1.SM Framing and Context Supplementary Material

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This Supplementary Material provides technical details of the calculations behind the figures in the chapter, as well as some supporting figures provided for sensitivity analysis or to provide support to the main assessment.

Note: this version is subject to final layout and proof reading.

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1.SM.1: Supplementary Material for Figure 1.1

Externally forced warming in Figure 1.1 is calculated for the Cowtan-Way (2014) dataset at every location and for each season following the method in Figure 1.3. The season with the greatest externally forced warming at every location (averaged over the 2006–2015 period) is indicated by the colour of that grid box in Figure 1.SM.1. Figure 1.SM.2 shows the warming to 2006–2015 in the season that has warmed the least.

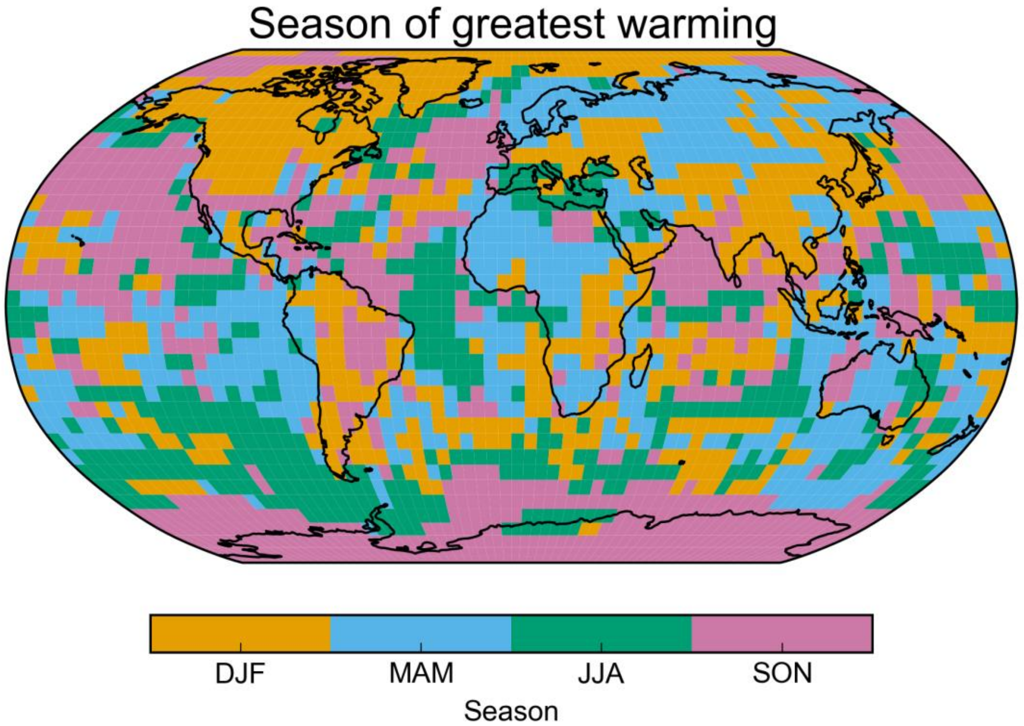

Figure 1.SM.1: Season of greatest human-induced warming in 2006–2015 relative to 1850–1900 for the data shown in Figure 1.1.

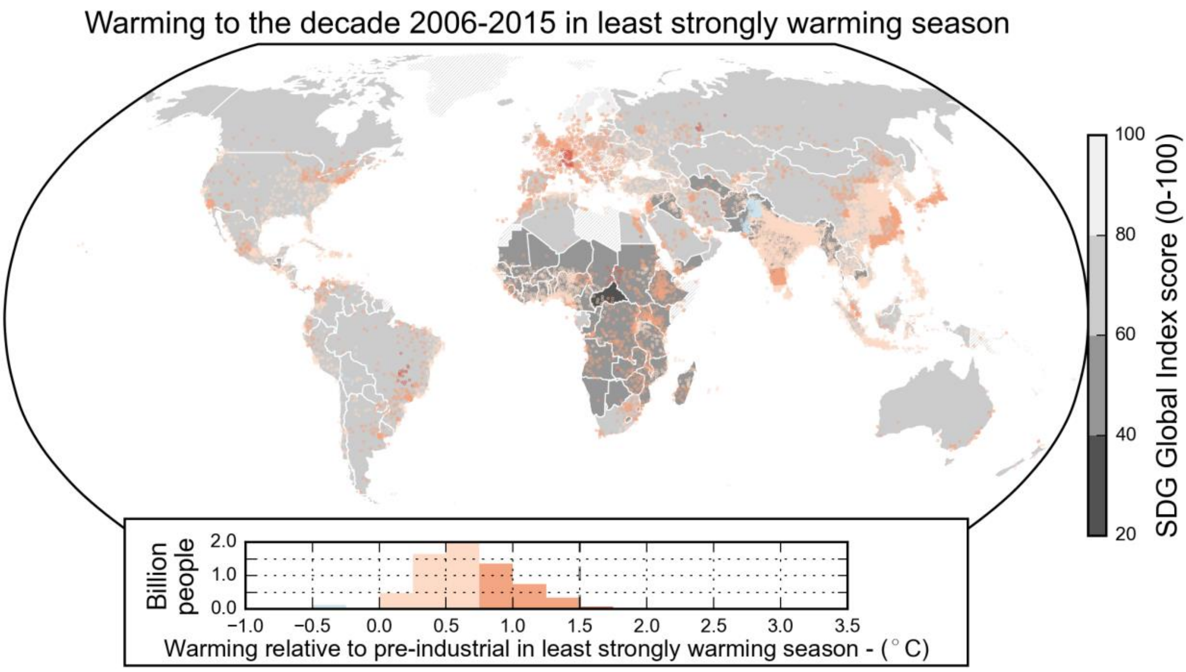

Figure 1.SM.2: As for Figure 1.1 but with scatter points coloured by warming in the season with least warming between the periods 1850–1900 and 2006–2015.

Population data is taken from Doxsey-Whitfield et al. (2015) for 2010. The number of scatter points shown in each 1° × 1° grid box is directly proportional to the population count in the grid box, with a maximum number of scatter points in a single grid box associated with the maximum population count in the dataset. For grid boxes with (non-zero) population counts that are below the population threshold consistent with just a single scatter point (approximately 650,000), the probability that a single scatter point is plotted reduces from unity towards zero with decreasing population in the grid box to give an accurate visual impression of population distribution.

The SDG Global Index Score is a quantitative measure of progress towards the 17 sustainable development goals (Sachs et al., 2017). The goals cut across the three dimensions of sustainable development – environmental sustainability, economic growth, and social inclusion. The index score has a range of 0–100, with 100 corresponding to all SDGs being met. Versions of Figure 1.1 using the HadCRUT4, NOAA and GISTEMP temperature datasets are shown in Figure 1.SM.3, Figure 1.SM.4 and Figure 1.SM.5 respectively.

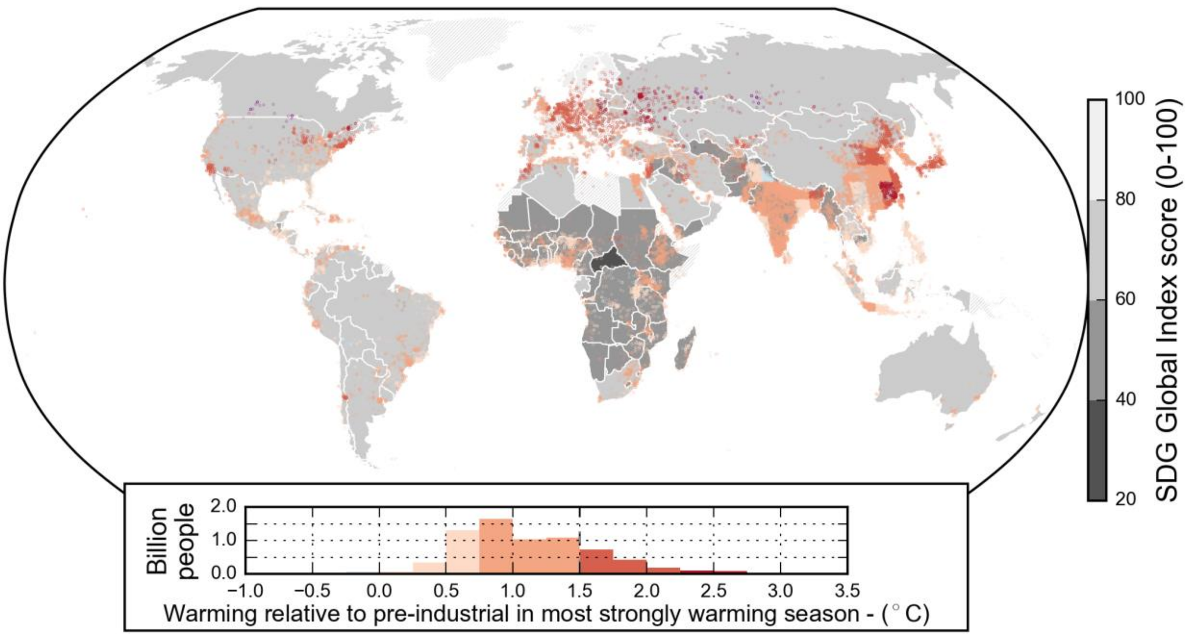

Figure 1.SM.3: As for Figure 1.1 but using the HadCRUT4 temperature dataset.

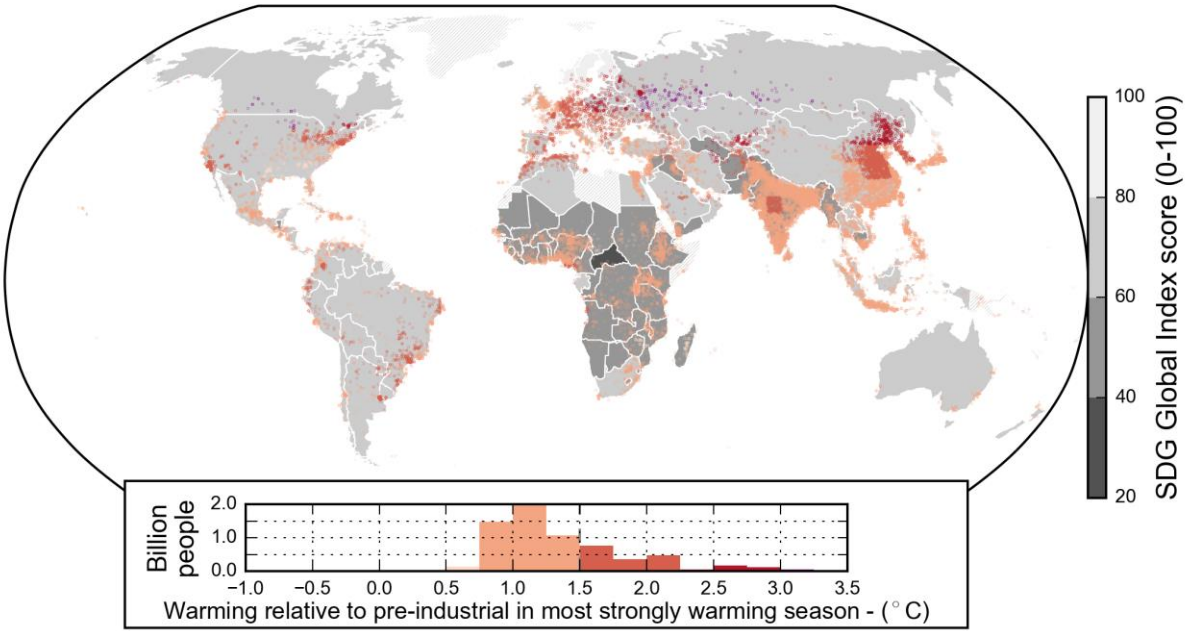

Figure 1.SM.4: As for Figure 1.1 but using the NOAA temperature dataset.

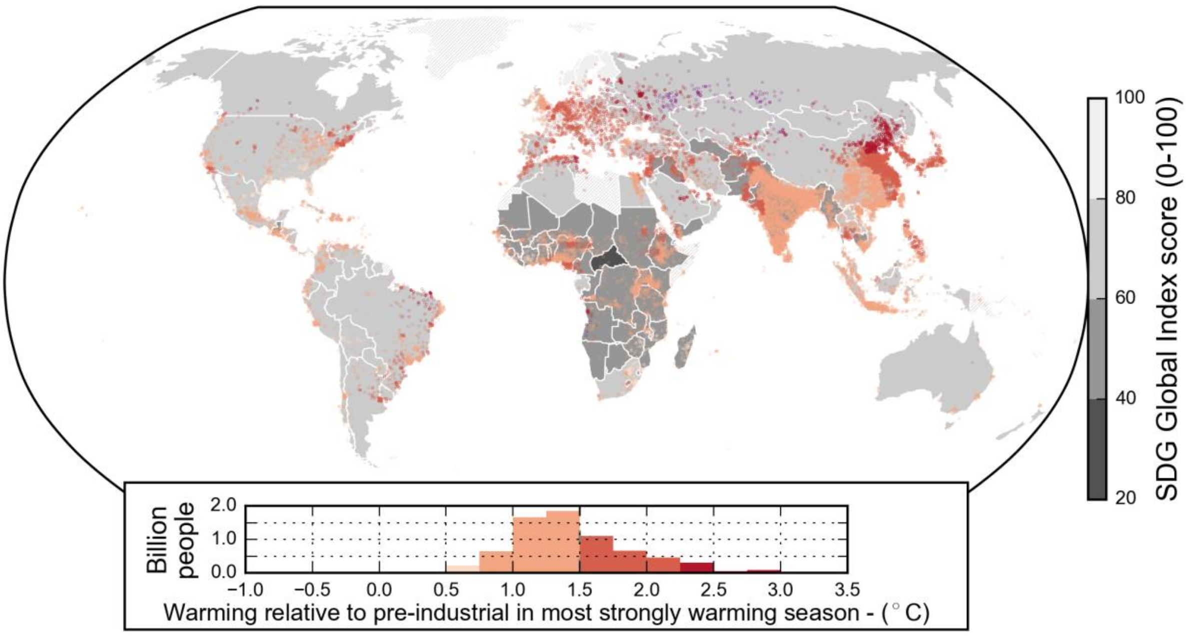

Figure 1.SM.5: As for Figure 1.1 but using the GISTEMP temperature dataset.

1.SM.2: Supplementary Material for Figure 1.2

Observational data used in Figure 1.2 are taken from the Met Office Hadley Centre (http://www.metoffice.gov.uk/hadobs/hadcrut4/), National Oceanic and Atmospheric Administration

(NOAA) (https://www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp), NASA's Goddard Institute for Space Studies (https://data.giss.nasa.gov/gistemp/) and the Cowtan & Way dataset (https://www-users.york.ac.uk/~kdc3/papers/coverage2013/series.html). The GISTEMP and NOAA observational products (which begin in 1880) are expressed relative to 1850–1900 by assigning these datasets the same anomaly as HadCRUT4 for the mean of the 1880–2017 period. All available data are used, through to the end of 2017, for all datasets. The grey "Observations range" shading indicates the range (minimum to maximum) monthly-mean anomaly across these four temperature datasets for the month in question.

CMIP5 multimodel means, shown as light blue dashed (full-field surface air temperature) and solid blue (masked and blended as in Cowtan et al. (2015)) lines are expressed relative to a 1861–1880 base period and then expressed relative to the 1850–1900 reference period using the anomaly between the periods in the HadCRUT4 product (0.02°C). Model data are taken from Richardson et al. (2018). Only RCP8.5 r1i1p1 ensemble members are used, with only one ensemble member per model used for calculating the mean lines in this figure.

The pink "Holocene" shading is derived from the "Standard$_{5\times5}$" reconstruction of Marcott et al. (2013) (expressed relative to 1850–1900 using the HadCRUT4 anomaly between this reference period and the 1961–90 base period of the data). The vertical extent of the solid shading is determined by the maximum and minimum temperature anomalies in the dataset in the period before 1850. Marcott et al. (2013) report data with a periodicity of 20 years, so the variability shown by the solid pink shading is not directly comparable to the higher-frequency variability seen in the observational products, which are reported every month, but this Holocene range can be compared to the emerging signal of human-induced warming. Above and below the maximum and minimum temperature anomalies from Marcott et al. (2013), the pink shading fades out to white after a magnitude of warming that is equal to the standard deviation of monthly temperature anomalies in the HadCRUT4 dataset over the pre-industrial reference period of 1850–1900, and as such this faded shading does not bound all monthly anomalies in the pre-industrial reference period.

Near-term projections from AR5 (Kirtman et al., 2013) for the period 2016–2035 were assessed by AR5 to be *likely* (>66% probability) between 0.3°C and 0.7°C above the 1986–2005 average, assuming no climatically significant future volcanic eruptions. These are expressed relative to pre-industrial levels using the updated 0.63°C warming to the 1986–2005 period (Section 1.2.1).

Human-induced temperature change (thick yellow line) and total (human+natural) externally forced temperature change (thick orange line) are estimated using the method of Haustein et al. (2017) applied to the four-dataset mean. Best-estimate historical radiative forcings, extended until the end of 2016, are taken from Myhre et al. (2013), incorporating the significant revision to the methane forcing proposed by Etminan et al. (2016). The 2-box thermal impulse-response model used in Myhre et al. (2013), with modified thermal response time scales to match the multimodel mean from Geoffroy et al. (2013), is used to derive the shape of the global mean temperature response time series to total anthropogenic and natural (combined volcanic and solar) forcing. Both of these time series are expressed as anomalies relative to their simulated 1850–1900 averages and then used as independent regressors in a multivariate linear regression to derive scaling factors on the two time series that minimize the residual between the combined forced response and the multi-dataset observational mean. The transparent shading around the thick yellow line indicates the *likely* range in attributed human-induced warming conservatively assessed at ±20%. Note that the corresponding *likely* range of ±0.1°C uncertainty in the 0.7°C best-estimate anthropogenic warming trend over the 1951–2010 period assessed in Bindoff et al. (2013) corresponds to a smaller fractional uncertainty (±14%): the broader range reflects greater uncertainty in early-century warming.

The vertical extent of the 1986–2005 cross denotes the 5–95% observational uncertainty range of ±0.06□C (see Table 1.1) while that of the 2006–2015 cross denotes the assessed *likely* uncertainty range of ±0.12□C (Section 1.2.1).

To provide a methodologically independent check on the attribution of human-induced warming since the 19th century (quantitative attribution results quoted in AR5 being primarily focused on the period 1951–2010), Figure 1.SM.6 shows a recalculation of the results of Ribes and Terray (2013; figure 1 in the paper), applied to the CMIP5 multimodel mean response. Details of the calculation are provided in the original paper. In order to quantify the level of human-induced warming since the late 19th century, observations of global mean surface temperature (GMST) are regressed onto the model responses to either natural-only (NAT) or anthropogenic-only (ANT) forcings, consistent with many attribution studies assessed in AR5. Prior to this analysis, model outputs are preprocessed in order to ensure consistency with observations: spatial resolution is lowered to 5°, the spatio-temporal observational mask is applied, and all missing data are set to 0. Global and decadal averages of near-surface temperature are calculated over the 1901–2010 period (11 decades), and translated into anomalies by subtracting the mean over the entire period (1901–2010). Multimodel mean response patterns are calculated over a subset of 7 CMIP5 models providing at least 4 historical simulations and 3 historical NAT-only simulations, all covering the 1901–2010 period. The regression analysis indicates how these multimodel mean responses have to be rescaled in order to best fit observations, accounting for internal variability in both observations and model responses, but neglecting observational uncertainty. Almost no rescaling is needed for ANT (regression coefficient: 1.05 ± 0.18), while the NAT simulated response is revised downward (regression coefficient: 0.28 ± 0.49). The resulting estimate of the total externally forced response is very close to observations (Figure 1.SM.6). The ANT regression coefficient can then be used to assess the human-induced warming over a longer period. Estimated in this way, the human-induced linear warming trend for 1880–2012 is found to be 0.86°C ± 0.14°C.

