and to reduce poverty. Policies facilitating healthy and sustainable diets can contribute to both climate change mitigation and adaptation (*high confidence*), as well as improve public health. {1.2.2, 1.3.1, 3.7.3, 4.8.1, 4.8.2, 4.9, 5.5.2, 6.5}**

C2.1. Enabling policies to incentivise sustainable land management include improved access to markets, empowering women farmers, expanding access to agricultural and climate services, strengthening land tenure security and access to land, and facilitating payments for ecosystem services (*high confidence*). Supporting local management of natural resources, while strengthening cooperation between actors and institutions at different levels of governance increase the chances of success of land restoration and rehabilitation. {3.7.3, 4.2.6, 4.6.4, 4.9.2, 4.9.4, 7.3}.

C2.2. Reflecting the environmental costs to climate and land of land-degrading land practices in markets can enable more sustainable land management through reducing incentives for unsustainable practices *(high confidence)*. Examples of relevant policies are emissions pricing and supporting markets for sustainable food. Reflecting the environmental costs in market prices may also reduce food waste and its associated GHG and land footprint. {3.7.3, 5.5.1, 5.5.2, 5.7, 7.5.4}

C2.3. Adaptation and enhanced resilience to extreme events in food systems can be facilitated by risk sharing and transfer mechanisms such as insurance markets and well-designed index-based weather insurance *(high confidence)*. Scaling up adaptation throughout the food system entails breeding programs for heat and drought tolerance and pest resistance, encouragement of crop diversification, expansion of market access, and advance preparation for supply chain disruption. {5.3.2, 5.3.3, 5.3.5}

C2.4. A range of policies can create enabling conditions for supply-side mitigation in crops and livestock (*medium confidence*). To encourage supply-side mitigation in crop production, investments in agricultural research and development are needed to close yield gaps. In livestock production, enabling conditions include incentives to increase productivity, animal health and welfare standards, and awareness that increases in total production can lead to rebound effects. {5.5.1}

C2.5. Encouraging the adoption of healthy and sustainable diets can contribute to climate change mitigation and adaptation. Public health policies to improve nutrition, such as diversity of food sources in school procurement, health insurance incentives, and awareness-raising campaigns, can potentially modify demand, reduce health-care costs, improve resilience, and contribute to lower GHG emissions *(limited evidence, high agreement)*. This approach can enable more sustainable land management and contribute to achieving multiple sustainable development goals *(high confidence)*. {3.5.2, 4, 5.1, 5.7, 6.4, 6.5}

**C 3. Adopting governance approaches that acknowledge and balance benefits and trade-offs, work to overcome barriers to implementation, and integrate the consideration of synergies, can provide co-benefits for climate change mitigation and adaptation (*medium confidence*). This applies to many response options that combat land degradation and desertification, deliver greater food security, and increase the resilience to the impacts of climate change (*high confidence*). {4.10, 5.6, 6.5, 7.4, 7.5.9, 7.7.2, SPM Fig. 3}**

C3.1. Addressing desertification, land degradation, and food security in a coordinated manner through sustainable land management, pursuing land degradation neutrality, and related response options and policies provides many potential co-benefits, including lower GHG emissions, poverty reduction, increased biodiversity conservation, and less water and air pollution. Portfolios of measures and policy mixes, such as integrated agricultural systems that provide both adaptation and mitigation benefits while increasing food security or reducing land degradation, can be applied across scales, from farm-level measures to international agreements (*high confidence*). A combination of dietary change and other demand-side measures and with waste reduction and other supply-side measures could expand the potential to apply other options by freeing as much as 5.8 million km$^2$ of land (*low confidence*). {4.10, 5.6, 6.5, 7.5.6, 7.5.8, 7.7.2}

C3.2. Technological, biophysical, and cultural factors can limit the near-term adoption of many response options. Many sustainable land management practices are not widely adopted due to insecure property rights, lack of access to credit and agricultural advisory services, insufficient private incentives, and lack of knowledge (*high confidence*). The land and food sectors face particular challenges of institutional fragmentation, and often suffer from a lack of engagement between stakeholders at different scales (*medium confidence*). {3.7.1, 3.7.2, 5.5.2, 5.6, 6.3, 6.5, 7.5, 7.6, 7.7}

C3.3. Public discourse, policy interventions, and market changes can reduce barriers to implementation (*medium confidence*). Linking sustainable land management and demand-side approaches with other non-land sectors, such as public health, transportation, energy, and infrastructure, increases effectiveness. Best practices learned from integration of policies across sectors include using coordinated policy mixes, simultaneously working across multiple scales, adaptive and anticipatory planning that incorporates risk management, and participatory approaches. (*high confidence*). {2.5.1, 5.6.3, 5.7, 6.3, 7.2, 7.4, 7.5}

C3.4. Some response options and policies may result in trade-offs, including social impacts, ecosystem services damage, or high costs, that cannot be well-managed, even with institutional best practices. Knowledge gaps create higher risk for certain land options. Explicit acknowledgement of potential trade-offs and knowledge gaps is necessary in evidence-based policymaking to weigh the costs and benefits of specific responses for different stakeholders. (*medium confidence*). {6.5.2, 6.5.5}

**C 4. Involvement of people, particularly the most vulnerable in decision-making and the selection, evaluation, implementation, and monitoring of policy instruments surrounding land-based response options, trade-offs and synergies, improves decision-making and governance (*high confidence*). Integration across sectors and scales increases the chance of maximising co-benefits and minimising trade-offs (*medium confidence*). {1.3.1, 1.4.1, 1.4.2; 4.10.2, 7.5.8, 7.7.4}**

C4.1. Sustainable land management is advanced by involving local people in identifying land use pressures, including species decline, habitat loss, land use change in agriculture, food production and forestry, as well as decisions preventing, reducing and restoring degraded land (*medium* *confidence*). People-centred integrated landscape planning coordinates across sectors and regional and national frameworks. Involving people in decisions and governance surrounding agriculture, forestry, and pastoral activities, wildlife and forest conservation, and encroachment of settlements and agricultural areas, can reduce conflict (*medium confidence*). {7.7.2}

C4.2. Inclusiveness in the monitoring, reporting and verification of the performance of policy instruments enables sustainable land management (*medium confidence*). Engaging people in citizen science mediates and facilitates landscape conservation planning, policy choice, and early warning systems (*medium confidence*). Involving people in the selection of indicators, collection of climate data, land modelling and land use planning, facilitates social learning and improves sustainable land management by reassessing and responding to new information and data as it becomes available. When social learning is combined with collective action, transformative change can occur addressing tenure issues and changing land use practices (*medium confidence*). {3.8.5, 7.5.1, 7.5.4, 7.6.3, 7.6.4, 7.6.5, 7.7.4, 7.7.6}

C4.3. Land titling and recognition programs, particularly those that authorize and respect indigenous and communal tenure, can lead to improved management of forests, including for carbon storage, primarily by providing legally secure mechanisms for the exclusion of others (*medium confidence*). Policies that secure land access for women increase sustainable land management through incentivising and facilitating agricultural investments (*high confidence*). {7.4, Cross-Chapter Box 11: ‘Gender’ in Chapter 7}

C4.4. The consideration of indigenous practices in choosing response options and policies for land challenges, contributes to enhancing resilience against climate change and combatting desertification (*medium confidence*). Agroecological traditional, local practices such as forest, water, soil, and fertility management, local seed use, improved grazing, and ecological restoration are often based on locally appropriate, non-quantifiable, indigenous knowledge. Innovative combinations of indigenous, local and scientific knowledge can contribute to overcoming combined challenges of climate change and desertification (*medium confidence*). {3.7.1, 3.7.2, 5.6, 5.7.1, 6.3, 7.4, 7.7.4}

C4.5. Empowering women can bring synergies and co-benefits among household food security and sustainable land management (*high confidence*). The overwhelming presence of women in many land-based activities including agriculture provides opportunities to increase sustainable land management and food security through policy instruments that account for gender differences (*medium confidence*). Gender-disaggregated data provides a basis for selecting, monitoring and reassessing policy instruments that account for gender differentiated land and climate change needs (*medium confidence*). {5.1.3, Box 5.1, Cross-Chapter Box 11: ‘Gender’ in Chapter 7}