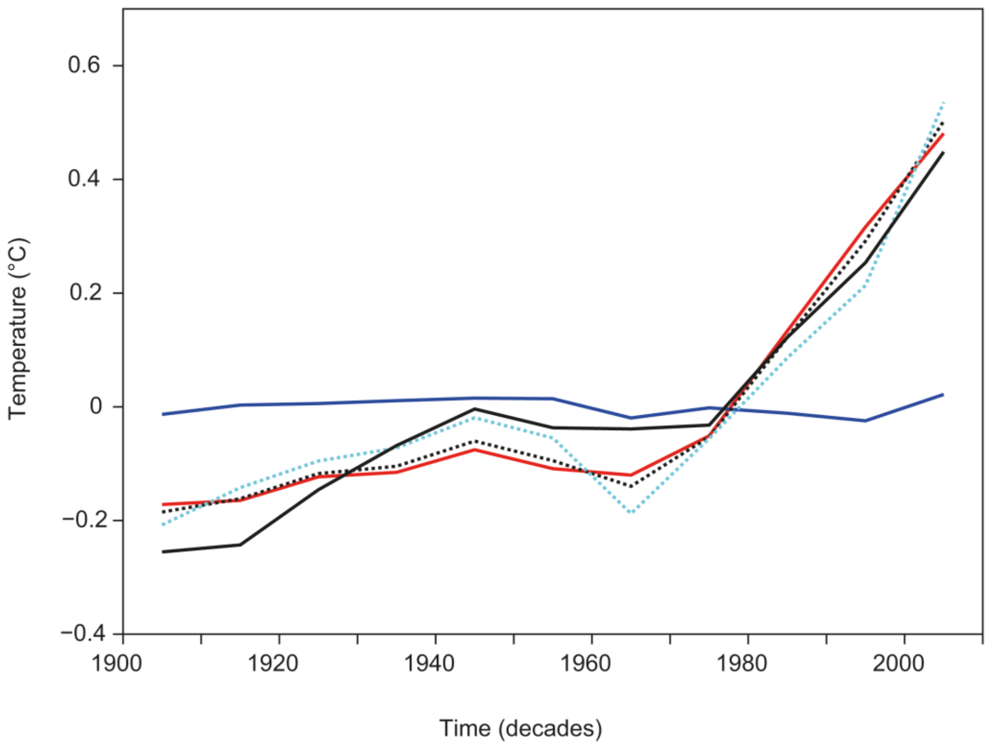

Figure 1.SM.6: Contributions of natural (NAT) and anthropogenic (ANT) forcings to changes in GMST over the period 1901–2010. Decadal time series of GMST in HadCRUT4 observations (solid black), from multimodel mean response without any rescaling (dotted cyan), and as reconstructed by the linear regression

(dotted black). The estimated contributions of NAT forcings only (solid blue) and anthropogenic forcing only (solid red) correspond to the CMIP5 multimodel mean response to these forcings, after rescaling. All temperatures are anomalies with respect to the 1901–2010 average, after preprocessing (missing data treated as 0). Vertices are plotted at the midpoint of the corresponding decade.

To quantify the potential impact of natural (externally forced or internally generated) variability on decadal-mean temperatures in 2006–2015, Figure 1.SM.7 shows an estimate of the observed warming rate, corrected for the effects of natural variability according to the method of Foster and Rahmstorf (2011) applied to the mean of the four observational GMST datasets used in this report, updated to the end of 2017. The grey line shows the raw monthly GMST observations (with shading showing inter-dataset range), while the green line shows the sum of the linear trend plus estimated known sources of variability, such as El Niño events or volcanic eruptions, estimated using an empirical regression model. The orange line shows the linear trend, after correcting for the impact of these known sources of variability, of 0.18°C per decade, while the two black lines show the recent reference periods used in this report. For comparison, the AR5 near-term predicted warming rate of 0.3°C–0.7°C over 30 years (Kirtman et al, 2013) is shown as the pale blue plume.

The blue line in the lower panel shows residual fluctuations that cannot be attributed to known sources or modes of variability, reflecting internally generated chaotic weather variability (the difference between grey and green lines in the top panel). The green line is not persistently below the yellow line, nor is the blue line persistently negative, over the period 2006–2015. There is a downward excursion in the residual "unexplained" variability around 2012–2013, and a strong ENSO cool phase event in 2011, but even together these depress the decadal average by only a couple of hundredths of a degree.

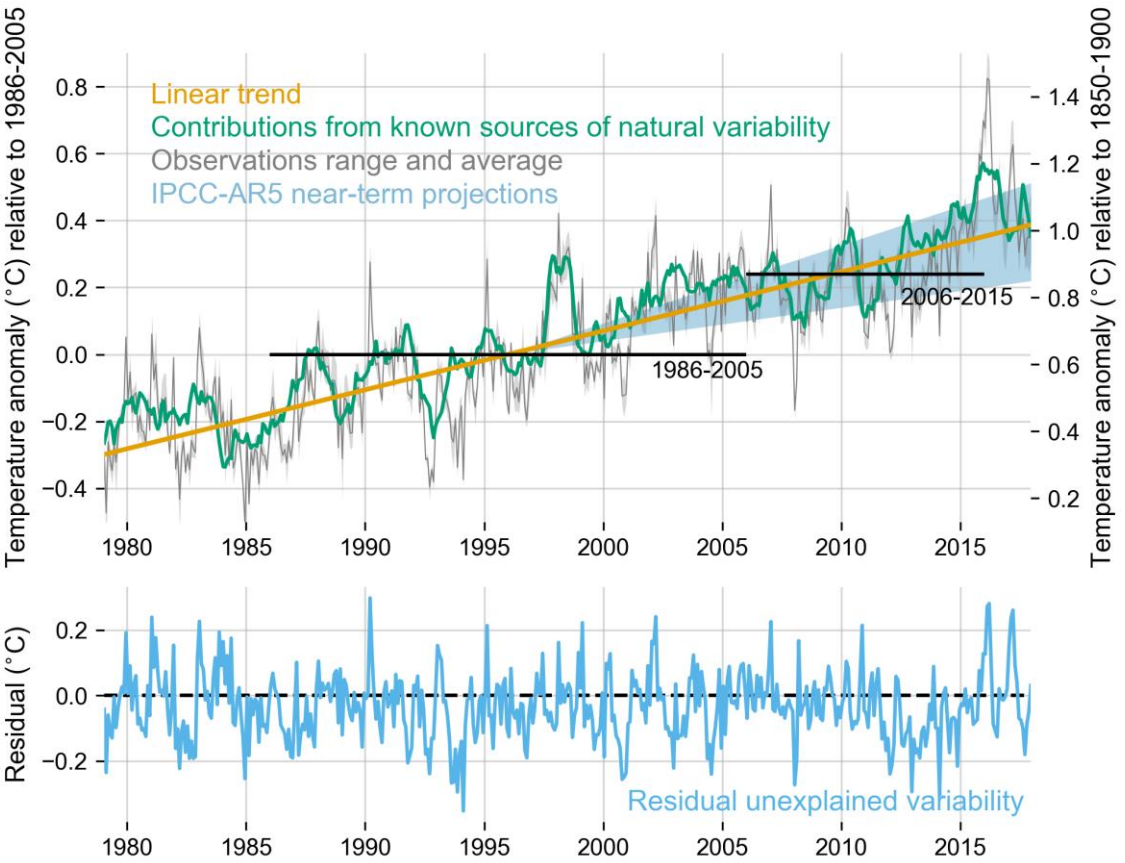

Figure 1.SM.7: Warming and warming rate for 1979–2017. The solid grey line shows the average of the four observational GMST datasets used in this assessment report, with the observational range shown by grey shading. The yellow line shows the linear trend through the observational data, corrected for the effects of known sources of natural variability (green line). The blue shading indicates that current warming rates are compatible with the AR5 near-term projections. The lower panel shows the residual unexplained variability (difference between grey and green lines in upper panel) after accounting for known sources, including ENSO, solar variability and volcanic activity.

1.SM.3: Supplementary Material for Figure 1.3

Regional warming shown in Figure 1.3 is derived using a similar method to the calculation of externally forced warming in Figure 1.2. At every grid box location in the native Cowtan–Way resolution, the time series of local temperature anomalies in the Cowtan-Way dataset are regressed onto the associated externally forced warming time series, calculated as in Figure 1.1 using all available historical monthly-mean anomalies. The best-fit relationship between these two quantities is then used to estimate the forced warming relative to 1850–1900 at this location. The maps in Figure 1.3 show the average of these estimated local forced warming time series over the 2006–2015 period. Trends are only plotted only where over 50% of the entire observational record at this location is available.

Supplementary maps are included below for the NOAA, GISTEMP and HadCRUT4 observational data. The regression of local temperature anomalies onto the global mean externally forced warming allows warming to be expressed relative to 1850–1900 despite many local series in these datasets beginning after 1900, but clearly these inferred century-time-scale warming levels are subject to a lower confidence level than the corresponding global values.

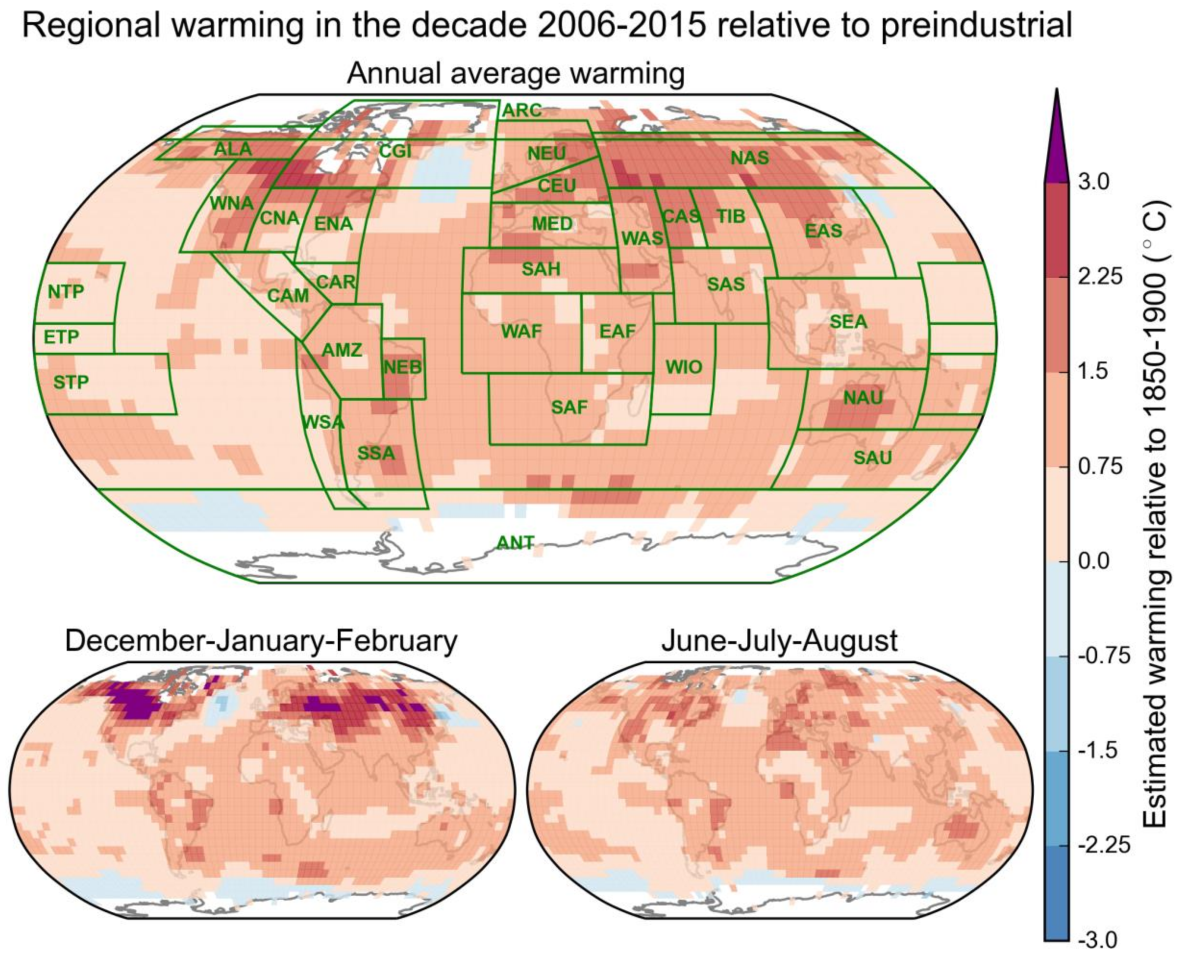

Figure 1.SM.8: Externally forced warming for the average of 2006–2015 relative to 1850–1900 calculated for the NOAA observational dataset as for Figure 1.3.

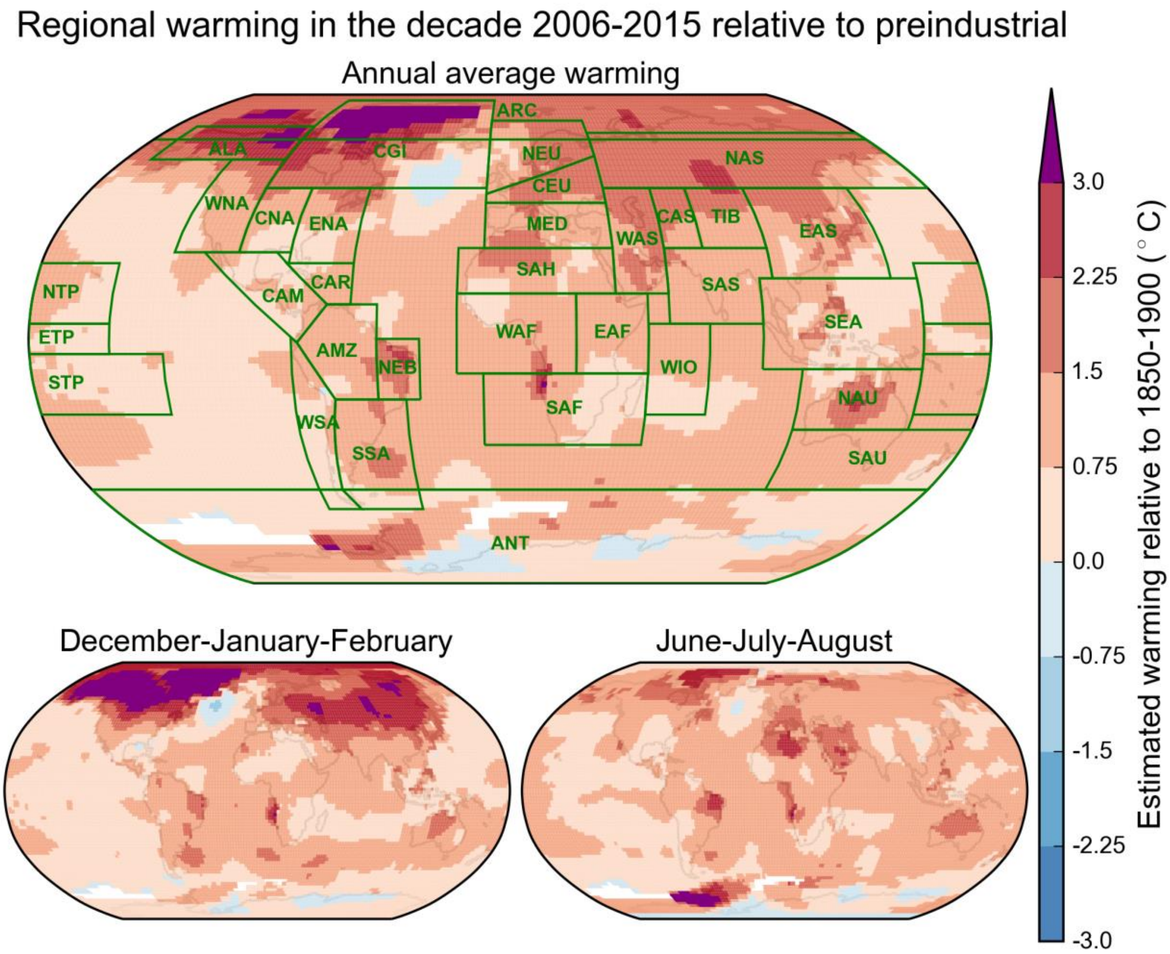

Figure 1.SM.9: Externally forced warming for the average of 2006–2015 relative to 1850–1900 calculated for the GISTEMP observational dataset as for Figure 1.3.

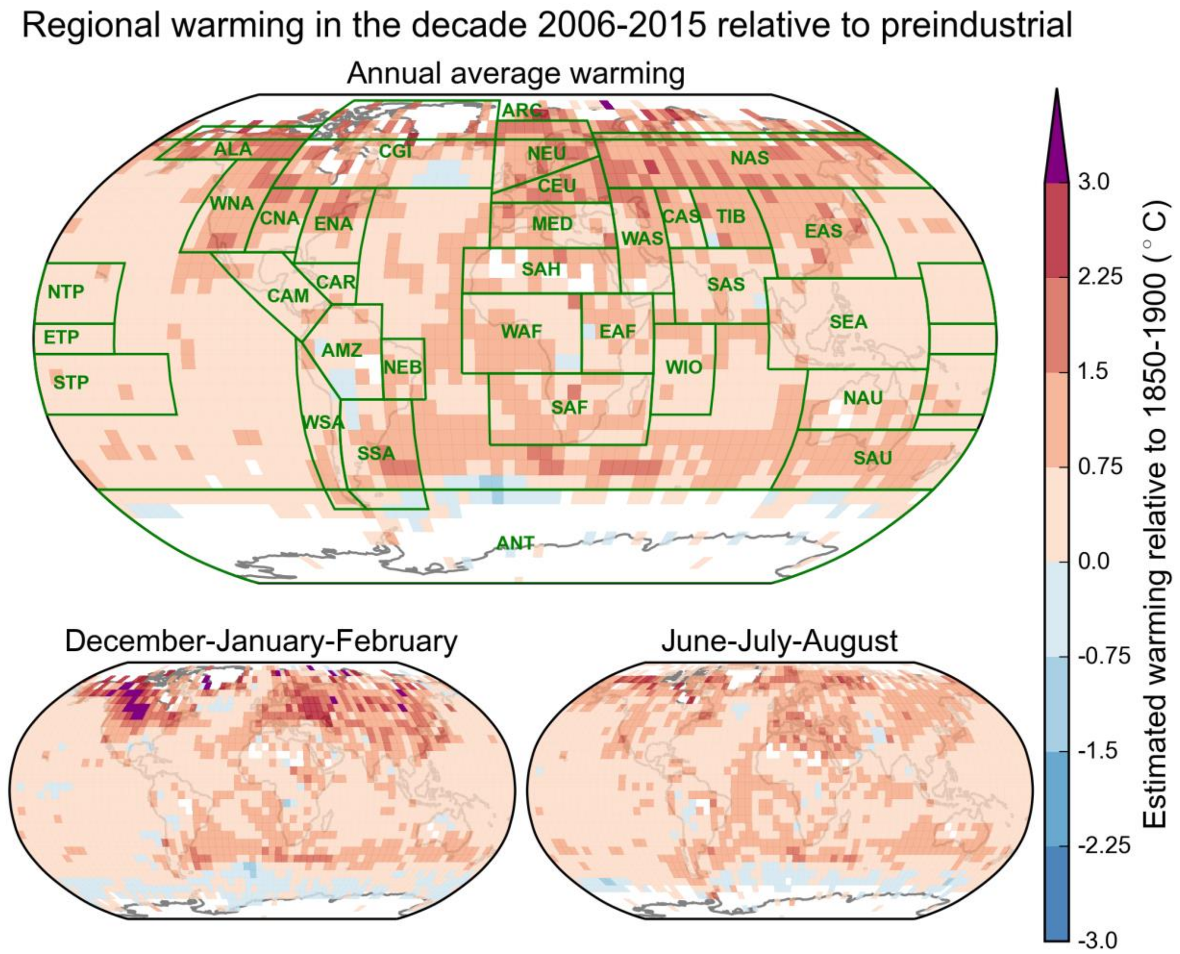

Figure 1.SM.10: Externally forced warming for the average of 2006–2015 relative to 1850–1900 calculated for the HadCRUT4 observational dataset as for Figure 1.3.

1.SM.4: Supplementary Material for Figure 1.4

Idealized temperature pathways are computed by specifying the level of human-induced warming in 2017, $T_{2017} = 1°C$, with temperatures from 1850 to 2017 approximated by an exponential rise, with the exponential rate constant, γ, set to give a rate of human-induced warming in 2017 of 0.2°C/decade. Projected temperatures for 2018–2100 are determined by fitting a smooth 4th-order polynomial through specified warming values at particular times after 2017.