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## Illustrative pathways linking policy, land use and climate change

Socioeconomic development influences the evolution of the land system including the relative amount of land allocated to agriculture, energy crops, and forest. This has implications for climate change mitigation, adaptation and other sectoral characteristics. The lines shows the range across models for three alternative shared socioeconomic pathways: SSP1 (green), SSP2 (blue), and SSP3 (magenta), under two different warming targets in 1.5°C and 2.5 to 3°C scenarios. Note that 1.5 °C is not possible from SSP3 and thus is excluded.

**AGRICULTURE** and Socio-Economic Development
SSP1 has the lowest agricultural land expansion. This socio-economic pathway is characterised by sustainable land management, the achievement of Land Degradation Neutrality targets, sustainable intensification, enhancement of ecosystem services, changing dietary patterns, and the reduction of food waste. Sustainable land management and demand side changes are not included in SSP3. SSP2 is similar to SSP1, but changes start later and are less effective.

**BIOENERGY** and Socio-Economic Development
All pathways use bioenergy, with more use in the SSP2 and SSP3 than in the SSP1. All three pathways include carbon prices that incentivise bioenergy use. The presence of other response options, including sustainable land management, however, results in less bioenergy in the SSP1 than the SSP3. In the SSP2, more bioenergy is needed sooner than in the SSP1 to compensate for other emissions.

**FOREST** and Socio-Economic Development
SSP1 has the greatest forest expansion. This socio-economic pathway is characterised by land use regulation, forest protection, and biodiversity preservation, including incentives for reforestation and afforestation. Forest expansion is primarily on abandoned agricultural land, resulting in less competition for land than in SSP2. SSP2 is similar to SSP1, but changes start later and have less impact. Land use regulation and biodiversity conservation are absent in SSP3.

| Quantitative indicators for the Shared Socio Economic Pathways (SSPs) | | 1.5 °C | | 2.5 to 3 °C | | |
|---|---|---|---|---|---|---|
| | | SSP1 | SSP2 | SSP1 | SSP2 | SSP3 |
| *Change in Non-Energy Cropland from 2010 (Mkm²)* | 2050 | -1.2 (-0.3, -4.6) | -1.2 (0.3, -2.0) | 0.1 (1.5, -3.2) | 1.2 (2.7, -0.9) | 2.3 (3.0, 1.2) |
| | 2100 | -5.2 (-1.8, -7.6) | -2.9 (0.1, -4.0) | -2.3 (-1.6, -6.4) | 0.7 (3.1, -2.6) | 3.4 (4.5, 1.9) |
| *Change in Pasture from 2010 (Mkm²)* | 2050 | -4.1 (-2.5, -5.6) | -4.8 (-0.4, -6.2) | -2.4 (-0.9, -3.3) | -0.1 (1.6, -2.5) | 2.1 (3.8, -0.1) |
| | 2100 | -6.5 (-4.8, -12.2) | -7.6 (-1.3, -11.7) | -4.6 (-2.7, -7.3) | -2.8 (1.9, -5.3) | 2.0 (4.4, -2.5) |
| *Change in Energy Cropland from 2010 (Mkm²)* | 2050 | 2.1 (5.0, 0.9) | 4.5 (7.0, 2.1) | 0.8 (1.3, 0.5) | 1.5 (2.1, 0.1) | 1.3 (2.0, 1.3) |
| | 2100 | 4.3 (7.2, 1.5) | 6.6 (11.0, 3.6) | 1.9 (3.7, 1.4) | 4.1 (6.3, 0.4) | 4.6 (7.1, 1.5) |
| *Change in Forest from 2010 (Mkm²)* | 2050 | 3.4 (9.4, -0.1) | 3.4 (7.0, -0.9) | 0.6 (4.2, -0.7) | -0.9 (2.9, -2.5) | -2.4 (-1.0, -4.0) |
| | 2100 | 7.5 (15.8, 0.4) | 6.4 (9.5, -0.8) | 3.9 (8.8, 0.2) | -0.5 (5.9, -3.1) | -3.1 (-0.3, -5.5) |
| *Change in Other Natural Land from 2010 (Mkm²)* | 2050 | 0.5 (1.0, -4.9) | -2.2 (0.6, -7.0) | 0.5 (1.7, -1.0) | -2.2 (0.7, -2.2) | -3.4 (-2.0, -4.4) |
| | 2100 | 0.0 (7.1, -7.3) | -2.3 (2.7, -9.6) | 1.8 (6.0, -1.7) | -3.4 (1.5, -4.7) | -6.2 (-5.4, -6.8) |
| *Carbon Price (US\$2010/t $CO_2$)* | 2050 | 510 (4304, 151) | 756 (1080, 260) | 9 (35, 1) | 38 (73, 14) | 67 (75, 61) |
| | 2100 | 2164 (35038, 263) | 4354 (10150, 2998) | 65 (287, 43) | 172 (598, 112) | 590 (727, 320) |
| *Agriculture Price (Index 2010=1)* | 2050 | 1.2 (1.8, 0.8) | 1.6 (2.0, 1.4) | 0.9 (1.1, 0.7) | 1.1 (1.2, 1.0) | 1.2 (1.7, 1.1) |
| | 2100 | 1.9 (7.0, 0.4) | 6.5 (13.1, 1.8) | 0.8 (1.2, 0.4) | 1.1 (2.5, 0.9) | 1.7 (3.4, 1.3) |
| *Emissions\|$CH_4$\|AFOLU (% rel to 2010)* | 2050 | -39.0 (-3.8, -68.9) | -11.7 (31.4, -59.4) | -2.9 (22.4, -23.9) | 7.5 (43.0, -15.5) | 15.0 (20.1, 3.1) |
| | 2100 | -60.5 (-41.7, -77.4) | -40.3 (33.1, -58.4) | -47.6 (-24.4, -54.1) | -13.0 (63.7, -45.0) | 8.0 (37.6, -9.1) |
| *Emissions\|$N_2O$\|AFOLU (% rel to 2010)* | 2050 | -13.1 (-4.1, -26.3) | 8.8 (38.4, -14.5) | 0.1 (34.6, -14.5) | 25.4 (37.4, 5.5) | 34.0 (50.8, 29.3) |
| | 2100 | -42.0 (4.3, -49.4) | -1.7 (46.8, -37.8) | -25.6 (-3.4, -51.2) | 19.5 (66.7, -21.4) | 53.9 (65.8, 30.8) |
| *Cumulative AFOLU $CO_2$ Emissions until 2100 ($GtCO_2$)* | | -127.3 (5.9, -683.0) | -126.8 (153.0, -400.7) | -54.9 (52.1, -545.2) | 40.8 (277.0, -372.9) | 188.8 (426.6, 77.9) |

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[See Figure SPM 4]

**Figure SPM.4 Illustrative pathways linking policy, land use and climate change.**

**Illustrative pathways linking policy, land use and climate change. Future pathways provide a framework for understanding the implications of policy and socioeconomics on land and climate. These scenarios use the Shared Socioeconomic Pathways (SSPs) {6.2, Cross-Chapter Box 2: 'Implications of large-scale conversion from non-forest to forest land' in Chapter 1, Cross-chapter box 9: 'Illustrative Climate and Land Pathways' in Chapter 6, SPM Box A7} to span a range of different socioeconomic assumptions, policies, and warming levels. They were selected to show different future land use evolutions and their implications for land cover, emissions, and prices. The change in agricultural land (including non-energy crops and pasture), bioenergy cropland, and forest land from 2010 are shown. For each pathway, the shaded areas show the range across all models that represent all SSPs for a particular warming level. SSP1 is shown in green, SSP2 in blue, and SSP3 in magenta for 1.5˚C (first row) and 2.5 to 3˚C (second row) pathways; the line indicates the median across models. Further characteristics for each of these pathways are listed in the figure table. All indicators in the table are outcomes of integrated assessment models (IAMs) and include the full range of model pathways. Limiting global warming to 1.5˚C is not possible under SSP3 and thus this pathway is excluded; in addition, two models cannot limit warming to 1.5˚C in SSP2 {2.7, 6.2, 7.6, Cross-chapter box 9: 'Illustrative Climate and Land Pathways' in Chapter 6}. Additional risks related to bioenergy expansion are shown in SPM Fig. 2 Panel C. Pathways are labelled by their long-term temperature levels (either 1.5˚C or 2.5 to 3˚C). Temperature rise in 2100 is 1.3ºC in the 1.5ºC pathways and 2.6ºC in the 2.5 to 3ºC pathways. Pathways include effects of mitigation, but exclude climate change impacts on society, and do not account for the biophysical feedbacks of land on regional climate. SPM Fig. 2 panel b shows these effects for pathways SSP1 and SSP3. {3.8.5, 4.10.1, 5.7.1, 5.7.2, 6.5.4, 7.5.2, 7.5.4, 7.5.5, 7.5.6, 7.5.7, 7.5.8, 7.6.3, 7.6.6; Cross-Chapter Box 9: 'Illustrative Climate and Land Pathways' in Chapter 6}**