Radiative forcing series F that would give the temperature pathways described above are computed using a 2-time-constant climate response function (Myhre et al., 2013b), with equilibrium climate sensitivity (ECS) of 2.7°C, a transient climate response (TCR) of 1.6°C, and other parameters as given in Millar et al. (2017). Equivalent CO_2 concentrations are given by $C = 278 \times \exp(F/5.4)$ ppm.

Cumulative CO_2-forcing-equivalent emissions (Jenkins et al, 2018), or the CO_2 emission pathways that would give the CO_2 concentration pathways compatible with each temperature scenario, are computed using an invertible simple carbon cycle model (Myhre et al., 2013b), modified to account for changing CO_2 airborne fraction over the historical period (Millar et al., 2017). These would be proportional to CO_2 emissions under the assumption of a constant fractional contribution of non-CO_2

forcers to warming. An indicative cumulative impact variable (e.g., sea level rise) is computed from temperature pathways shown using the semiempirical model of Kopp et al. (2016).

1.SM.5: Supplementary Material for Figure 1.5

All scenarios in Figure 1.5 start with a 1000-member ensemble of the FaIR model (Smith et al., 2018) driven with emissions from the RCP historical dataset from 1765 to 2000 (Meinshausen et al., 2011), SSP2 from 2005 to 2020 (Fricko et al., 2017), and a linear interpolation between the two inventories for 2000 to 2005. Equilibrium climate sensitivity (ECS) and transient climate response (TCR) parameters are drawn from a joint lognormal distribution informed by CMIP5 models. Uncertainties in present-day non-CO_2 effective radiative forcing (ERF) are drawn from the distributions in Myhre et al. (2013) and uncertainties in the carbon cycle response are given a 5–95% range of 13% around the best estimate (Millar et al., 2017). All uncertainties except TCR and ECS are assumed to be uncorrelated with each other.

FaIR derives an ERF time series from emissions, from which temperature change is calculated. Greenhouse gas concentrations are first calculated, from which the radiative forcing relationships from Myhre et al. (1998) are used to determine ERF. An increase of ERF of 25% for methane forcing is applied which approximates the updated relationship from Etminan et al. (2016). The Myhre et al. (1998) relationships with a scaling for methane rather than the newer Etminan et al. (2016) relationships are used because the former does not assume any band overlap between CO_2 and N_2O, and isolating CO_2 forcing from N_2O forcing is problematic for certain commitments where CO_2 emissions are set to zero and N_2O forcing is held constant.

Aerosol forcing is based on the Aerocom radiative efficiencies (Myhre et al., 2013a) for ERFari (ERF from aerosol-radiation interactions) and a logarithmic dependence on emissions of black carbon, organic carbon and sulphate aerosols for ERFaci (ERF from aerosol–cloud interactions) based on the model of Ghan et al. (2013). Tropospheric ozone forcing is based on Stevenson et al. (2013). Other minor categories of anthropogenic forcing are derived from simple relationships that approximate the evolution of ERF in Annex II of Working Group I of AR5 (Prather et al., 2013) as described in Smith et al. (2018). For forcing categories other than methane (for which a significant revision to the best estimate ERF has occurred since AR5), a time-varying scaling factor is implemented over the historical period, so that for a best-estimate forcing, the AR5 ERF time series is replicated. This historical scaling decays linearly between 2000 and 2011 so that in 2011 onwards the FaIR ERF estimate is used for projections. For the 2000–2011 period the impact of the historical scaling is small, because FaIR emissions-forcing relationships are mostly derived from AR5 best estimates in 2005 or 2011 (Smith et al., 2018).

Two ensembles are produced: a historical (1765–2014) ensemble containing all (anthropogenic plus natural) forcing, and a historical+future (1765–2100) ensemble containing only anthropogenic forcing for each commitment scenario. In the ensemble where natural forcing is included, solar forcing for the historical period is calculated by using total solar irradiance from the SOLARIS HEPPA v3.2 dataset (Matthes et al., 2017) for 1850–2014 and from Myhre et al. (2013) for 1765–1850: the 1850–1873 mean is subtracted from the time series which is then multiplied by 0.25 (annual illumination factor) times 0.7 (planetary co-albedo) to generate the effective radiative forcing (ERF) timeseries. Volcanic forcing is taken by using stratospheric aerosol optical depths from the CMIP6 historical Easy Volcanic Aerosol dataset (Toohey et al., 2016) prepared for the HadGEM3 CMIP6 historical integrations for 1850–2014. The integrated stratospheric aerosol optical depth at 550 nm (tau) is calculated and converted to ERF by the relationship ERF = −18×tau, based on time slice experiments in the HadGEM3 general circulation model, which agrees well with earlier HadGEM2 and HadCM3 versions of the UK Met Office Hadley Centre model (Gregory et al., 2016). The 1850–2014 mean volcanic ERF of −0.107 is subtracted as an offset to define the mean historical volcanic ERF as zero.

Owing to rapid adjustments to stratospheric aerosol forcing, which are included in the definition of ERF, this less negative value of −18×tau is adopted for volcanic ERF than the RF = −25×tau used in AR5.

The historical all-forcing scenario is then used to constrain parameter sets that satisfy the historical observed temperature trend of 0.90°C ± 0.19°C (mean and 5 to 95% range) over the 1880 to 2014 period, using the mean of the HadCRUT4, GISTEMP and NOAA datasets. The trend was derived using an inflation factor for autocorrelation of residuals, and is the same method used to derive linear temperature trends in AR5 (Hartmann et al., 2013). The uncertainty bounds used here are wider than, but consistent with, the 1-sigma range of ±0.12°C assessed for the temperature change in 2006–2015 relative to 1850–1900. The parameter sets that satisfy the historical temperature constraint in the historical ensemble (323 out of 1000) are then selected for the anthropogenic-only ensembles that include commitments.

Each commitment scenario is driven with the following assumptions:

1. Zero CO_2 emissions, constant non-CO2 forcing (blue): FaIR spun up with anthropogenic forcing to 2020. Total non-CO_2 forcing in 2020 is used as the input to the 2021–2100 period with all CO_2 fossil and land-use emissions abruptly set to zero.

2. Phase out of CO_2 emissions with 1.5°C commitment (blue dotted): FaIR spun up with anthropogenic forcing to 2020. Total non-CO_2 forcing in 2020 is used as the input to the 2021–2100 period. Fossil and land-use CO_2 emissions are ramped down to zero at a linear rate over 50 years from 2021 to 2070, consistent with a 1.5°C temperature rise above pre-industrial levels at the point of zero CO_2 emissions in 2070 with these climate response parameters and constant 2020 non-CO_2 forcing.

3. Linear continuation of 2010–2020 temperature trend (blue dashed, in bottom panel only).

4. Zero GHG emissions, constant aerosol forcing (pink): FaIR spun up with anthropogenic forcing to 2020. All GHG emissions set abruptly to zero in 2021, with aerosol emissions held fixed at their 2020 levels.

5. Zero CO_2 and aerosol emissions, constant non-CO_2 GHG forcing (teal): FaIR spun up with anthropogenic forcing to 2020. Total non-CO_2 GHG forcing in 2020, which also includes the proportion of tropospheric ozone forcing attributable to methane emissions, is used as the input to the 2021–2100 period. Fossil and land-use CO_2 and aerosol emissions abruptly set to zero in 2021.

6. Zero emissions (yellow, including uncertainty range): FaIR spun up with anthropogenic forcing to 2020. All emissions set abruptly to zero in 2021.

1.SM.6: Supplementary Material for FAQ 1.2 Figure 1 and Figure SPM 1

This section provides supporting material for FAQ 1.2, Figure 1 and Figure SPM 1 in the Summary for Policymakers. Figure 1.SM.11, top panel, shows time series of annual CO_2 emissions from the Global Carbon Project (Le Quéré et al, 2018) (black line and grey band, with the width of the band indicating the *likely* range, or one standard error, uncertainty in annual emissions), extrapolated to 2020 and then declining in a straight line to reach net zero in either 2055 (grey line) or 2040 (blue line).

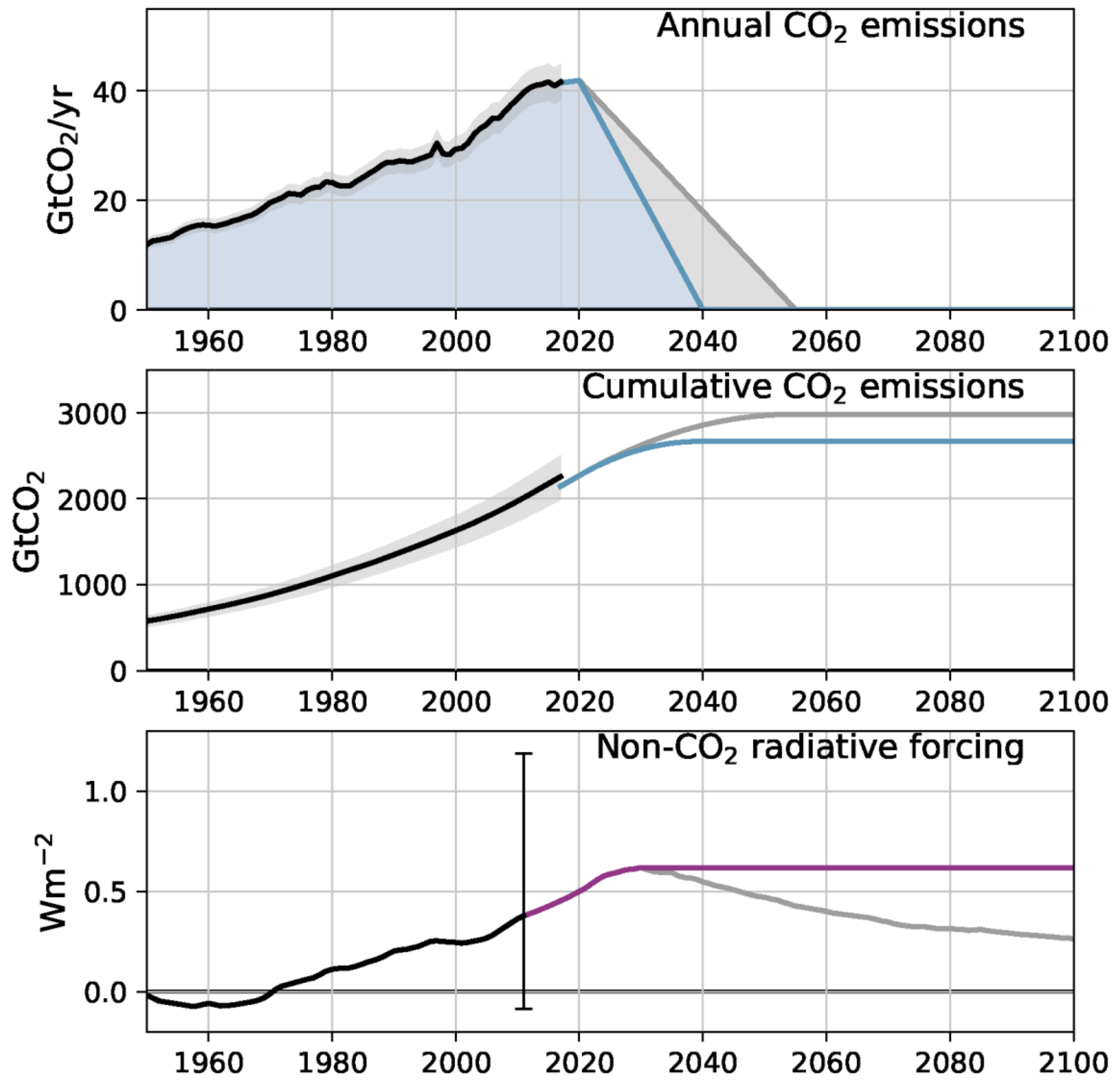

Figure 1.SM.11: Time series of (top) annual CO_2 emissions, (middle) cumulative CO_2 emissions, and (bottom) non-CO_2 radiative forcing corresponding to observation-based estimates over the historical period and stylized 1.5°C-consistent pathways.

The middle panel in Figure 1.SM.11 shows cumulative (time-integrated) CO_2 emissions, with black line and grey band showing observed emissions from the Global Carbon Project, and grey and blue lines corresponding to the areas highlighted as blue+grey or blue, respectively, in the top panel. Grey and blue lines show, from 2017 onwards, cumulative emissions diagnosed from a simple climate–carbon-cycle model (Millar et al, 2017) with historical airborne fraction scaled to reproduce median estimated annual emissions in 2017. Note this does not precisely reproduce median observed cumulative emissions in 2017 but is well within the range of uncertainty: Figure SPM.1 shows diagnosed cumulative emissions throughout.

The bottom panel in Figure 1.SM.11 shows median non-CO_2 ERF used to drive the model over the historical period, extending forcing components using the RCP8.5 scenario (http://www.pik-potsdam.de/~mmalte/rcps/) between 2011 and 2020, with scaling applied to each forcing component time series to match the corresponding AR5 ERF component in 2011. The vertical bar in 2011 shows a simple indication of the *likely* range of non-CO_2 forcing in 2011 obtained by subtracting the best-estimate CO_2 forcing from the total anthropogenic forcing uncertainty, assuming the latter is normally distributed: AR5 did not give a full assessment of the distribution of non-CO_2 radiative forcing. It demonstrates there is considerable uncertainty in this quantity, which translates into uncertainty in climate system properties inferred from these data. However, this uncertainty has a much smaller impact on estimated human-induced warming to date, because this is also constrained by temperature observations. The grey line shows non-CO_2 forcing in an indicative 1.5°C pathway consistent with those assessed by Chapter 2, while the purple line shows a stylized pathway in which non-CO_2 forcing remains constant after 2030.

For all percentiles of the climate response distribution, non-CO_2 forcing time series for these stylized scenarios are scaled to fit the temperature response to the corresponding percentiles of the assessed *likely* range of human-induced warming in 2017, assuming the latter is normally distributed. All non-CO_2 forcing components other than aerosols are scaled following their corresponding ranges of uncertainty of values in 2011 given in AR5, with low values of 2011 ERF corresponding to high values of TCR and vice versa. This accounts for the anti-correlation between estimated values of the TCR and estimates of current anthropogenic forcing. Then aerosol ERF (the most uncertain component) is scaled to reproduce the correct percentile of human-induced warming in 2011. Values of TCR, ECS and 2011 forcing components are given in Table 1.SM.1. For each combination of TCR and ECS, the strength of carbon cycle feedbacks are varied to span the range in the CMIP5 RCP2.6 Earth System Model ensemble (±100%), co-varying with climate response to maximize the range of Transient Climate Response to Emissions (TCRE) following Millar et al (2017). Uncertainty in carbon cycle feedbacks makes only a minor contribution to overall response uncertainty in these low-emissions scenarios. In each case, overall airborne fraction is scaled to reproduce observed annual emissions in 2017.

Figure 1.SM.12 shows time series of observed and human-induced warming to 2017 and responses to these stylized future emissions scenarios. Observed and human-induced warming estimates are reproduced exactly as in Figure 1.2, with the orange shaded band showing the assessed uncertainty range of ±20%. The dashed line shows a simple linear extrapolation of the current rate of warming, as calculated over the past five years. Responses to stylized future CO_2 emissions and non-CO_2 forcing trajectories are simulated with the FaIR simple climate–carbon cycle model (Millar et al, 2017b). The four values of the TCR shown (giving the borders of the grey, blue and purple shaded plumes) correspond to the 17th, 33rd, 67th and 83rd percentiles of a normal distribution compatible with the *likely* range of TCR as assessed by AR5, combined with the same percentiles of a log-normal distribution for the ECS similarly anchored to the AR5 *likely* range for this quantity. Other thermal climate response parameters (short and long adjustment time scales) are set to match those given in Myhre et al (2013) as used in Millar et al (2017a).

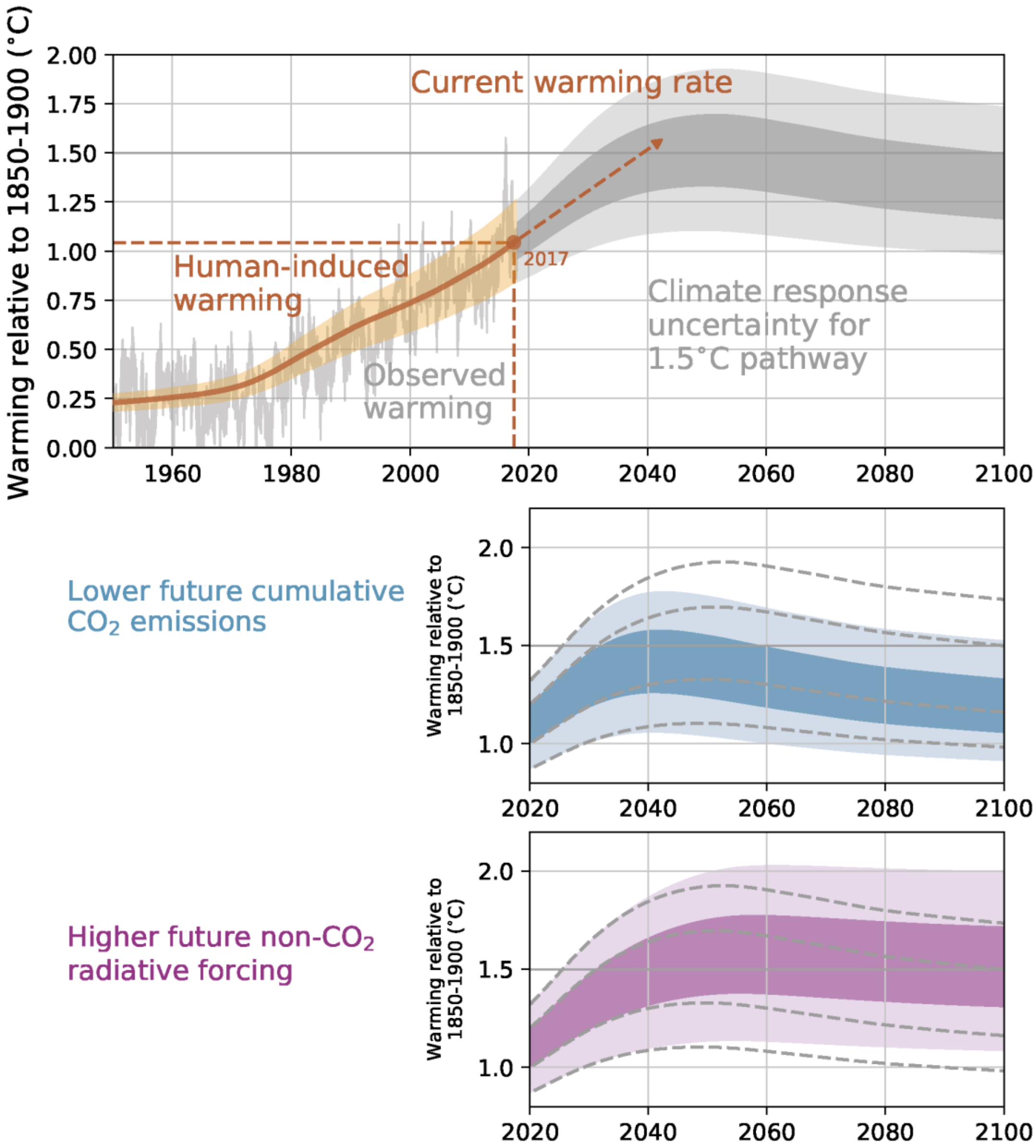

Figure 1.SM.12: Time series of observed and human-induced warming to 2017 and responses to stylized 1.5°C pathways of CO_2 and non-CO_2 forcing shown in Figure 1.SM.11. Light shading in response plumes indicates *likely* range (17th to 83rd percentiles) while dark shading indicates central tercile (33rd to 67th percentiles).

The smooth grey shaded bands in the top panel of Figure 1.SM.12 show the temperature response to CO_2 emissions declining from 2020 to net zero in 2055 (grey line in top panel of Figure 1.SM.11), with non-CO_2 forcing following the indicative 1.5°C pathway shown by the grey line in the bottom panel of Figure 1.SM.11. The middle panel of Figure 1.SM.12 shows the impact on future warming of bringing forward the date of net zero emissions to 2040 (blue line in top panel of Figure 1.SM.11), with the grey dashed lines showing the original percentiles from the top panel. This reduces cumulative CO_2 emissions up to the time they reach net zero and hence reduces future warming, with the impact emerging after 2030, such that the entire *likely* range of future warming is now (on this estimate of the climate response distribution) below 1.5°C in 2100.