# D. Action in the near-term

**D 1. Actions taken in the near–term can enable longer-term responses that enable mitigation and adaptation to climate change as well as addressing desertification, land degradation and food insecurity. These include actions to fill knowledge gaps, accelerate knowledge transfer, implement early warning systems and build capacity (*high confidence*). {3.7, 5.5, 5.6, 5.7, 6.3, 6.5, 7.4, 7.5, 7.7}**

D1.1. Addressing knowledge gaps relating to the effectiveness, co-benefits and risks of emerging response options, particularly those involving $CO_2$ removal and those reaching or surpassing limits to adaptation, can improve sustainable land management in the long term (*high confidence*). Some response options have been implemented only at small-scale demonstration facilities; challenges exist with upscaling these options (*medium confidence*). Knowledge is needed on both supply-side and demand-side mitigation in the food system, addressing food loss and waste, consumption patterns, agricultural technologies and the potential of urban agriculture. {5.5.1, 5.5.2, 5.6.1, 5.6.5, 5.7.5, 6.3, 6.5}

D1.2. Long-term capacity-building efforts for both resource management and governance mechanisms can strengthen technology transfer for mitigation and adaptation in land sectors. Reciprocal knowledge transfer can help optimise the use of natural resources for food and nutrition security under changing climate conditions (*medium confidence*). {7.4, 7.5.4, 7.7.4}

D1.3. There are high returns on investments in human and institutional capacities, including access to early warning, hydro-meteorological and remote sensing-based earth monitoring systems and data, and expanded use of digital technologies (*medium confidence*). Expanded use of new information and communication technologies, remotely sensed information and 'citizen science' for data collection help in measuring progress in addressing desertification and land degradation, and achieving land degradation neutrality under a changing climate (*medium confidence*). {3.7.2, 3.7.3, 3.8.6, 7.5.3, 7.6.5}

D1.4. Early warning systems for weather, crop, yields, seasonal climate, and fast and slow onset climate change events are critical for protecting lives and property, adapting to climate change, and effecting adaptive climate risk management (*high confidence*). Their performance improves with involvement of people, for example through the selection of indicators of sustainable land management, such as soil erosion, soil salinization, desertification, water quality and water supply and demand (*medium confidence*). This helps measure and evaluate the success of decision making surrounding response options and policy portfolios (*medium confidence*). {3.7, 3.8.6, 5.3.1, 5.6.6, 7.5.3, 7.6.4; 7.6.5; 7.7.4}

D1.5. Early action in implementing land-based response options to avoid, reduce and reverse land degradation and desertification, have multiple co-benefits and would reduce the cost of mitigation and adaptation, if barriers to implementation and barriers to sustainable land management are overcome (*high confidence*). {3.7.1; 3.7.2; 5.2.6; 5.3.3; 5.6.4; 3.8.2; 7.4; 7.5.9}

**D 2. Early action to address climate change mitigation and adaptation, desertification, land degradation and food security can bring near-term social, economic and development benefits. These include more resilient livelihoods and poverty reduction among poor and marginalised social groups. (*high confidence*) {5.1, 5.3, 5.6}**