All 1.5°C pathways that are also consistent with current emissions and radiative forcing trends show increasing total non-CO_2 radiative forcing over the coming decade, as emissions of cooling aerosol precursors are reduced, but there is greater variation between scenarios in non-CO_2 radiative forcing after 2030. The bottom panel in Figure 1.SM.12 shows the impact of varying future non-CO_2 radiative forcing (grey and purple lines in Figure 1.SM.11, bottom panel). Failure to reduce non-CO_2 forcing after 2030 means that a scenario that would otherwise be *likely* to give temperatures below 1.5°C in 2100 instead would only be *as likely as not* to give temperatures below 1.5°C in 2100. If non-CO_2 forcing were allowed to increase further (as it does in some scenarios due primarily to methane emissions), temperatures in 2100 would increase even further.

These changes demonstrate how future warming is determined by cumulative CO_2 emissions up to the time of net zero and non-CO_2 forcing in the decades immediately prior to that time.

Table 1.SM.1: Climate system properties in the versions of the FaIR model used in Figure 1.SM.12 and Figure 1.SM.13 as well as the FAQ 1.2, Figure 1 and Figure SPM 1. TCR, ECS and total anthropogenic forcing (F_{ant}) in 2011 are set consistent with corresponding distributions in AR5, TCRE is diagnosed from the model while aerosol forcing (F_{aer}) is adjusted to reproduce the corresponding percentile of human-induced warming in 2017.

Percentile	TCR (°C)	ECS (°C)	TCRE (°C TtC^{-1})	F_{aer} in 2011 (W m^{-2})	F_{ant} in 2011 (W m^{-2})
17%	1.0	1.5	0.9	-0.58	3.11
33%	1.4	2.0	1.3	-0.89	2.52
50%	1.75	2.6	1.5	-0.94	2.25
67%	2.1	3.3	1.7	-0.91	2.06
83%	2.5	4.5	2.1	-0.81	1.88

Carbon budget calculations in Chapter 2 are based on temperatures relative to 2006–2015, offset by a constant 0.87°C representing the best-estimate observed warming from pre-industrial to that decade. This has little effect on median estimates of future warming, because the median estimated human-induced warming to the decade 2006–2015 was close to the observed warming, but it does affect uncertainties: the uncertainty in 2030 warming relative to 2006–2015 is lower than the uncertainty in 2030 warming relative to pre-industrial because of the additional information provided by the current climate state and trajectory. This additional information is particularly important for the response to rapid mitigation scenarios in which peak warming occurs a small number of decades into the future (Millar et al, 2017a; Leach et al, 2018), highlighting the particular importance of a "seamless" approach to seasonal-to-decadal forecasting (Palmer et al, 2008; Boer et al, 2016) in the context of 1.5°C. The impact of this additional information is illustrated in Figure 1.SM.13, which is constructed identically to Figure 1.SM.12 but shows all time series expressed as anomalies relative to 2006–2015 rather than 1850–1900. The thick grey line at 0.63°C shows 1.5°C relative to pre-industrial expressed relative to this more recent decade. The central estimate is unaffected, as is the estimate of the time at which temperatures reach 1.5°C if the current rate of warming continues, but uncertainties are reduced. For example, the stylized pathway with CO_2 emissions reaching zero in 2040 is *likely* to limit warming to less than 0.63°C above 2006–2015, even though it just overshoots 1.5°C relative to 1850–1900.

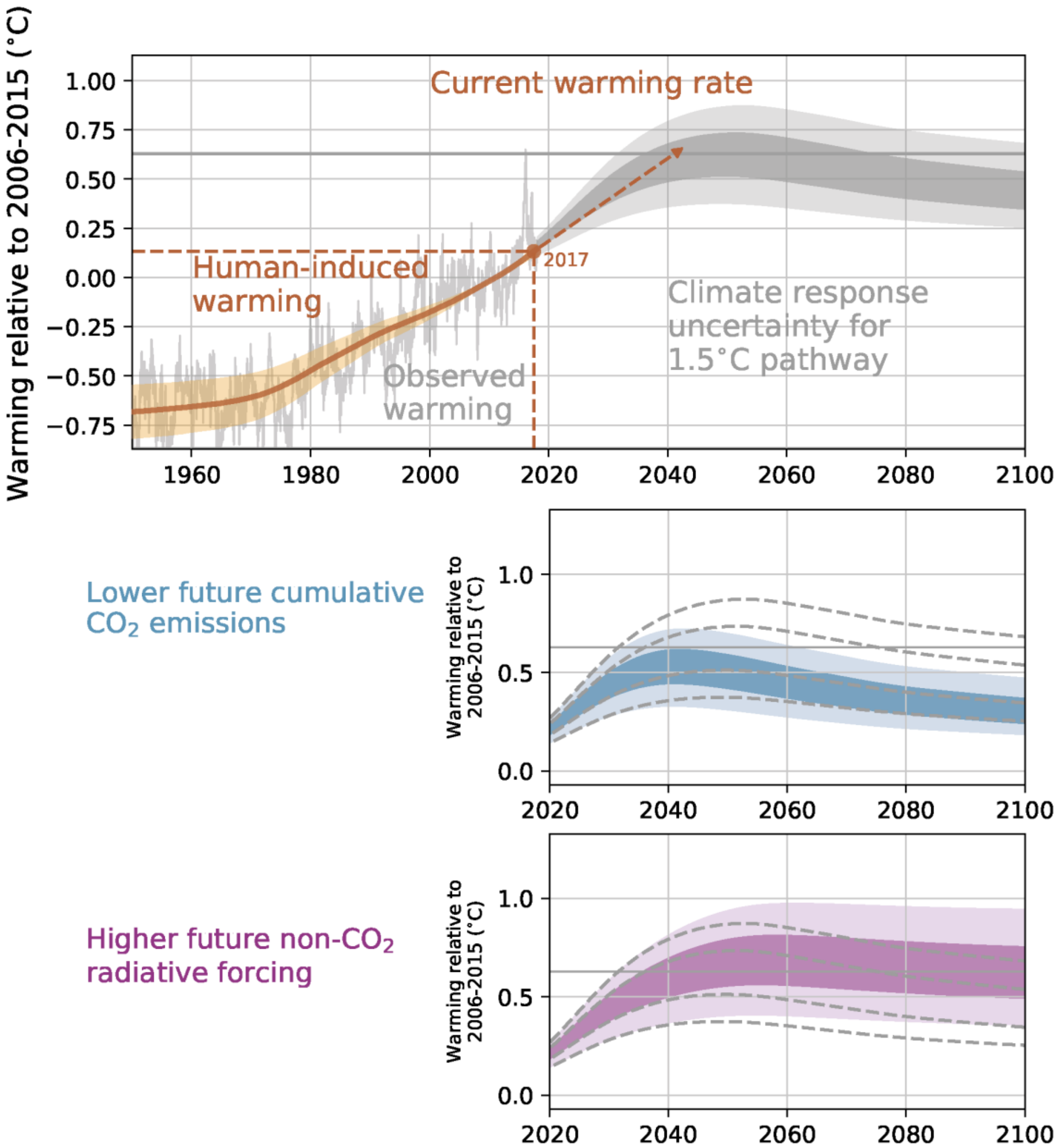

Figure 1.SM.13: As Figure 1.SM.12, but showing time series of observed and human-induced warming to 2017 and responses to stylized 1.5°C-consistent pathways relative to 2006–2015. The level of warming corresponding to 1.5°C relative to pre-industrial, given the central estimate of observed warming of 0.87°C from 1850–1900 to 2006–2015, is shown by the horizontal line at 0.63°C.

1.SM.7: Recent Trends in Emissions and Radiative Forcing

Figure 1.2 shows a small increase in the estimated rate of human-induced warming since 2000, reaching 0.2°C per decade in the past few years. This is attributed (Haustein et al., 2017) to recent changes in a range of climate forcers, reviewed in this section.

Most studies partition anthropogenic climate forcers into two groups by their lifetime. CO_2 and other long-lived greenhouse gases such as nitrous oxide, sulphur hexafluoride and some halogenated gases contribute to forcing over decades and centuries. Other halogenated gases, ozone precursors and aerosols are defined as short-lived climate forcers (SLCF) due to their residence time of less than several years in the atmosphere. Although methane is either considered as either a long-lived climate forcer or SLCF in published studies or reports (Bowerman et al., 2013; Estrada et al., 2013; Heede, 2014; Jacobson, 2010; Kerr, 2013; Lamarque et al., 2011; Saunois et al., 2016a; WMO, 2015), we assign methane as a SLCF for the purpose of climate assessment because its lifetime is comparable to or shorter than the thermal adjustment time of the climate system (Smith et al., 2012).

CO_2, methane and nitrous oxide are the most prominent contributors of anthropogenic radiative forcing, contributing 63%, 20% and 6% of the anthropogenic radiative forcing in 2016 respectively, as shown in Figure 1.SM.14a. Other long-lived greenhouse gases, including halogenated gases, and SLCFs such as tropospheric ozone are responsible of about 37% of the anthropogenic radiative forcing (figures add up to more than 100% because of the compensating effect of aerosols). Emissions such as black carbon and sulphur dioxide form different types of aerosol particles, which interact with both shortwave and longwave radiation and alter clouds. The resulting net aerosol radiative forcing is spatially inhomogeneous and uncertain. Globally averaged, it is estimated to have reduced the globally averaged anthropogenic forcing by about 27% (figures from Myhre et al. (2013), updated: uncertainties in aerosol forcing in particular are reviewed in AR5, and will be reassessed in AR6. This report continues to work from the AR5 estimates.).

As shown in Figure 1.SM.14b, the growth of CO_2 emissions has slowed since 2013 because of changes in the energy mix moving from coal to natural gas and increased renewable energy generation (Boden et al., 2015). This slowdown in CO_2 emission growth has occurred despite global GDP growth increasing to 3% y^{-1} in 2015, implying a structural shift away from carbon intensive activities (Jackson et al., 2015; Le Quéré et al., 2018). In 2016, however, anthropogenic CO_2 emissions are 36.18 $GtCO_2\,y^{-1}$ and have begun to grow again by 0.4% with respect to 2015 (Le Quéré et al., 2018). Global average concentration in 2016 has reached 402.3 ppm, which represents an increase of about 38.4% from 1850–1900 average (290.7 ppm).

Figure 1.SM.14c and d show that methane and nitrous oxide emissions, unlike $CO_{2,}$ have followed the most emission-intensive pathways assessed in AR5 (Saunois et al., 2016b; Thompson et al., 2014). However, current trends in methane and nitrous oxide emissions are not driven in the same way by human activities. About 60% of methane emissions are attributed to human activities (e.g. ruminants, rice agriculture, fossil fuel exploitation, landfills and biomass burning, Saikawa et al., 2014; Saunois et al., 2016b), while about 40% of nitrous oxide emissions are caused by various industrial processes and agriculture (Bodirsky et al., 2012; Thompson et al., 2014). It is thus more complicated to link rates of emissions to economic trends or energy demands than is the case with CO_2 (Peters et al., 2011).

Estimates of anthropogenic emissions for methane and nitrous oxide are uncertain as shown by the difference between datasets in Figure 1.4. EDGARV4.2 (JRC, 2011) estimates and US–EPA projections give a global amount of methane emission ranging between 392.87 and 378.29 $TgCH_4y^{-1}$ in 2016, an increase of 0.6–1% compared to 2015. However, livestock emissions in these databases are considered to be underestimated (Wolf et al., 2017). Similar uncertainties exist for anthropogenic N_2O emissions, for which only US–EPA projections are available. According to US–EPA projections, anthropogenic N_2O emissions reached 11.2 $TgN_2O\ y^{-1}$ in 2016, an increase of 1% on 2015. Anthropogenic CH_4 and N_2O emissions also appear to respond to major economic crises.

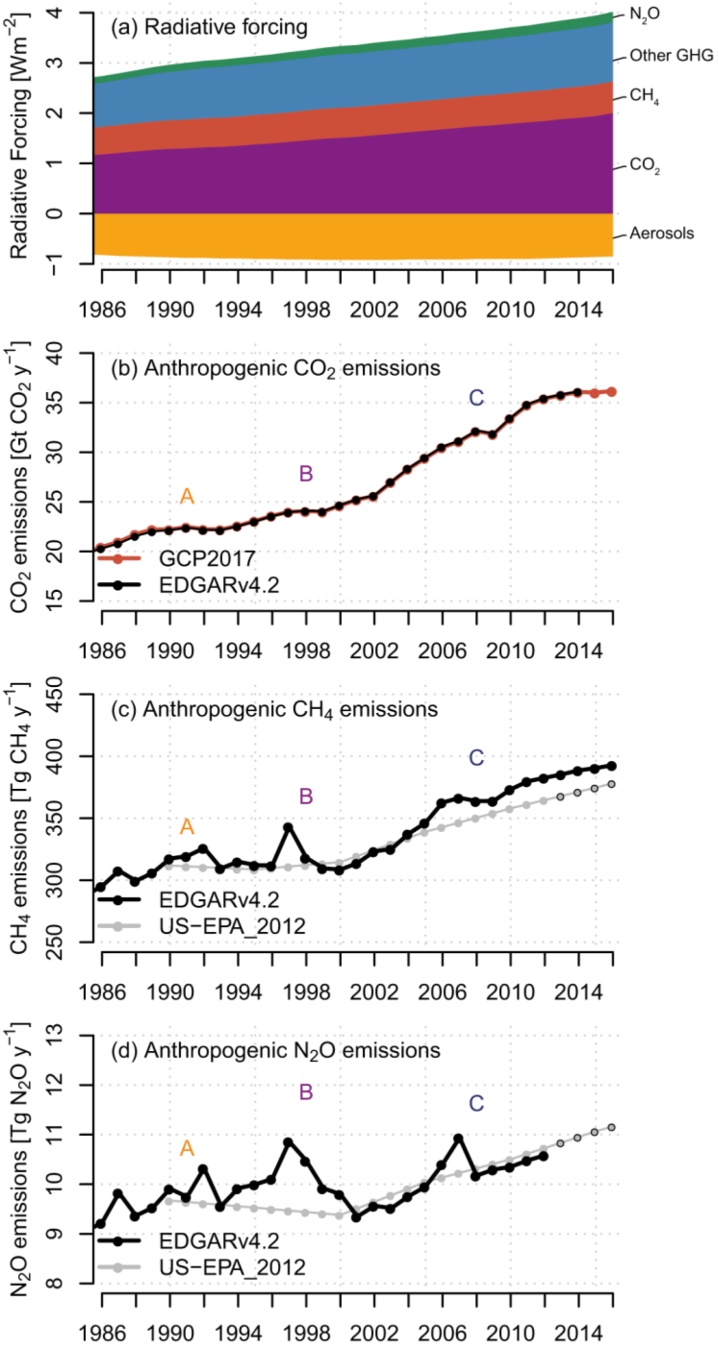

Figure 1.SM.14: Time series of (a) anthropogenic radiative forcing, (b) CO_2, (c) methane (CH_4) and (d) nitrous oxide emissions for the period 1986–2016. Anthropogenic radiative forcing data is from Myhre et al., (2013), extended from 2011 until the end of 2017 with greenhouse gas data from Dlugokencky and Tans (2016), updated radiative forcing approximations for greenhouse gases (Etminan et al., 2016) and extended aerosol forcing following Myhre et al. (2017). Bar graph shows the sum of different forcing agents. Anthropogenic CO_2 emissions are from the Global Carbon Project (GCP2017; Le Quéré et al., 2018) and EDGAR (Joint Research Centre, 2011) datasets. Anthropogenic emissions of CH_4 and N_2O (e) are estimated from EDGAR (JRC, 2011) and the US Environmental Protection Agency (EPA, 1990). The letters A, B, and C indicate dates of economic crises (A: former Soviet Union; B: Asian financial crisis; C: global financial crisis), which are reported following the methodology of (Peters et al., 2011).

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2.SM Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development – Supplementary Material

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Note: this version is subject to final lay out and proof reading.

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2.SM.1 Part 1

2.SM.1.1 Geophysical Relationships and Constraints

2.SM.1.1.1 Reduced-complexity climate models

The 'Model for the Assessment of Greenhouse Gas Induced Climate Change' (MAGICC6, Meinshausen et al., 2011a), is a reduced-complexity carbon cycle, atmospheric composition and climate model that has been widely used in prior IPCC Assessments and policy literature. This model is used with its parameter set as identical to that employed in AR5 for backwards compatibility. This model has been shown to match temperature trends very well compared to CMIP5 models (Collins et al., 2013; Clarke et al., 2014).

The 'Finite Amplitude Impulse Response' (FAIRv1.3, Smith et al., 2018) model is similar to MAGICC but has even simpler representations of the carbon cycle and some atmospheric chemistry. Its parameter sets are based on AR5 physics with updated methane radiative forcing (Etminan et al., 2016). The FAIR model is a reasonable fit to CMIP5 models for lower emissions pathways but underestimates the temperature response compared to CMIP5 models for RCP8.5 (Smith et al., 2018). It has been argued that its near-term temperature trends are more realistic than MAGICC (Leach et al., 2018).

The MAGICC model is used in this report to classify the different pathways in terms of temperature thresholds and its results are averaged with the FAIR model to support the evaluation of the non-CO_2 forcing contribution to the remaining carbon budget. The FAIR model is less established in the literature but can be seen as being more up to date in regards to its radiative forcing treatment. It is used in this report to help assess uncertainty in the pathway classification approach and to support the carbon budget evaluation (Chapter 2, Section 2.2 and 2.SM.1.1.2).

This section analyses geophysical differences between FAIR and MAGICC to help provide confidence in the assessed climate response findings of the main report (Sections 2.2 and 2.3).

There are structural choices in how the models relate emissions to concentrations and effective radiative forcing. There are also differences in their ranges of climate sensitivity, their choice of carbon cycle parameters, and how they are constrained, even though both models are consistent with AR5 ranges. Overall, their temperature trends are similar for the range of emission trajectories (Figure 2.1 of the main report). However, differences exist in their near-term trends, with MAGICC exhibiting stronger warming trends than FAIR (see Figure 2.SM.1). Leach et al. (2018) also note that that MAGICC warms more strongly than current warming rates. By adjusting FAIR parameters to match those in MAGICC, more than half the difference in mean near-term warming trends can be traced to parameter choices. The remaining differences are due to choices regarding model structure (Figure 2.SM.1).

A structural difference exists in the way the models transfer from the historical period to the future. The setup of MAGICC used for AR5 uses a parametrization that is constrained by observations of hemispheric temperatures and ocean heat uptake, as well as assessed ranges of radiative forcing consistent with AR4 (Meinshausen et al., 2009). From 1765 to 2005 the setup used for AR5 bases forcing on observed concentrations and uses emissions from 2006. It also ramps down the magnitude of volcanic forcing from 1995 to 2000 to give zero forcing in future scenarios, and solar forcing is fixed at 2009 values in the future. In contrast, FAIR produces a constrained set of parameters from emissions runs over the historic period (1765–2017) using both natural and anthropogenic forcings, and then uses this set to run the emissions model with only anthropogenic emissions for the full period of analysis (1765–2110). Structural choices in how aerosol, CH_4 and N_2O are implemented in the model are apparent (see Figure 2.SM.2). MAGICC has a weaker CH_4 radiative forcing, but a stronger total aerosol effective radiative forcing that is close to the AR4 best estimate of -1.2 Wm^{-2} for the total aerosol radiative forcing (Forster et al., 2007). As a result, its forcing is larger than either FAIR or the AR5 best estimate (Figure 2.SM.2), although its median aerosol forcing is well within the IPCC range (Myhre et al., 2013). The difference in N_2O forcings between the models result both from a slightly downwards-revised radiative forcing estimate for N_2O in Etminan et al. (2016) and the treatment of how the models account for natural emissions and atmospheric lifetime of N_2O. The stronger aerosol forcing and its stronger recovery in MAGICC has the largest effect on near-term trends, with CH_4

and N_2O also contributing to stronger warming trends in the MAGICC model.

The transient climate response to cumulative carbon emissions (TCRE) differences between the models are an informative illustration of their parametric differences (Figure 2.SM.3). In the setups used in this report, FAIR has a TCRE median of 0.38°C (5–95% range of 0.25°C to 0.57°C) per 1000 GtO_2 and MAGICC a TCRE median of 0.47°C (5–95% range of 0.13°C to 1.02°C) per 1000 $GtCO_2$. When directly used for the estimation of carbon budgets, this would make the remaining carbon budgets considerably larger in FAIR compared to MAGICC. As a result, rather than to use their budgets directly, this report bases its budget estimate on the AR5 TCRE *likely* (greater than 16–84%) range of 0.2°C to 0.7°C per 1000 $GtCO_2$ (Collins et al., 2013) (see Section 2.SM.1.1.2).

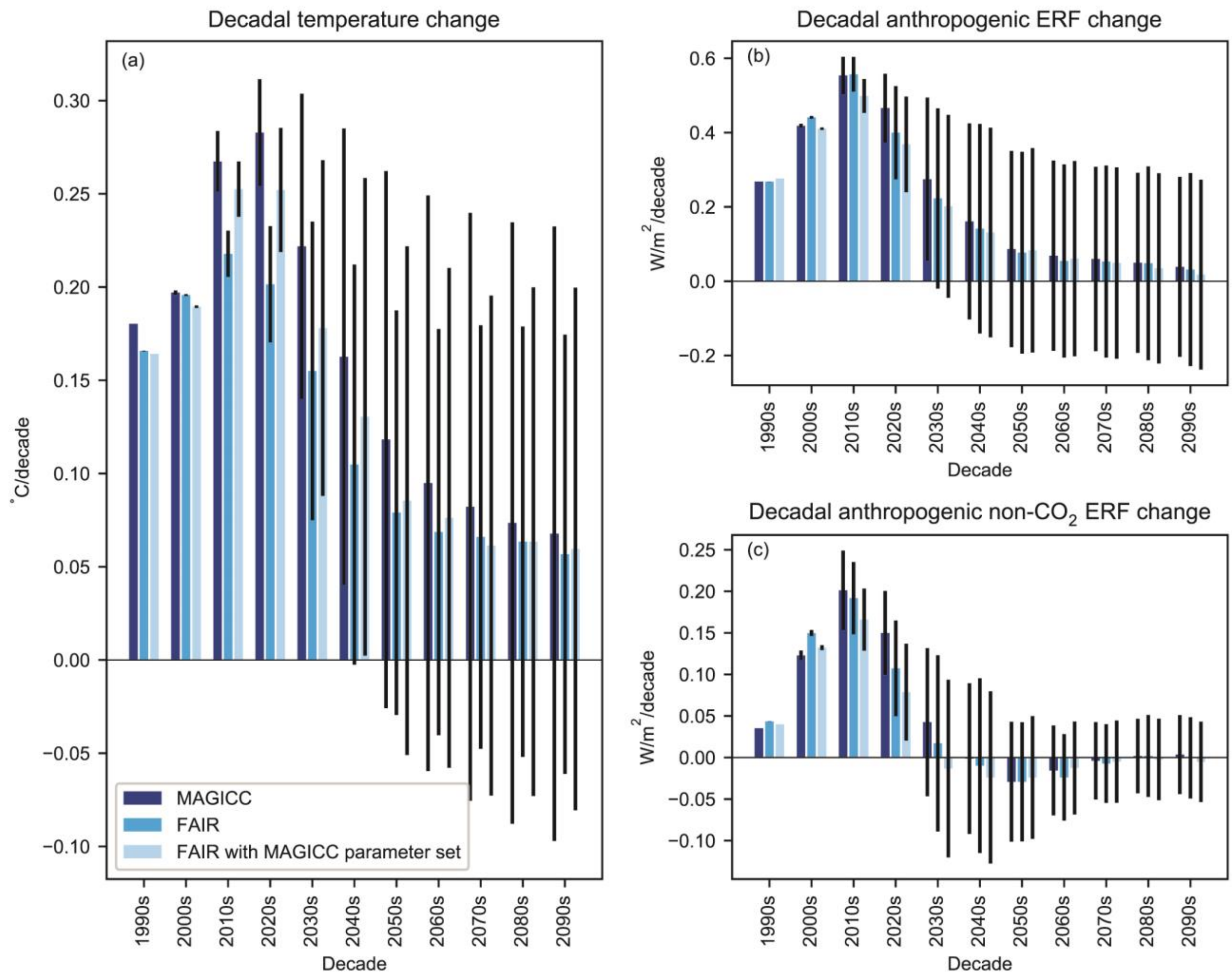

Figure 2.SM.1: Warming rates per decade for MAGICC (dark blue), FAIR (sky blue) and FAIR matching the MAGICC parameter set (light blue) for the scenario dataset used in this report. These bars represent the mean of regression slopes taken over each decade (years 0 to 9) for scenario median temperature changes, over all scenarios. The black bars show the standard deviation over the set of scenarios.

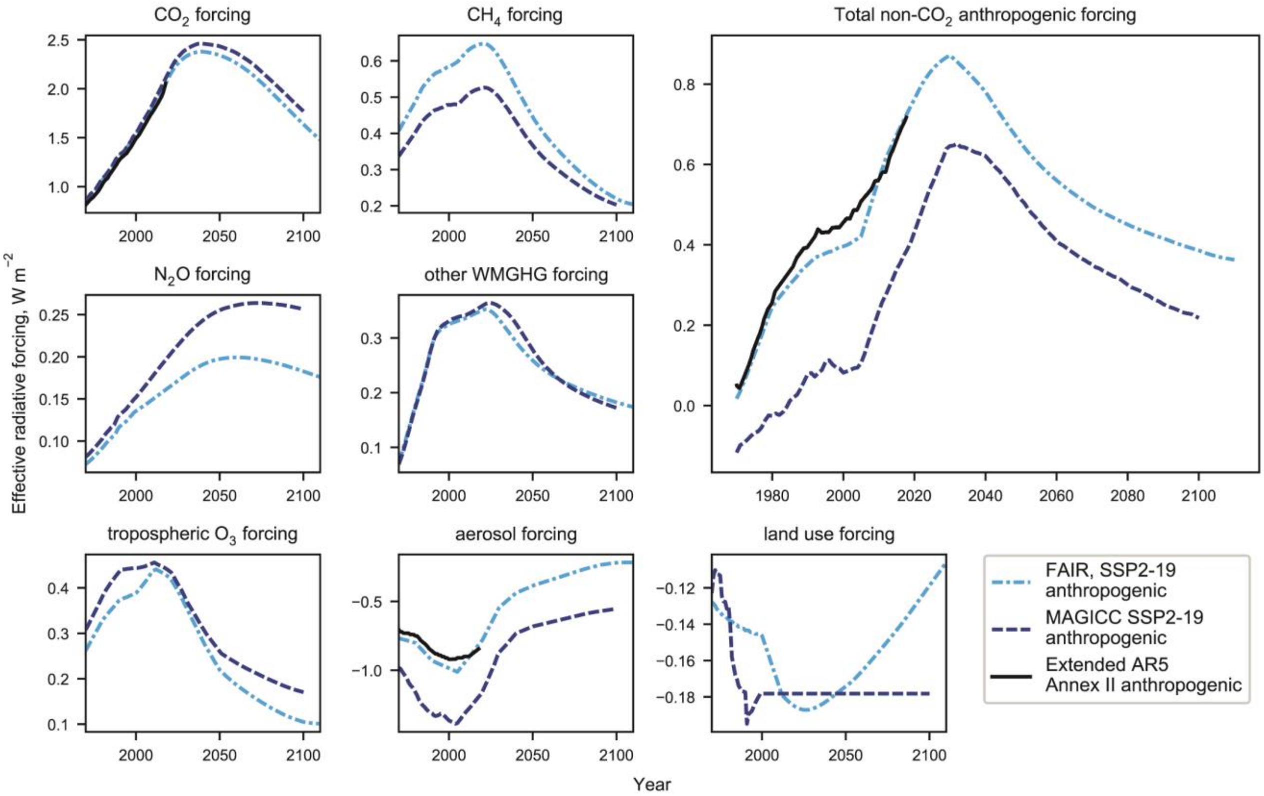

Figure 2.SM.2: Time series of MAGICC (dark blue dashed) and FAIR (sky blue dash-dotted) effective radiative forcing for an example emission scenario for the main forcing agents where the models exhibit differences. AR5 data is from Myhre et al. (2013), extended from 2011 until the end of 2017 with greenhouse gas data from NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/), updated radiative forcing approximations for greenhouse gases (Etminan et al., 2016) and extended aerosol forcing following (Myhre et al., 2017).

The summary assessment is that both models exhibit plausible temperature responses to emissions. It is too premature to say that either model may be biased. As MAGICC is more established in the literature than FAIR and has been tested against CMIP5 models, the classification of scenarios used in this report is based on MAGICC temperature projections. There is *medium confidence* in this classification and the likelihoods used at the boundaries could prove to underestimate the probability of staying below given temperatures thresholds if near-term temperatures in the applied setup of MAGICC turn out to be warming too strongly. However, neither model accounts for possible permafrost melting in their setup used for this report (although MAGICC does have a setting that would allow this to be included (Schneider von Deimling et al., 2012, 2015)), so biases in MAGICC could cancel in terms of their effect on long-term temperature targets. The veracity of these reduced-complexity climate models is a substantial knowledge gap in the overall assessment of pathways and their temperature thresholds.

The differences between FAIR and MAGICC have a substantial effect on their remaining carbon budgets (see Figure 2.SM.3), and the strong near-term warming in the specific MAGICC setup applied here (Leach et al., 2018) may bias its results to smaller remaining budgets (green line on Figure 2.SM.3). Likewise, the relatively small TCRE in FAIR (compared to AR5) might bias its results to higher remaining budgets (orange line on Figure 2.SM.3). Rather than using the entire model response, only the contribution of non-CO_2 warming from each model is used, using the method discussed next.

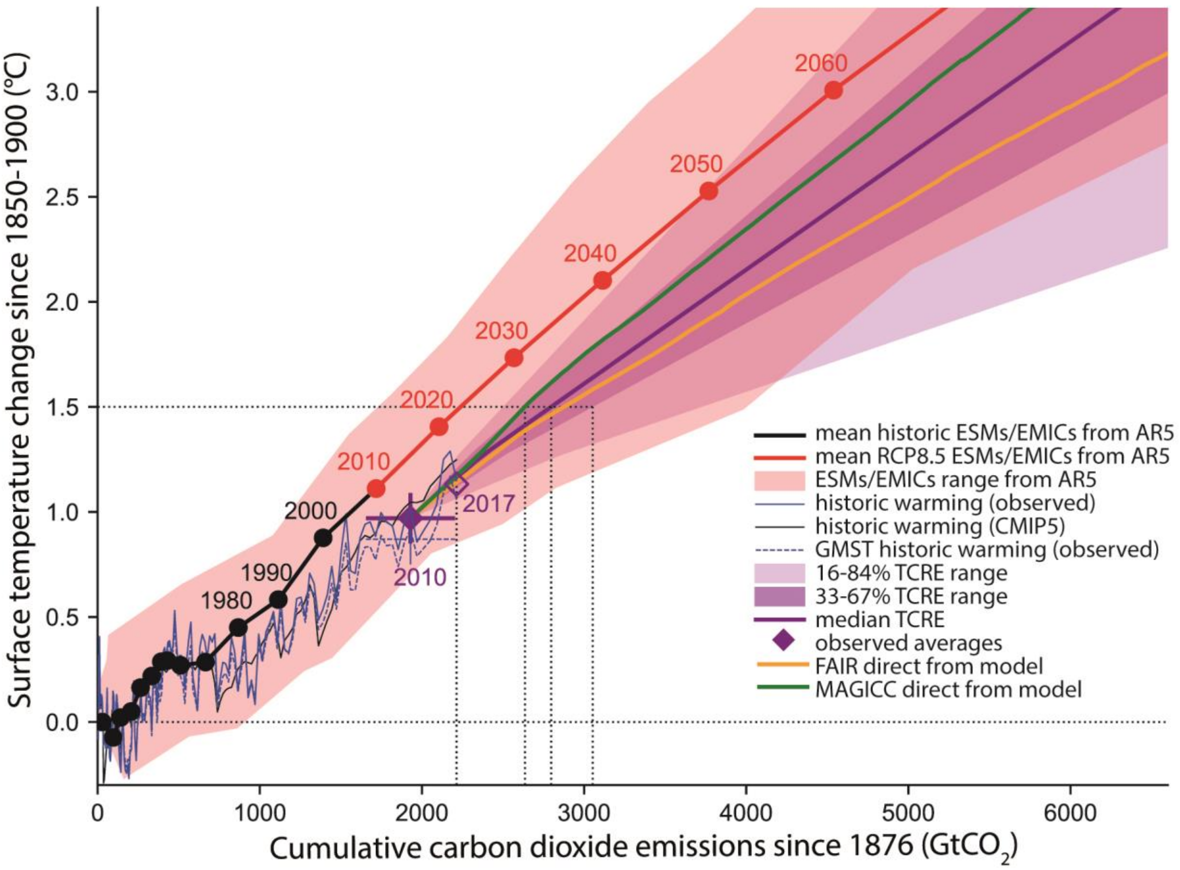

Figure 2.SM.3: This figure follows Figure 2.3 of the main report but with two extra lines showing FAIR (orange) and MAGICC (green) results separately. These additional lines show the full model response averaged across all scenarios and geophysical parameters.

2.SM.1.1.2 Methods for Assessing Remaining Carbon Budgets

First, the basis for the median remaining carbon budget estimate is described based on MAGICC and FAIR non-CO_2 warming contributions. This is then compared to a simple analysis approach. Lastly, the uncertainty analysis is detailed.

2.SM.1.1.2.1 Median remaining carbon budget basis

This assessment employs historical net cumulative CO_2 emissions reported by the Global Carbon Project (Le Quéré et al., 2018). They report 2170 ± 240 $GtCO_2$ emitted between 1 January 1876 and 31 December 2016. Annual CO_2 emissions for 2017 are estimated at about 42 ± 3 $GtCO_2\,yr^{-1}$ (Le Quéré et al., 2018) (Version 1.3 accessed 22 May 2018). From 1 Jan 2011 until 31 December 2017, an additional 290 $GtCO_2$ (270–310 $GtCO_2$, 1σ range) have been emitted (Le Quéré et al., 2018).

In WG1 AR5, TCRE was assessed to have a likely range of 0.22°C to 0.68°C per 1000 $GtCO_2$. The middle of this range (0.45°C per 1000 $GtCO_2$) is taken to be the best estimate, although no best estimate was explicitly defined (Collins et al., 2013; Stocker et al., 2013).

TCRE is diagnosed from integrations of climate models forced with CO_2 emissions only. However, the influence of other climate forcers on global temperatures should also be taken into account (see Figure 3 in Knutti and Rogelj (2015).

The reference non-CO_2 temperature contribution (RNCTC) is defined as the median future warming due to non-CO_2 radiative forcing until the time of net zero CO_2 emissions. The RNCTC is then removed from predefined levels of future peak warming (ΔT_{peak}) between 0.3°C to 1.2°C. The CO_2-only carbon budget is subsequently computed for this revised set of warming levels ($\Delta T_{\mathrm{peak}} - RNCTC$).

In FAIR, the RNCTC is defined as the difference in temperature between two experiments, one where all anthropogenic emissions are included and one where only CO_2 emissions are included, using the constrained parameter set. Parallel integrations with matching physical parameters are performed for the suite of 205 scenarios in which CO_2 emissions become net zero during the 21st century. The non-CO_2 warming from a 2006–2015 average baseline is evaluated at the time in which CO_2 emissions become net zero. A linear regression between peak temperature relative to 2006–2015 and non-CO_2 warming relative to 2006–2015 at the time of net zero emissions is performed over the set of 205 scenarios (Figure 2.SM.4). The RNCTC acts to reduce the ΔT_{peak} by an amount of warming caused by non-CO_2 agents, which also takes into account warming effects of non-CO_2 forcing on the carbon cycle response. In the MAGICC model the non-CO_2 temperature contribution is computed from the non-CO_2 effective radiative forcing time series for the same 205 scenarios, using the AR5 impulse response function (Myhre et al., 2013). As in FAIR, the RNCTC is then calculated from a linear regression of non-CO_2 temperature change against peak temperature.

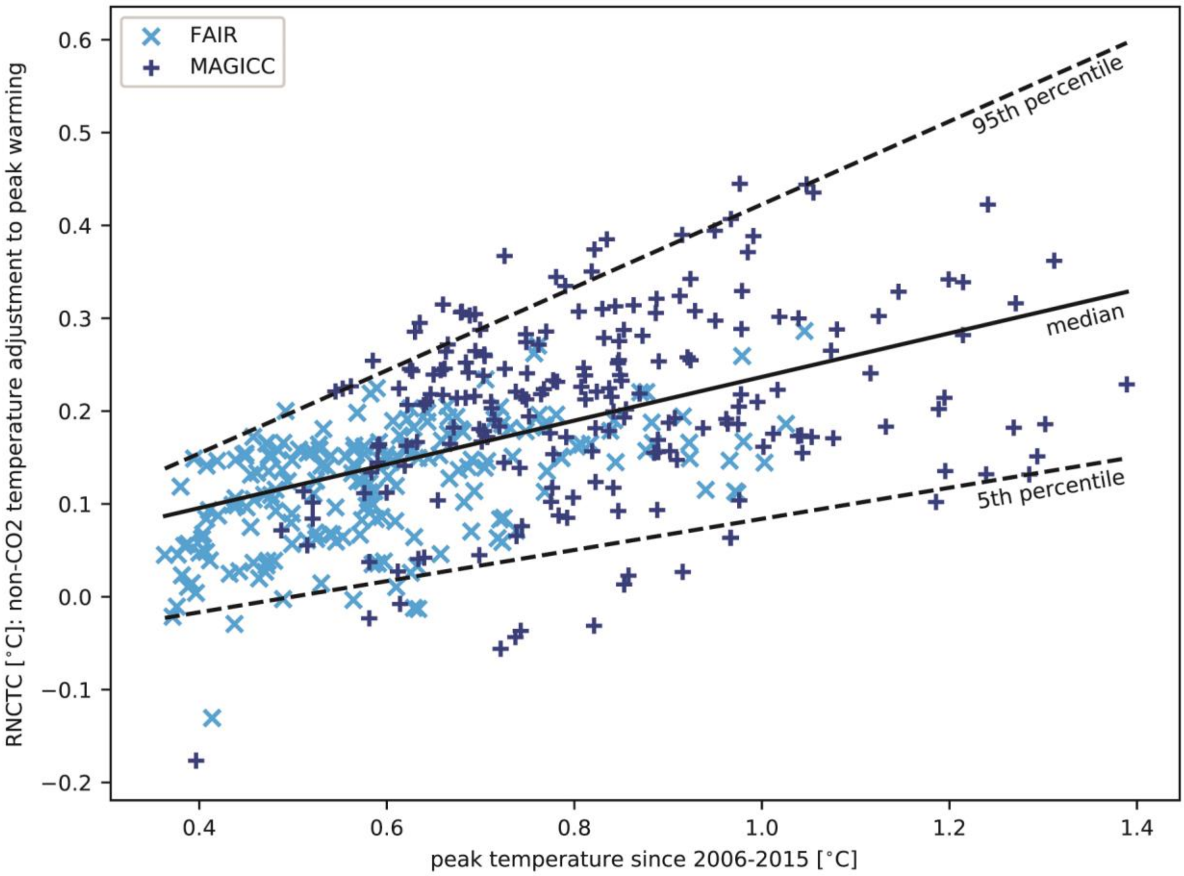

Figure 2.SM.4: Relationship of RNCTC with peak temperature in the FAIR and MAGICC models. The black line is the linear regression relationship between peak temperature and RNCTC. The dashed lines show the quantile regressions at the 5th and 95th percentile.

Table 2.SM.1 presents the CO_2-only budgets for different levels of future warming assuming both a normal and a log-normal TCRE distribution, where the overall distribution matches the AR5 *likely* TCRE range of 0.2°C to 0.7°C per 1000 $GtCO_2$. Table 2.SM.2 presents the RNCTC values for different levels of future warming and how they affect the remaining carbon budget for the individual models assuming the normal distribution of TCRE. These are then averaged and rounded to give the numbers presented in the main chapter (Table 2.2). The budgets are taken with respect to the 2006–2015 baseline for temperature and from 1 January 2018 for cumulative emissions. In the main report (Section 2.2), as well as in Table 2.SM.1, the estimates account for cumulative CO_2 emissions between the start of 2011 and the end of 2017 of about 290 $GtCO_2$.