D2.1. Improved social benefits accrue with timely action (*high confidence*). Early action to reduce land and food-related vulnerabilities, especially among the poor and marginalised social groups, can create more resilient livelihoods, reduced degradation of land, and improved food security (*high confidence*). For example, synergies between poverty reduction efforts, such as increasing access to markets, and the elimination of land-intensive low-productivity practices, such as slash and burn agriculture, overharvesting of fuelwood (*medium confidence*). Synergies can reduce air pollution and emissions of short-lived climate forcers. These multiple benefits provide mitigation, adaptation and development benefits at the same time as preserving ecosystem services. {2.5, 3.5.2, 3.7.3, Table 4.3, 3.7, 4.10, 7.3, 7.4, 7.5, 7.6, Cross-Chapter Box 12: 'Traditional Biomass Use' in Chapter 7}

D2.2. Every dollar invested in sustainable land management yields from three to six dollars of returns in terms of ecosystem services, benefiting the entire global community. While they can require upfront investment, actions to ensure sustainable land management can improve crop yields and the economic value of pasture. Land restoration and rehabilitation measures, such as soil carbon sequestration, improve livelihood systems and provide both short-term positive economic returns and longer-term benefits in terms of climate change adaptation and mitigation (*high confidence*). {3.7.1, 3.7.3, 4.9.1, 7.3.4, 7.3.3, 7.4.1}

D2.3. Not all early actions are costly (*high confidence*). Incremental actions in crops and livestock production, dietary change, and reducing food loss and waste sustainable land management simultaneously ease economic burdens of ill health caused by malnutrition in all its forms. {3.7.3, 4.9 5.3, 5.5, 5.7, 6.5, 7.6.5; Cross-Chapter Box 9: 'Illustrative Climate and Land Pathways' in Chapter 6}.

**D 3. Delaying climate mitigation and adaptation responses in the land sector would lead to social impacts and rising costs, and would reduce the prospect of following climate resilient development, low emission pathways. Acting early may avert or reduce losses and generate benefits to society and returns on investment (*medium confidence*), while delayed action would increase the risk of irreversible impacts on food security and the ecosystems upon which humans depend (*high confidence*). {6.5, 7.3, 7.4.1, 7.5.7, SPM Fig.2}**

D3.1. Policies and institutions which accentuate cycles of poverty and ill-health, land degradation and climate change are barriers to achieving climate resilient development (*high confidence*). Prompt action on these challenges could deliver immediate benefits in many countries and reduce the vulnerability of millions of people to desertification, degradation and food insecurity (*high confidence*). {3.5.2, 3.6.2, 4.9.1, 4.9.3, 5.2.3, 5.3.1, 6.5, 7.4.1}

D3.2. The consequences of inaction on climate change exceed the costs of immediate action in areas such as food and livelihood security, ecosystem viability, and economic prosperity and stability (*medium confidence)*. In future scenarios, deferral of emissions reductions implies trade-offs leading to higher costs of several orders of magnitude and risks associated with larger levels of global warming (*medium confidence*). {1.4.1, 3.7.2.1, 4.10, 4.11.1, 5.5.2.4, 6.4, 6.5, 7.3, 7.4, Cross-Chapter Box 10: 'Economic Dimensions' in Chapter 7}

D3.3. Delaying mitigation responses to climate change can limit the effectiveness and range of land-based adaptation options in most regions of the world, and will further reduce the effectiveness of future land-based mitigation options (*high confidence*). For example, the potential for some response options, such as increasing soil organic carbon, decreases as climate change intensifies due to reduced sink capacity for carbon sequestration (*high confidence*). Delays in implementing response options to stem losses and reverse ecosystem changes (including reducing deforestation, reducing peatland and coastal wetland losses, reducing rangeland degradation) leaves these carbon-rich ecosystems at risk, with long-term consequences such as the potential irreversibility of ecosystem change  and the difficulties and costs of restoration (including rapid declines in productivity of rangelands, or barriers to peatland rewetting) (*medium confidence*).{6.3, 6.4, 6.5, 6.5.2, SPM Fig. 2}