Table 2.SM.1: Remaining CO_2-only budget in $GtCO_2$ from 1 January 2018 for different levels of warming from 2006–2015 for normal and log-normal distributions of TCRE based on the AR5 likely range. 290 $GtCO_2$ have been removed to account for emissions between the start of 2011 and the end of 2017. Additional global warming is expressed as changes in global near-surface air temperature.

CO_2-Oonly Remaining Budgets ($GtCO_2$)	Normal Distribution			Log-Normal Distribution		
	TCRE 0.35°C per 1000 $GtCO_2$	TCRE 0.45°C per 1000 $GtCO_2$	TCRE 0.55°C per 1000 $GtCO_2$	TCRE 0.30°C per 1000 $GtCO_2$	TCRE 0.38°C per 1000 $GtCO_2$	TCRE 0.50°C per 1000 $GtCO_2$
Additional warming from 2006–2015 (°C)	TCRE 33%	TCRE 50%	TCRE 67%	TCRE 33%	TCRE 50%	TCRE 67%
0.3	571	376	253	709	487	315
0.4	859	598	434	1042	746	517
0.5	1146	820	615	1374	1005	718
0.6	1433	1042	796	1707	1265	920
0.7	1720	1264	977	2040	1524	1122
0.8	2007	1486	1158	2373	1783	1323
0.9	2294	1709	1339	2706	2042	1525
1	2581	1931	1520	3039	2301	1726
1.1	2868	2153	1701	3372	2560	1928
1.2	3156	2375	1882	3705	2819	2130

Table 2.SM.2: Remaining carbon dioxide budget from 1 January 2018 reduced by the effect of non-CO_2 forcers. Budgets are for different levels of warming from 2006–2015 for a normal distribution of TCRE based on the AR5 *likely* range of 0.2°C to 0.7°C per 1000 $GtCO_2$. 290 $GtCO_2$ have been removed to account for emissions between the start of 2011 and the end of 2017. This method employed the RNCTC estimates of non-CO_2 temperature change until the time of net zero CO_2 emissions. Additional global warming is expressed as changes in global near-surface air temperature.

Remaining Carbon Budgets ($GtCO_2$) Additional warming from 2006–2015 (°C)	**MAGICC RNCTC** (°C)	MAGICC TCRE 33%	MAGICC TCRE 50%	MAGICC TCRE 67%	**FAIR RNCTC** (°C)	FAIR TCRE 33%	FAIR TCRE 50%	FAIR TCRE 67%
0.3	0.14	184	77	9	0.06	402	245	146
0.4	0.15	434	270	166	0.08	629	421	289
0.5	0.16	681	461	322	0.10	856	596	433
0.6	0.18	930	654	480	0.12	1083	772	576
0.7	0.19	1177	845	635	0.14	1312	949	720
0.8	0.20	1427	1038	793	0.16	1539	1125	863
0.9	0.22	1674	1229	948	0.18	1766	1300	1006
1	0.23	1924	1422	1106	0.20	1993	1476	1149
1.1	0.24	2171	1613	1262	0.22	2223	1653	1294
1.2	0.26	2421	1806	1419	0.25	2449	1829	1437

2.SM.1.1.2.2 Checks on approach

A simple approach to infer the carbon budget contribution from non-CO_2 forcers has been proposed based on global warming potential and is found to hold for a wide range of mitigation scenarios (Allen et al., 2018) This is based on an empirical relationship between peak temperature, TCRE, cumulative CO_2 emissions (G_{CO2}), non-CO_2 forcing ($\Delta F_{\text{non-CO2}}$) and the Absolute Global Warming Potential of CO_2 ($\text{AGWP}_H(\text{CO}_2)$) over time horizon H, taken to be 100 years:

$$\Delta T_{\text{peak}} \approx \text{TCRE} \times \left(G_{\text{CO2}} + \Delta F_{\text{non-CO2}} \times (H/\text{AGWP}_H(\text{CO}_2))\right) \quad (2.SM.1)$$

This method reduces the budget by an amount proportional to the change in non-CO_2 forcing. To determine this non-CO_2 forcing contribution, a reference non-CO_2 forcing contribution (RNCFC) is estimated from the MAGICC and FAIR runs. The RNCFC is defined as $\Delta F_{\text{non-CO2}}$ in Equation 2.SM.1, which is a watts-per-metre-squared difference in the non-CO_2 effective radiative forcing between the 20 years before peak temperature is reached and 1996–2015. This provides an estimate of the non-CO_2 forcing contribution to the change in carbon budget. A similar calculation was performed for aerosol forcing in isolation (ΔF_{aer}) and the results showed that the weakening aerosol forcing is the largest contributor to the smaller carbon budget, compared to the CO_2-only budget. $AGWP_{100}$ values are taken from AR5 (Myhre et al., 2013) and the resultant remaining carbon budgets are given in Table 2.SM.3. This method reduces the remaining carbon budget by 1091 $GtCO_2$ per Wm^{-2} of non-CO_2 effective radiative forcing (with a 5% to 95% range of 886 to 1474 $GtCO_2$). These results show good agreement to those computed with the RNCTC method from Table 2.SM.2, adding confidence to both methods. The RNCFC method is approximate and the choice of periods to use for averaging forcing is somewhat subjective, so the RNCTC is preferred over the RNCFC for this assessment.

Table 2.SM.3: Remaining carbon dioxide budgets from 1 January 2018 reduced by the effect of non-CO_2 forcers calculated by using a simple empirical approach based on non-CO_2 forcing (RNCFC) computed by the FAIR model. Budgets are for different levels of warming from 2006–2015 and for a normal distribution of TCRE based on the AR5 likely range of 0.2°C to 0.7°C per 1000 $GtCO_2$. 290 $GtCO_2$ have been removed to account for emissions between the start of 2011 and the end of 2017. Additional global warming is expressed as changes in global near-surface air temperature.

Remaining Budgets ($GtCO_2$) Additional warming from 2006-2015 (°C)	**FAIR RNCFC** (Wm^{-2})	**FAIR** TCRE 33%	TCRE 50%	TCRE 67%
0.3	0.191	363	168	45
0.4	0.211	629	368	204
0.5	0.232	893	568	362
0.6	0.253	1157	767	521
0.7	0.273	1423	967	680
0.8	0.294	1687	1166	838
0.9	0.314	1952	1366	997
1	0.335	2216	1566	1155
1.1	0.356	2481	1765	1314
1.2	0.376	2746	1965	1473

2.SM.1.1.2.3 Uncertainties

Uncertainties are explored across several lines of evidence and summarized in Table 2.2 of the main report. Expert judgement is used to estimate the overall uncertainty and to estimate the amount of 100 $GtCO_2$ that is removed to account for possible missing permafrost and wetlands feedbacks (see Section 2.2). Irrespective of the metric used to estimate global warming, the uncertainty in global warming since pre-industrial levels (1850–1900) up to the 2006–2015 reference period as estimated in Chapter 1 is of the order of 0.1°C (*likely* range). This uncertainty affects how close warming since pre-industrial levels is to the 1.5°C and 2°C limits. To illustrate this impact, the remaining carbon budgets for a range of future warming thresholds between 0.3°C and 1.2°C above present-day are analysed. The uncertainty in 2006–2015 warming compared to 1850–1900 relates to a ±250 $GtCO_2$ uncertainty in carbon budgets for a best-estimate TCRE.

A measure of the uncertainty due to variations in the consistent level of non-CO_2 mitigation at the time that net zero CO_2 emissions are reached in pathways is analysed by a quantile regression of each pathway's median peak temperature against its corresponding median RNCTC (evaluated with the FAIR model), for the 5th, median and 95th percentiles of scenarios. A variation of approximately ±0.1°C around the median RNCTC is observed for median peak temperatures between 0.3° and 1.2°C above the 2006–2015 mean. This variation is equated to a ±250 $GtCO_2$ uncertainty in carbon budgets for a median TCRE estimate of about

0.45°C per 1000 $GtCO_2$. An uncertainty of −400 to +200 $GtCO_2$ is associated with the non-CO_2 forcing and response. This is analysed from a regression of 5th and 95th percentile RNCTC against 5th and 95th percentile peak temperature calculated with FAIR, compared to the median RNCTC response. These uncertainty contributions are shown in Table 2.2 in the main chapter

The effects of uncertainty in the TCRE distribution were gauged by repeating the remaining budget estimate for a log-normal distribution of the AR5 *likely* range. This reduces the median TCRE from 0.45°C per 1000 $GtCO_2$ to 0.38°C per 1000 $GtCO_2$ (see Table 2.SM.1.1). Table 2.SM.1.4 presents these remaining budgets and shows that around 200 $GtCO_2$ would be added to the budget by assuming a log-normal *likely* range. The assessment and evidence supporting either distribution is discussed in the main chapter.

Table 2.SM.4: Remaining carbon dioxide budget from 1 January 2018 reduced by the effect of non-CO_2 forcers. Numbers are differences between estimates of the remaining budget made with the log-normal distribution compared to that estimated with a normal distribution of TCRE based on the AR5 *likely* range (see Table 2.SM.1). 290 $GtCO_2$ have been removed to account for emissions between the start of 2011 and the end of 2017. This method employed the FAIR model RNCTC estimates of non-CO_2 temperature response. Additional global warming is expressed as changes in global near-surface air temperature.

Remaining Budgets ($GtCO_2$)	Log-Normal Minus Normal TCRE Distribution		
Additional warming from 2006–2015 (°C)	TCRE 33%	TCRE 50%	TCRE 67%
0.3	110	89	50
0.4	146	118	66
0.5	183	148	82
0.6	219	177	99
0.7	255	207	115
0.8	291	236	131
0.9	328	265	148
1	364	294	164
1.1	400	324	180
1.2	436	353	197

Uncertainties in past CO_2 emissions ultimately impact estimates of the remaining carbon budgets for 1.5°C or 2°C. Uncertainty in CO_2 emissions induced by past land-use and land-cover changes contribute most, representing about 240 $GtCO_2$ from 1870 to 2017. Yet this uncertainty is substantially reduced when deriving cumulative CO_2 emissions from a recent period. The cumulative emissions from the 2006–2015 reference period to 2017 used in this report are approximately 290 $GtCO_2$ with an uncertainty of about 20 $GtCO_2$.

2.SM.1.2 Integrated Assessment Models

The set of process-based integrated assessment models (IAMs) that provided input to this assessment is not fundamentally different from those underlying the IPCC AR5 assessment of transformation pathways (Clarke et al., 2014), and an overview of these integrated modelling tools can be found there. However, there have been a number of model developments since AR5, in particular improving the sectoral detail of IAMs (Edelenbosch et al., 2017b), the representation of solar and wind energy (Creutzig et al., 2017; Johnson et al., 2017; Luderer et al., 2017; Pietzcker et al., 2017), the description of bioenergy and food production and associated sustainability trade-offs (Havlík et al., 2014; Weindl et al., 2017; Bauer et al., 2018; Frank et al., 2018), the representation of a larger portfolio of carbon dioxide removal (CDR) technologies (Chen and Tavoni, 2013; Marcucci et al., 2017; Strefler et al., 2018b), the accounting of behavioural change (van Sluisveld et al., 2016; McCollum et al., 2017; van Vuuren et al., 2018) and energy demand developments (Edelenbosch et al., 2017a, c; Grubler et al., 2018), and the modelling of sustainable development implications (van Vuuren et al., 2015; Bertram et al., 2018), for example, relating to water use (Bonsch et al., 2014; Hejazi et al., 2014; Fricko et al., 2016; Mouratiadou et al., 2016, 2018), access to clean water and sanitation (Parkinson et al., in press), materials use (Pauliuk et al., 2017), energy access (Cameron et al., 2016), air quality (Rao et al., 2017), and bioenergy use and food security (Frank et al., 2017; Humpenöder et al., 2018). Furthermore, since AR5, a harmonized model documentation of IAMs and underlying assumptions has been established within the framework of the EU ADVANCE project, which is available at http://www.fp7-advance.eu/content/model-documentation.

2.SM.1.2.1 Short Introduction to the Scope, Use and Limitations of Integrated Assessment Modelling

IAMs are characterized by a dynamic representation of coupled systems, including energy, land, agricultural, economic and climate systems (Weyant, 2017). They are global in scope and typically cover sufficient sectors and sources of greenhouse gas emissions to project anthropogenic emissions and climate change and identify the consistency of different pathways with long-term goals of limiting warming to specific levels (Clarke et al., 2014). IAMs can be applied in a forward-looking manner to explore internally consistent socio-economic–climate futures, often extrapolating current trends under a range of assumptions or using counterfactual "no policy" assumptions to generate baselines for subsequent climate policy analysis. They can also be used in a back-casting mode to explore the implications of climate policy goals and climate targets for systems transitions and near-to-medium-term action. In most IAM-based studies, both applications of IAMs are used concurrently (Clarke et al., 2009; Edenhofer et al., 2010; Luderer et al., 2012; Kriegler et al., 2014, 2015b, 2016; Riahi et al., 2015; Tavoni et al., 2015). Sometimes the class of IAMs is defined more narrowly as the subset of integrated pathway models with an economic core and equilibrium assumptions on supply and demand, although non-equilibrium approaches to integrated assessment modelling exist (Guivarch et al., 2011; Mercure et al., 2018). IAMs with an economic core describe consistent price–quantity relationships, where the "shadow price" of a commodity generally reflects its scarcity in the given setting. To this end, the price of greenhouse gas emissions emerging in IAMs reflects the restriction of future emissions imposed by a warming limit (Cross-Chapter Box 5 in Chapter 2, Section 2.SM.1.2.2). Such a price needs to be distinguished from suggested levels of emissions pricing in multidimensional policy contexts that are adapted to existing market environments and often include a portfolio of policy instruments (Chapter 2, Section 2.5.2) (Stiglitz et al., 2017).

Detailed-process IAMs that describe energy–land transitions on a process level are critically different from stylized cost–benefit IAMs that aggregate such processes into stylized abatement cost and climate damage relationships to identify cost-optimal responses to climate change (Weyant, 2017). A key component of cost–benefit IAMs is the representation of climate damages, which has been debated in the recent literature (Revesz et al., 2014; Cai et al., 2015; Lontzek et al., 2015; Burke et al., 2016; Stern, 2016). In the meantime, new approaches and estimates for improving the representation of climate damages are emerging (Dell et al., 2014; Burke et al., 2015, 2018; Hsiang et al., 2017) (Chapter 3, Box 3.6). A detailed discussion of the strengths and weaknesses of cost-benefit IAMs is provided in AR5 (Clarke et al., 2014; Kolstad et al., 2014; Kunreuther et al., 2014) (see also Cross-Chapter Box 5 in Chapter 2). The assessment of 1.5°C-consistent pathways in Chapter 2 relies entirely on detailed-process IAMs. These IAMs have so far rarely attempted a full representation of climate damages on socio-economic systems, mainly for three reasons: a focus on the implications of mitigation goals for transition pathways (Clarke et al., 2014); the computational challenge to represent, estimate and integrate the complete range of climate impacts on a process level (Warszawski et al., 2014); and ongoing fundamental research on measuring the breadth and depth of how biophysical climate impacts can affect societal welfare (Dennig et al., 2015; Adler et al., 2017; Hallegatte and Rozenberg, 2017). While some detailed-process IAMs account for climate impacts in selected sectors, such as agriculture (Stevanović et al., 2016), these IAMs do not take into account climate impacts as a whole in their pathway modelling. The 1.5°C and 2°C-consistent pathways available to this report hence do not reflect climate impacts and adaptation challenges below 1.5°C and 2°C, respectively. Pathway modelling to date is also not able to identify socio-economic benefits of avoided climate damages between 1.5°C-consistent pathways and pathways leading to higher warming levels. These limitations are important knowledge gaps (Chapter 2, Section 2.6) and are a subject of active research. Due to these limitations, the use of the integrated pathway literature in this report is concentrated on the assessment of mitigation action to limit warming to 1.5°C, while the assessment of impacts and adaptation challenges in 1.5°C-warmer worlds relies on a different body of literature (see Chapters 3 to 5).

The use of IAMs for climate policy assessments has been framed in the context of solution-oriented assessments (Edenhofer and Kowarsch, 2015; Beck and Mahony, 2017). This approach emphasizes the exploratory nature of integrated assessment modelling to produce scenarios of internally consistent, goal-oriented futures. They describe a range of pathways that achieve long-term policy goals, and at the same time highlight trade-offs and opportunities associated with different courses of action. This literature has noted, however, that such exploratory knowledge generation about future pathways cannot be completely isolated from societal discourse, value formation and decision making and therefore needs to be reflective of its performative character (Edenhofer and Kowarsch, 2015; Beck and Mahony, 2017). This suggests an interactive approach which engages societal values and user perspectives in the pathway production process. It also requires transparent documentation of IAM frameworks and applications to enable users to contextualize pathway results in the assessment process. Integrated assessment modelling results assessed in AR5 were documented in Annex II of AR5 (Krey et al., 2014b), and this Supplementary Material aims to document the IAM frameworks that fed into the assessment of 1.5°C-consistent pathways in Chapter 2 of this report. It draws upon increased efforts to extend and harmonize IAM documentations[1] (Section 2.SM.1.2.5). Another important aspect for the use of IAMs in solution-oriented assessments is building trust in their applicability and validity. The literature has discussed approaches to IAM evaluation (Schwanitz, 2013; Wilson et al., 2017), including model diagnostics (Kriegler et al., 2015a; Wilkerson et al., 2015; Craxton et al., 2017) and comparison with historical developments (Wilson et al., 2013; van Sluisveld et al., 2015).

2.SM.1.2.2 Economics and Policy Assumptions in IAMs

Experiments with IAMs most often create scenarios under idealized policy conditions which assume that climate change mitigation measures are undertaken where and when they are the most effective (Clarke et al., 2014). Such 'idealized implementation' scenarios assume that a global price on GHG emissions is implemented across all countries, all economic sectors, and rises over time through 2100 in a way that will minimize discounted economic costs. The emissions price reflects marginal abatement costs and is often used as a proxy of climate policy costs (see Chapter 2, Section 2.5.2). Scenarios developed under these assumptions are often referred to as 'least-cost' or 'cost-effective' scenarios because they result in the lowest aggregate global mitigation costs when assuming that global markets and economies operate in a frictionless, idealized way (Clarke et al., 2014; Krey et al., 2014b). However, in practice, the feasibility (see Cross-Chapter Box 3 in Chapter 1) of a global carbon pricing mechanism deserves careful consideration (see Chapter 4, Section 4.4). Scenarios from idealized conditions provide benchmarks for policymakers, since deviations from the idealized approaches capture important challenges for socio-technical and economic systems and resulting climate outcomes.

Model experiments diverging from idealized policy assumptions aim to explore the influence of policy barriers to implementation of globally cost-effective climate change mitigation, particularly in the near term. Such scenarios are often referred to as 'second-best' scenarios. They include, for instance, (i) fragmented policy regimes in which some regions champion immediate climate mitigation action (e.g., by 2020) while other regions join this effort with a delay of one or more decades (Clarke et al., 2009; Blanford et al., 2014; Kriegler et al., 2015b), (ii) prescribed near-term mitigation efforts (until 2020 or 2030) after which a global climate target is adopted (Luderer et al., 2013, 2016; Rogelj et al., 2013b; Riahi et al., 2015), or (iii) variations in technology preferences in mitigation portfolios (Edenhofer et al., 2010; Luderer et al., 2012; Tavoni et al., 2012; Krey et al., 2014a; Kriegler et al., 2014; Riahi et al., 2015; Bauer et al., 2017, 2018). Energy transition governance adds a further layer of potential deviations from cost-effective mitigation pathways and has been shown to lead to potentially different mitigation outcomes (Trutnevyte et al., 2015; Chilvers et al., 2017; Li and Strachan, 2017). Governance factors are usually not explicitly accounted for in IAMs.

Pricing mechanisms in IAMs are often augmented by assumptions about regulatory and behavioural climate

[1]http://www.fp7-advance.eu/content/model-documentation

policies in the near- to mid-term (Bertram et al., 2015; van Sluisveld et al., 2016; Kriegler et al., 2018). The choice of GHG price trajectory to achieve a pre-defined climate goal varies across IAMs and can affect the shape of mitigation pathways. For example, assuming exponentially increasing CO_2 pricing to stay within a limited CO_2 emissions budget is consistent with efficiency considerations in an idealized economic setting but can lead to temporary overshoot of the carbon budget if carbon dioxide removal (CDR) technologies are available. The pricing of non-CO_2 greenhouse gases is often pegged to CO_2 pricing using their global warming potentials (mostly GWP_{100}) as exchange rates (see Cross-Chapter Box 2 in Chapter 1). This leads to stringent abatement of non-CO_2 gases in the medium- to long-term, but also incentivizes continued compensation of these gases by CDR even after their full abatement potential is exploited, thus contributing to the pattern of peaking and declining temperatures in many mitigation pathways.

The choice of economic discount rate is usually reflected in the increase of GHG pricing over time and thus also affects the timing of emissions reductions. For example, the deployment of capital-intensive abatement options like renewable energy can be pushed back by higher discount rates. IAMs make different assumptions about the discount rate, with many of them assuming a social discount rate of ca. 5% per year (Clarke et al., 2014). In a survey of modelling teams contributing scenarios to the database for this assessment, discount rate assumptions varied between 2% yr^{-1} and 8% yr^{-1} depending on whether social welfare considerations or the representation of market actor behaviour is given larger weight. Some IAMs assume fixed charge rates that can vary by sector, taking into account the fact that private actors require shorter time horizons to amortize their investment. The impact of the choice of discount rate on mitigation pathways is underexplored in the literature. In general, the choice of discount rate is expected to have a smaller influence on low-carbon technology deployment schedules for tighter climate targets, as they leave less flexibility in the timing of emissions reductions. However, the introduction of large-scale CDR options might increase sensitivity again. It was shown, for example, that if a long-term CDR option like direct air capture with CCS (DACCS) is introduced in the mitigation portfolio, lower discount rates lead to more early abatement and less CDR deployment (Chen and Tavoni, 2013). If discount rates vary across regions, with higher costs of capital in developing countries, industrialized countries mitigate more and developing countries less, resulting in higher overall mitigation costs compared to a case with globally uniform discounting (Iyer et al., 2015). More work is needed to study the sensitivity of the deployment schedule of low-carbon technologies to the choice of the discount rate. However, as overall emissions reductions need to remain consistent with the choice of climate goal, mitigation pathways from detailed process-based IAMs are still less sensitive to the choice of discount rate than cost-optimal pathways from cost-benefit IAMs (see Box 6.1 in Clarke et al., 2014) which have to balance near-term mitigation with long-term climate damages across time (Nordhaus, 2007; Dietz and Stern, 2008; Kolstad et al., 2014; Pizer et al., 2014) (see Cross-Chapter Box 5 in Chapter 2).

2.SM.1.2.3 Technology Assumptions and Transformation Modelling

Although model-based assessments project drastic near-, medium- and long-term transformations in 1.5°C scenarios, projections also often struggle to capture a number of hallmarks of transformative change, including disruption, innovation, and non-linear change in human behaviour (Rockström et al., 2017). Regular revisions and adjustments are standard for expert and model projections, for example, to account for new information such as the adoption of the Paris Agreement. Costs and deployment of mitigation technologies will differ in reality from the values assumed in the full-century trajectories of the model results. CCS and nuclear provide examples of where real-world costs have been higher than anticipated (Grubler, 2010; Rubin et al., 2015), while solar PV is an example where real-world costs have been lower (Creutzig et al., 2017; Figueres et al., 2017; Haegel et al., 2017). Such developments will affect the low-carbon transition for achieving stringent mitigation targets. This shows the difficulty of adequately estimating social and technological transitions and illustrates the challenges of producing scenarios consistent with a quickly evolving market (Sussams and Leaton, 2017).

Behavioural and institutional frameworks affect the market uptake of mitigation technologies and socio-technical transitions (see Chapter 4, Section 4.4). These aspects co-evolve with technology change and determine, among others, the adoption and use of low-carbon technologies (Clarke et al., 2014), which in turn can affect both the design and performance of policies (Kolstad et al., 2014; Wong-Parodi et al., 2016).

Predetermining technological change in models can preclude the examination of policies that aim to promote disruptive technologies (Stanton et al., 2009). In addition, knowledge creation, networks, business strategies, transaction costs, microeconomic decision-making processes and institutional capacities influence (no-regret) actions, policy portfolios and innovation processes (and vice versa) (Mundaca et al., 2013; Lucon et al., 2014; Patt, 2015; Wong-Parodi et al., 2016; Geels et al., 2017); however, they are difficult to capture in equilibrium or cost-minimization model-based frameworks (Laitner et al., 2000; Wilson and Dowlatabadi, 2007; Ackerman et al., 2009; Ürge-Vorsatz et al., 2009; Mundaca et al., 2010; Patt et al., 2010; Brunner and Enting, 2014; Grubb et al., 2014; Patt, 2015; Turnheim et al., 2015; Geels et al., 2017; Rockström et al., 2017). It is argued that assessments that consider greater end-user heterogeneity, realistic market behaviour, and end-use technology details can address a more realistic and varied mix of policy instruments, innovation processes and transitional pathways (Ürge-Vorsatz et al., 2009; Mundaca et al., 2010; Wilson et al., 2012; Lucon et al., 2014; Li et al., 2015; Trutnevyte et al., 2015; Geels et al., 2017; McCollum et al., 2017). So-called 'rebound' effects in which behavioural changes partially offset policies, such as consumers putting less effort into demand reduction when efficiency is improved, are captured to a varying, and in many cases only limited, degree in IAMs.

There is also substantial variation in mitigation options represented in IAMs (see Section 2.SM.1.2.6) which depend on the one hand on the constraints of individual modelling frameworks and on the other hand on model development decisions influenced by modellers' beliefs and preferences (Chapter 2, Section 2.3.1.2). Further limitations can arise on the system level. For example, trade-offs between material use for energy versus other uses are not fully captured in many IAMs (e.g., petroleum for plastics, biomass for material substitution). An important consideration for the analysis of mitigation potential is the choice of baseline. For example, IAMs often assume, in line with historical experience, that economic growth leads to a reduction in local air pollution as populations become richer (i.e., an environmental Kuznets curve) (Rao et al., 2017). In such cases, the mitigation potential is small because reference emissions that take into account this economic development effect are already low in scenarios that see continued economic development over their modelling time horizon. Assumptions about reference emissions are important because high reference emissions lead to high perceived mitigation potentials and potential overestimates of the actual benefit, while low reference emissions lead to low perceived benefits of mitigation measures and thus less incentive to address these important climate- and air-pollutants (Gschrey et al., 2011; Shindell et al., 2012; Amann et al., 2013; Rogelj et al., 2014; Shah et al., 2015; Velders et al., 2015).

2.SM.1.2.4 Land Use and Bioenergy Modelling in IAMs

The IAMs used in the land-use assessment in this chapter and that are based on the SSPs (Popp et al., 2017; Riahi et al., 2017) all include an explicit land model.[2] These land models calculate the supply of food, feed, fibre, forestry, and bioenergy products (see also Chapter 2, Box 2.1). The supply depends on the amount of land allocated to the particular good, as well as the yield for the good. Different IAMs have different means of calculating land allocation and different assumptions about yield, which is typically assumed to increase over time, reflecting technological progress in the agricultural sector (see Popp et al., 2014 for examples). In these models, the supply of bioenergy (including BECCS) depends on the price and yield of bioenergy, the policy environment (e.g., any taxes or subsidizes affecting bioenergy profits), and the demand for land for other purposes. Dominant bioenergy feedstocks assumed in IAMs are woody and grassy energy crops (second-generation biomass) in addition to residues. Some models implement a "food first" approach, where food demands are met before any land is allocated to bioenergy. Other models use an economic land allocation approach, where bioenergy competes with other land uses depending on profitability. Competition between land uses depend strongly on socio-economic drivers such as population growth and food demand, and are typically varied across scenarios. When comparing global bioenergy yields from IAMs with the bottom-up literature, care must be taken that assumptions are comparable. An in-depth assessment of the land-use components of IAMs is outside the scope of this Special Report.

[2] There are other IAMs that do not include an explicit land-use representation. These models use supply curves to represent bioenergy; that is, they have an exogenously specified relationship between the quantity of bioenergy supplied and the price of bioenergy. These models include land-use change (LUC) emissions in a similar manner, with the amount of emissions depending on the amount of bioenergy supplied. For some of these models, LUC emissions are assumed to be zero, regardless of the amount of bioenergy.

In all IAMs that include a land model, the land-use change emissions associated with these changes in land allocation are explicitly calculated. Most IAMs use an accounting approach to calculating land-use change emissions, similar to Houghton et al. (2012). These models calculate the difference in carbon content of land due to the conversion from one type to another and then allocate that difference across time in some manner. For example, increases in forest cover will increase terrestrial carbon stock, but that increase may take decades to accumulate. If forestland is converted to bioenergy, however, those emissions will enter the atmosphere more quickly.

IAMs often account for carbon flows and trade flows related to bioenergy separately. That is, IAMs may treat bioenergy as "carbon neutral" in the energy system, in that the carbon price does not affect the cost of bioenergy. However, these models will account for any land-use change emissions associated with the land conversions needed to produce bioenergy. Additionally, some models will separately track the carbon uptake from growing bioenergy and the emissions from combusting bioenergy (assuming it is not combined with CCS).

Table 2.SM.5: Land-use type descriptions as reported in pathways (adapted from the SSP database: https://tntcat.iiasa.ac.at/SspDb/)

Land Use Type	**Description/Examples**
Energy crops	Land dedicated to second-generation energy crops. (e.g., switchgrass, *Miscanthus*, fast-growing wood species)
Other crops	Food and feed/fodder crops
Pasture	Pasture land. All categories of pasture land – not only high-quality rangeland. Based on FAO definition of "permanent meadows and pastures"
Managed forest	Managed forests producing commercial wood supply for timber or energy but also afforestation (note: woody energy crops are reported under "energy crops")
Natural forest	Undisturbed natural forests, modified natural forests and regrown secondary forests
Other natural land	Unmanaged land (e.g., grassland, savannah, shrubland, rock ice, desert), excluding forests

2.SM.1.2.5 Contributing Modelling Framework Reference Cards

For each of the contributing modelling frameworks a reference card has been created highlighting the key features of the model. These reference cards are either based on information received from contributing modelling teams upon submission of scenarios to the SR1.5 database, or alternatively drawn from the ADVANCE IAM wiki documentation, available at http://www.fp7-advance.eu/content/model-documentation, and updated. These reference cards are provided in part 2 of this Supplementary Material.

2.SM.1.2.6 Overview of Mitigation Measures in Contributed IAM Scenarios

Table 2.SM.6: Overview of the representation of mitigation measures in the integrated pathway literature, as submitted to the database supporting this report. Levels of inclusion have been elicited directly from contributing modelling teams by means of a questionnaire. The table shows the reported data. Dimensions of inclusion are explicit versus implicit, and endogenous or exogenous. An implicit level of inclusion is assigned when a mitigation measure is represented by a proxy like a marginal abatement cost curve in the agriculture, forestry and other land-use (AFOLU) sector without modelling individual technologies or activities. An exogenous level of inclusion is assigned when a mitigation measure is not part of the dynamics of the modelling framework but can be explored through alternative scenarios.

Levels of Inclusion

	Explicit	Implicit
Endogenous	A	C
Exogenous	B	D

E: Not represented by model

Levels of Inclusion / Model Names	AIM	BET	COPPE-COFFEE	C-ROADS	DNE21+	GCAM 4.2	GEM-E3 3.0	GENESYSmod 1.0	GRAPE 1.0	IEA ETP	IEA WEM	IMACLIM 1.1	IMACLIM NLU 1.0	IMAGE 3.0	MERGE-ETL 6.0	MESSAGE-GLOBIOM	MESSAGEix-GLOBIOM	POLES	REMIND-MAgPIE	Shell WEM v1	WITCH
Demand-Side Measures																					
Energy efficiency improvements in energy end-uses (e.g., appliances in buildings, engines in transport, industrial processes)	A	A	C	D	A	D	B	D	B	A	A	A	A	A	C	C	B	C	C	B	C
Electrification of transport demand (e.g., electric vehicles, electric rail)	A	A	A	D	A	A	B	A	A	A	A	A	A	A	C	A	A	A	A	B	A
Electrification of energy demand for buildings (e.g., heat pumps, electric/induction stoves)	A	A	A	D	A	A	B	A	D	A	A	C	C	A	C	A	A	A	A	B	C
Electrification of industrial energy demand (e.g., electric arc furnace, heat pumps, electric boilers, conveyor belts, extensive use of motor control, induction heating, industrial use of microwave heating)	A	A	C	D	A	C	D	A	D	A	A	C	C	A	C	A	A	C	C	B	C
CCS in industrial process applications (cement, pulp and paper, iron steel, oil and gas refining, chemicals)	A	E	A	D	D	A	E	E	C	A	A	E	E	A	E	A	A	E	A	B	C
Higher share of useful energy in final energy (e.g., insulation of buildings, lighter weight vehicles, combined heat and power generation, district heating, etc.)	C	E	C	D	A	C	D	D	C	B	B	D	D	A	C	A	A	A	C	D	C
Reduced energy and service demand in **industry** (e.g., process innovations, better control)	C	C	C	D	C	C	C	D	D	B	B	C	C	B	C	C	B	B	C	C	C
Reduced energy and service demand in **buildings** (e.g., via behavioural change, reduced material and floor space demand, infrastructure and buildings configuration)	C	C	C	D	C	C	C	D	D	C	C	D	D	C	C	C	B	B	C	C	C
Reduced energy and service demand in **transport** (e.g., via behavioural change, new mobility business models, modal shift in individual transportation, eco-driving, car/bike-sharing schemes)	C	C	C	D	C	A	B	D	B	B	C	C	C	C	C	C	B	B	C	C	C
Reduced energy and service demand in **international transport** (international shipping and aviation)	A	E	A	D	D	A	C	E	B	B	B	C	C	C	C	B	B	A	D	C	C
Reduced material demand via higher resource efficiency, structural change, behavioural change and material substitution (e.g., steel and cement substitution, use of locally available building materials)	A	E	E	D	D	D	C	E	D	B	B	E	E	B	E	D	B	E	C	C	C

Levels of Inclusion	Explicit	Implicit
Endogenous	A	C
Exogenous	B	D
E	Not represented by model	

Levels of Inclusion / Model Names	AIM	BET	COPPE-COFFEE	C-ROADS	DNE21+	GCAM 4.2	GEM-E3 3.0	GENESYSmod 1.0	GRAPE 1.0	IEA ETP	IEA WEM	IMACLIM 1.1	IMACLIM NLU 1.0	IMAGE 3.0	MERGE-ETL 6.0	MESSAGE-GLOBIOM	MESSAGEix-GLOBIOM	POLES	REMIND-MAgPIE	Shell WEM v1	WITCH
Urban form (including integrated on-site energy, influence of avoided transport and building energy demand)	E	E	E	D	D	E	E	D	E	B	E	D	D	E	E	E	B	E	E	C	E
Switch from traditional biomass and solid fuel use in the residential sector to modern fuels, or enhanced combustion practices, avoiding wood fuel	D	A	A	D	D	B	E	A	A	A	A	E	E	A	E	A	A	B	B	C	A
Dietary changes, reducing meat consumption	A	E	E	D	D	A	E	E	B	E	E	E	B	B	E	B	B	B	B	E	E
Substitution of livestock-based products with plant-based products (cultured meat, algae-based fodder)	C	E	E	D	E	E	E	E	E	E	E	E	B	B	E	E	E	E	E	E	E
Food processing (e.g., use of renewable energies, efficiency improvements, storage or conservation)	C	E	E	D	E	E	E	E	E	C	C	E	E	E	E	B	B	E	D	E	E
Reduction of food waste (including reuse of food processing refuse for fodder)	B	E	E	D	E	D	E	E	E	E	E	E	D	B	E	B	B	E	B	E	E
Supply-Side Measures																					
Decarbonization of Electricity:																					
Solar photovoltaics (PV)	A	A	A	D	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Concentrated solar power (CSP)	E	E	A	D	E	A	E	A	E	A	A	A	A	A	A	A	A	A	A	A	A
Wind (on-shore and off-shore)	A	A	A	D	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydropower	A	A	A	D	A	A	B	A	A	A	A	A	A	B	A	A	A	A	A	A	A
Bioelectricity, including biomass co-firing	A	A	A	D	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Nuclear energy	A	A	A	D	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Advanced, small modular nuclear reactor designs (SMR)	E	E	A	D	E	A	E	E	E	C	C	E	E	E	A	E	E	E	E	C	E
Fuel cells (hydrogen)	E	E	A	D	A	A	E	A	A	A	A	E	E	A	A	A	A	A	A	A	A
CCS at coal- and gas-fired power plants	A	A	A	D	A	A	B	E	A	A	A	A	A	A	A	A	E	A	A	B	A
Ocean energy (including tidal and current energy)	E	E	E	D	E	E	D	A	E	A	A	E	E	E	E	E	E	A	E	A	E
High-temperature geothermal heat	A	B	A	D	A	A	D	E	A	A	A	E	E	B	E	A	A	A	E	C	E
Decarbonization of Non-Electric Fuels:																					
Hydrogen from biomass or electrolysis	E	A	A	D	A	A	E	A	A	A	C	E	E	A	A	A	A	A	A	A	E
1st generation biofuels	A	E	A	D	A	A	B	E	A	A	A	C	A	A	A	B	B	A	B	A	A
Second-generation biofuels (grassy or woody biomass to liquids)	A	A	A	D	A	A	B	A	A	A	A	E	A	A	A	A	A	A	A	A	A
Algae biofuels	E	E	A	D	E	E	E	C	E	E	C	E	E	E	E	E	E	E	E	A	E
Power-to-gas, methanization, synthetic fuels	E	C	A	D	A	E	E	A	E	E	B	E	E	E	A	A	A	E	E	E	E

Levels of Inclusion	Explicit	Implicit
Endogenous	A	C
Exogenous	B	D

E: Not represented by model

Levels of Inclusion / Model Names	AIM	BET	COPPE-COFFEE	C-ROADS	DNE21+	GCAM 4.2	GEM-E3 3.0	GENESYSmod 1.0	GRAPE 1.0	IEA ETP	IEA WEM	IMACLIM 1.1	IMACLIM NLU 1.0	IMAGE 3.0	MERGE-ETL 6.0	MESSAGE-GLOBIOM	MESSAGEix-GLOBIOM	POLES	REMIND-MAgPIE	Shell WEM v1	WITCH
Solar and geothermal heating	E	E	A	D	E	E	B	A	E	A	A	E	E	E	E	A	A	A	A	A	E
Nuclear process heat	E	E	E	D	E	E	E	E	E	A	A	E	E	E	E	A	A	E	E	C	E
Other Processes:																					
Fuel switching and replacing fossil fuels by electricity in end-use sectors (partially a demand-side measure)	A	A	C	D	A	A	B	A	A	A	A	C	C	A	C	A	A	A	A	A	A
Substitution of halocarbons for refrigerants and insulation	C	E	E	D	E	C	C	E	E	E	E	E	E	A	E	A	A	A	D	E	C
Reduced gas flaring and leakage in extractive industries	C	E	A	D	D	C	C	E	E	E	A	E	E	C	E	B	B	A	C	D	D
Electrical transmission efficiency improvements, including smart grids	B	E	C	D	A	E	E	E	E	B	B	E	E	B	C	E	E	E	E	B	E
Grid integration of intermittent renewables	E	E	C	D	A	C	E	C	D	A	A	E	E	C	C	C	C	A	A	D	C
Electricity storage	E	E	A	D	A	C	E	A	E	A	C	E	E	C	C	A	A	A	A	E	C
AFOLU Measures																					
Reduced deforestation, forest protection, avoided forest conversion	A	E	A	D	B	A	E	E	B	D	D	E	B	B	E	A	A	B	A	D	C
Forest management	C	E	E	D	E	C	E	E	C	D	D	E	D	B	E	A	A	B	E	D	C
Reduced land degradation, and forest restoration	C	E	D	D	E	E	E	E	C	D	D	E	E	B	E	E	E	B	E	D	E
Agroforestry and silviculture	E	E	D	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Urban and peri-urban agriculture and forestry	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Fire management and (ecological) pest control	C	E	D	D	E	C	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Changing agricultural practices that enhance soil carbon	C	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	B	E	D	E
Conservation agriculture	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	A	A	E	E	E	C
Increasing agricultural productivity	A	E	A	D	A	B	E	E	B	D	D	E	A	B	E	A	A	E	A	D	C
Methane reductions in rice paddies	C	E	C	D	C	C	C	E	C	D	D	E	C	C	E	A	A	B	C	D	C
Nitrogen pollution reductions (e.g., by fertilizer reduction, increasing nitrogen fertilizer efficiency, sustainable fertilizers)	C	E	C	D	C	C	C	E	E	D	D	E	A	C	E	A	A	B	C	D	C
Livestock and grazing management, for example, methane and ammonia reductions in ruminants through feeding management or feed additives, or manure management for local biogas production to replace traditional biomass use	C	E	C	D	C	C	C	E	C	D	D	E	A	C	E	A	A	B	C	D	C
Manure management	C	E	C	D	C	C	C	E	C	D	D	E	C	C	E	A	A	E	C	E	C
Influence on land albedo of land-use change	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	D	D	E

Levels of Inclusion	Explicit	Implicit
Endogenous	A	C
Exogenous	B	D
E	Not represented by model	

Model Names

Carbon Dioxide (Greenhouse Gas) Removal	AIM	BET	COPPE-COFFEE	C-ROADS	DNE21+	GCAM 4.2	GEM-E3 3.0	GENESYSmod 1.0	GRAPE 1.0	IEA ETP	IEA WEM	IMACLIM 1.1	IMACLIM NLU 1.0	IMAGE 3.0	MERGE-ETL 6.0	MESSAGE-GLOBIOM	MESSAGEix-GLOBIOM	POLES	REMIND-MAgPIE	Shell WEM v1	WITCH
Biomass use for energy production with carbon capture and sequestration (BECCS) (through combustion, gasification, or fermentation)	A	A	A	D	A	A	E	E	A	A	A	A	A	A	A	A	E	A	A	B	A
Direct air capture and sequestration (DACS) of CO_2 using chemical solvents and solid absorbents, with subsequent storage	E	E	E	D	E	E	E	E	E	E	E	E	E	E	A	E	E	E	A	E	E
Mineralization of atmospheric CO_2 through enhanced weathering of rocks	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Afforestation/Reforestation	A	E	A	C	A	A	E	E	A	E	E	E	B	B	E	A	A	B	A	D	A
Restoration of wetlands (e.g., coastal and peat-land restoration, blue carbon)	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Biochar	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Soil carbon enhancement, enhancing carbon sequestration in biota and soils, e.g. with plants with high carbon sequestration potential (also AFOLU measure)	E	E	E	D	E	E	E	E	E	E	E	E	D	E	E	A	A	B	C	E	E
Carbon capture and usage (CCU); bioplastics (bio-based materials replacing fossil fuel uses as feedstock in the production of chemicals and polymers), carbon fibre	E	E	E	D	E	C	E	E	E	A	B	E	E	A	E	E	E	E	E	A	E
Material substitution of fossil CO_2 with bio-CO_2 in industrial applications (e.g., the beverage industry)	E	E	E	D	E	C	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Ocean iron fertilization	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Ocean alkalinization	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Removing CH_4, N_2O and halocarbons via photocatalysis from the atmosphere	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E

2.SM.1.3 Overview of SR1.5 Scenario Database Collected for the Assessment in the Chapter

The scenario ensemble collected in the context of this report represents an ensemble of opportunity based on available published studies. The submitted scenarios cover a wide range of scenario types and thus allow exploration of a wide range of questions. For this to be possible, however, critical scenario selection based on scenario assumptions and setup is required. For example, as part of the SSP framework, a structured exploration of 1.5°C pathways was carried out under different future socioeconomic developments (Rogelj et al., 2018). This facilitates determining the fraction of successful (feasible) scenarios per SSPs (Table 2.SM.7), an assessment which cannot be carried out with a more arbitrary ensemble of opportunity.

Table 2.SM.7: Summary of models (with scenarios in the database) attempting to create scenarios with an end-of-century forcing of 1.9W m^{-2}, consistent with limiting warming to below 1.5°C in 2100, and related shared policy assumptions (SPAs). Notes: 1 = successful scenario consistent with modelling protocol; 0 = unsuccessful scenario; x = not modelled; 0* = not attempted because scenarios for a 2.6 W m^{-2} target were already found to be unachievable in an earlier study. The SSP3-SPA3 scenario for a more stringent 1.9 W m^{-2} radiative forcing target has thus not been attempted anew by many modelling teams. Marker implementations for all forcing targets within each SSP have been selected for representing a specific SSP particularly adequately and are indicated in blue. Source: (Rogelj et al., 2018).

Model	Methodology	Reported scenario				
		SSP1-SPA1	SSP2-SPA2	SSP3-SPA3	SSP4-SPA4	SSP5-SPA5
AIM	General equilibrium (GE)	1	1	0*	0	0
GCAM4	Partial equilibrium (PE)	1	1	X	0	1
IMAGE	Hybrid (system dynamic models and GE for agriculture)	1	1	0*	X	X
MESSAGE-GLOBIOM	Hybrid (systems engineering PE model)	1	1	0*	X	X
REMIND-MAgPIE	General equilibrium (GE)	1	1	X	X	1
WITCH-GLOBIOM	General equilibrium (GE)	1	1	0	1	0

2.SM.1.3.1 Configuration of SR1.5 Scenario Database

The Integrated Assessment Modelling Consortium (IAMC), as part of its ongoing cooperation with Working Group III of the IPCC, issued a call for submissions of scenarios of 1.5°C global warming and related scenarios to facilitate the assessment of mitigation pathways in this special report. This database is hosted by the International Institute for Applied Systems Analysis (IIASA) at http://data.ene.iiasa.ac.at/sr1p5/. Upon approval of this report, the database of scenarios underlying this assessment will also be published. Computer scripts and tools used to conduct the analysis and generate figures will also be available for download from that website.

2.SM.1.3.1.1 Criteria for submission to the scenario database

Scenarios submitted to the database were required to either aim at limiting warming to 1.5°C or 2°C in the long term, or to provide context for such scenarios, for example, corresponding Nationally Determined Contribution (NDC) and baseline scenarios without climate policy. Model results should constitute an emissions trajectory over time, with underlying socio-economic development until at least the year 2050 generated by a formal model such as a dynamic systems, energy–economy, partial or general equilibrium or integrated assessment model.

The end of the 21st century is referred to as “long term” in the context of this scenario compilation. For models with time horizons shorter than 2100, authors and/or submitting modelling teams were asked to explain how they evaluated their scenario as being consistent with 1.5°C in the long term. Ultimately, scenarios that only covered part of the 21st century could only be integrated into the assessment to a very limited degree, as they lacked the longer-term perspective. Submissions of emissions scenarios for individual regions and specific sectors were possible, but no such scenarios were received.

Each scenario submission required a supporting publication in a peer-reviewed journal that was accepted on 15 May 2018. Alternatively, the scenario must have been published by the same date in a report that has been determined by IPCC to be eligible grey literature (see Table 2.SM.9). As part of the submission process, the authors of the underlying modelling team agreed to the publication of their model results in this scenario database.

2.SM.1.3.1.2 Historical consistency analysis of submitted scenarios

Submissions to the scenario database were compared to the following data sources for historical periods to identify reporting issues.

Historical emissions database (CEDS)
Historical emissions imported from the *Community Emissions Data System (CEDS) for Historical Emissions* (http://www.globalchange.umd.edu/ceds/) have been used as a reference and for use in figures (van Marle et al., 2017; Hoesly et al., 2018). Historical N_2O emissions, which are not included in the CEDS database, are compared against the RCP database (http://tntcat.iiasa.ac.at/RcpDb/).

Historical IEA World Energy Balances and Statistics
Aggregated historical time series of the energy system from the IEA World Energy Balances and Statistics (revision 2017) were used as a reference for validation of submitted scenarios and for use in figures.

2.SM.1.3.1.3 Verification of completeness and harmonization for climate impact assessment

Categorizing scenarios according to their long-term warming impact requires reported emissions time series until the end of the century of the following species: CO_2 from energy and industrial processes, methane, nitrous oxide and sulphur. The long-term climate impact could not be assessed for scenarios not reporting these species, and these scenarios were hence not included in any subsequent analysis.

For the diagnostic assessment of the climate impact of each submitted scenario, reported emissions were harmonized to historical values (base year 2010) as provided in the RCP database by applying an additive offset, which linearly decreased until 2050. For non-CO_2 emissions where this method resulted in negative values, a multiplicative offset was used instead. Emissions other than the required species that were not reported explicitly in the submitted scenario were filled from RCP2.6 (Meinshausen et al., 2011b; van Vuuren et al., 2011) to provide complete emissions profiles to MAGICC and FAIR (see Section 2.SM.1.1).

The harmonization and completion of non-reported emissions was only applied to the diagnostic assessment as input for the climate impact using MAGICC and FAIR. All figures and analysis used in the chapter analysis are based on emissions as reported by the modelling teams, except for column "Cumulative CO_2 emissions, harmonized" in Table 2.SM.12.

2.SM.1.3.1.4 Validity assessment of historical emissions for aggregate Kyoto greenhouse gases

The AR5 WGIII report assessed Kyoto greenhouse gases (GHG) in 2010 to fall in the range of 44.5–53.5 $GtCO_2e\ yr^{-1}$ using the GWP_{100} metric from the IPCC Second Assessment Report (SAR). As part of the diagnostics, the Kyoto GHG aggregation was recomputed using GWP_{100} according to SAR, AR4 and AR5 for all scenarios that provided sufficient level of detail for their emissions. A total of 33 scenarios from three modelling frameworks showed recomputed Kyoto GHG outside the year-2010 range assessed by the AR5 WGIII report. These scenarios were excluded from all analysis of near-term emissions evolutions, in particular in Figures 2.6, 2.7 and 2.8, and Table 2.4.

2.SM.1.3.1.5 Plausibility assessment of near-term development

Submitted scenarios were assessed for the plausibility of their near-term development across a number of dimensions. One issue identified were drastic reductions of CO_2 emissions from the land-use sector by 2020. Given recent trends, this was considered implausible and all scenarios from the ADVANCE and EMF33 studies reporting negative CO_2 emissions from the land-use sector in 2020 were excluded from the analysis throughout this chapter.

2.SM.1.3.1.6 Missing carbon price information

Out of the 132 scenarios limiting global warming to 2°C throughout the century (see Table 2.SM.8), a total of twelve scenarios submitted by three modelling teams reported carbon prices of zero or missing values in at least one year. These scenarios were excluded from the analysis.in Section 2.5 and Figure 2.26 in Chapter 2.

2.SM.1.3.2 Contributions to the SR1.5 Database by Modelling Framework

In total, 19 modelling frameworks submitted 529 individual scenarios-based manuscripts that were published or accepted for publication by 15 May 2018 (Table 2.SM.8).

Table 2.SM.8: Overview of submitted scenarios by modelling framework, including the categorization according to the climate impact (cf. Section 2.SM.1.4) and outcomes of validity and near-term plausibility assessment of pathways (cf. Section 2.SM.1.3.1).

	Below-1.5°C	**1.5°C Return with Low OS**	**1.5°C Return with High OS**	**Lower 2°C**	**Higher 2°C**	**Above 2°C**	**Scenarios Assessed**	**Not Full Century**	**Missing emissions species for Assessment**	**Negative CO^2 Emissions (AFOLU) in 2020**	**Scenarios Submitted**
AIM		6	1	24	10	49	**90**				**90**
BET									16		**16**
C-ROADS	2	1	2			1	**6**				**6**
DNE21+									21		**21**
FARM									13		**13**
GCAM		1	2	1	3	16	**23**			24	**47**
GEM-E3								4			**4**
GENeSYS-MOD								1			**1**
GRAPE									18		**18**
IEA ETP								1			**1**
IEA World Energy Model					1		**1**				**1**
IMACLIM								7	12		**19**
IMAGE		7	4	6	9	35	**61**				**61**
MERGE		1			1	1	**3**				**3**
MESSAGE		6	6	11	13	22	**58**				**58**
POLES	4	7	5	9	3	9	**37**				**37**
REMIND	2	11	17	16	16	31	**93**				**93**
Shell World Energy Model								1			**1**
WITCH	1	4		7	2	25	**39**				**39**
Total	**9**	**44**	**37**	**74**	**58**	**189**	**411**	**14**	**80**	**24**	**529**

2.SM.1.3.3 Overview and Scope of Studies Available in SR1.5 Database

Table 2.SM.9: Recent studies included in the scenario database that this chapter draws upon and their key foci indicating which questions can be explored by the scenarios of each study. The difference between “Scenarios Submitted” and “Scenarios Assessed” is due to criteria described in Section 2.SM.1.3.1. The numbers between brackets indicate the modelling frameworks assessed.

Study/Model Name	Key Focus	Reference Papers	Modelling Frameworks	Scenarios Submitted	Scenarios Assessed
Multimodel Studies					
SSPx-1.9	Development of new community scenarios based on the full SSP framework limiting end-of-century radiative forcing to 1.9 W m^{-2}.	Riahi et al. (2017) Rogelj et al. (2018)	6	126	126
ADVANCE	Aggregate effect of the INDCs, comparison to optimal 2°C/1.5°C scenarios ratcheting up after 2020. Decarbonization bottlenecks and the effects of following the INDCs until 2030 as opposed to ratcheting up to optimal ambition levels after 2020 in terms of additional emissions locked in. Constraint of 400 $GtCO_2$ emissions from energy and industry over 2011–2100.	Vrontisi et al. (2018) Luderer et al. (2018)	9 (6)	74	55
CD-LINKS	Exploring interactions between climate and sustainable development policies, with the aim to identify robust integral policy packages to achieve all objectives. Evaluating implications of short-term policies on the mid-century transition in 1.5°C pathways linking the national to the global scale. Constraint of 400 $GtCO_2$ emissions over 2011–2100.	McCollum et al. (2018)	8 (6)	36	36
EMF-33	Study of the bioenergy contribution in deep mitigation scenarios. Constraint of 400 $GtCO_2$ emissions from energy and industry over 2011–2100.	Bauer et al. (2018)	11 (5)	183	86
Single-Model Studies					
IMAGE 1.5	Understanding the dependency of 1.5°C pathways on negative emissions.	van Vuuren et al. (2018)		8	8
IIASA LED (MESSAGEix)	A global scenario of low energy demand (LED) for sustainable development below 1.5°C without negative emission technologies.	Grubler et al. (2018)		1	1
GENeSYS-MOD	Application of the open-source energy modelling system to the question of 1.5°C and 2°C pathways.	Löffler et al. (2017)		1	0
IEA WEO	World Energy Outlook.	OECD/IEA and IRENA (2017)		1	1
OECD/IEA ETP	Energy Technology Perspectives.	IEA (2017)		1	0
PIK CEMICS (REMIND)	Study of CDR requirements and portfolios in 1.5°C pathways.	Strefler et al. (2018a)		7	7
PIK PEP (REMIND-MAgPIE)	Exploring short-term policies as entry points to global 1.5°C pathways.	Kriegler et al. (2018)		13	13
PIK SD (REMIND-MAgPIE)	Targeted policies to compensate risk to sustainable development in 1.5°C scenarios.	Bertram et al. (2018)		12	12
AIM SFCM	Socio-economic factors and future challenges of the goal of limiting the increase in global average temperature to 1.5°C.	Liu et al. (2018)		33	33
C-Roads	Interactions between emissions reductions and carbon dioxide removal.	Holz et al. (2018)		6	6
PIK EMC	Exploring how delay closes the door to achieving various temperature targets, including limiting warming to 1.5°C	Luderer et al. (2013)		8	8
MESSAGE GEA	Exploring the relative importance of technological, societal, geophysical and political uncertainties for limiting warming to 1.5°C and 2°C.	Rogelj et al. (2013a, b, 2015)		10	10
AIM TERL	The contribution of transport policies to the mitigation potential and cost of 2 °C and 1.5 °C goals	Zhang et al. (2018)		6	6
MERGE-ETL	The role of direct air capture and storage (DACS) in 1.5°C pathways.	Marcucci et al. (2017)		3	3
Shell SKY	A technically possible, but challenging pathway for society to achieve the goals of the Paris Agreement.	Shell International B.V. (2018)		1	0

2.SM.1.3.4 Data Collected

A reporting template was developed to facilitate the collection of standardized scenario results. The template was structured in nine categories, and each category was divided into four priority levels: “Mandatory”, “High priority (Tier 1)”, “Medium priority (Tier 2)”, and “Other”. In addition, one category was included to collect input assumptions on capital costs to facilitate the comparison across engineering-based models. An overview and definitions of all variables will be made available as part of the database publication.

Table 2.SM.10: Number of variables (time series of scenario results) per category and priority level.

Category	Description	Mandatory (Tier 0)	High Priority (Tier 1)	Medium Priority (Tier 2)	Other	Total
Energy	Configuration of the energy system (for the full conversion chain of energy supply from primary energy extraction, electricity capacity, to final energy use)	19	91	83	0	193
Investment	Energy system investment expenditure	0	4	22	17	43
Emissions	Emissions by species and source	4	19	55	25	103
CCS	Carbon capture and sequestration	3	10	11	8	32
Climate	Radiative forcing and warming	0	11	2	8	21
Economy	GDP, prices, policy costs	2	15	25	7	49
SDG	Indicators on sustainable development goals achievement	1	9	11	1	22
Land	Agricultural production & demand	0	14	10	5	29
Water	Water consumption & withdrawal	0	0	16	1	17
Capital costs	Major electricity generation and other energy conversion technologies	0	0	0	31	31
Total		**29**	**173**	**235**	**103**	**540**

2.SM.1.4 Scenario Classification

A total of 529 scenarios were submitted to the scenario database. Of these, 14 scenarios did not report results until the end of the century and an additional 80 scenarios did not report the required emissions species. During the validation and diagnostics, 24 scenarios were excluded because of negative CO_2 emissions from the land-use sector by 2020 (see Section 2.SM.1.3). Therefore, the analysis in this report is based on 411 scenarios, of which 90 scenarios are consistent with 1.5°C at the end of the century and 132 remain below 2°C throughout the century (not including the 90 scenarios that are deemed consistent with 1.5°C). Table 2.SM.11 provides an overview of the number of scenarios per class. Table 2.SM.12 provides an overview of geophysical characteristics per class.

Table 2.SM.11: Overview of pathway class specifications

Pathway Group	Class Name	Short Name Combined Classes	MAGICC Exceedance Probability Filter	Number of Scenarios
1.5°C	Below 1.5°C	-	**P(1.5°C) ≤ 0.34**	**0**
	Below 1.5°C	Below-1.5°C	**0.34 < P(1.5°C) ≤ 0.5**	**9**
	1.5°C Return with low overshoot (OS)	1.5°C-low-OS	**0.5 < P(1.5°C) ≤ 0.67** AND **P(1.5°C in 2100) ≤ 0.34**	**34**
			0.5 < P(1.5°C) ≤ 0.67 AND **0.34 < P(1.5°C in 2100) ≤ 0.5**	**10**
	1.5°C Return with high OS	1.5°C-high-OS	**0.67 < P(1.5°C)** AND **P(1.5°C in 2100) ≤ 0.34**	**19**
			0.67 < P(1.5°C) AND **0.34 < P(1.5°C in 2100) ≤ 0.5**	**18**
2°C	Lower 2°C	Lower-2°C	**P(2°C) ≤ 0.34** (excluding above)	**74**
	Higher 2°C	Higher-2°C	**0.34 < P(2°C) ≤ 0.5** (excluding above)	**58**
	Above 2°C	-	**0.5 < P(2°C)**	**189**

As noted in the chapter text, scenario classification was based on probabilistic temperature outcomes assessed using the AR5 assessment of composition, forcing and climate response. These were represented within the MAGICC model (Meinshausen et al., 2009, 2011a) which was used in the same setup as AR5 WGIII analyses. As discussed in Chapter 2, Section 2.2, updates in geophysical understanding would alter such results were they incorporated within MAGICC, though central outcomes would remain well within the probability distribution of the setup used here (see Section 2.SM.1.1).

Table 2.SM.12: Geophysical characteristics of mitigation pathways derived at median peak temperature and at the end of the century (2100). Geophysical characteristics of overshoot for mitigation pathways exceeding 1.5°C is given in the last two columns. Overshoot severity is the sum of degree warming years exceeding 1.5°C over the 21st century. NA indicates that no mitigation pathways exhibit the given geophysical characteristics. Radiative forcing metrics are: total anthropogenic radiative forcing (RF all), CO_2 radiative forcing (RF CO_2), and non-CO_2 radiative forcing (RF non CO_2). Cumulative CO_2 emissions until peak warming or 2100 are given for submitted and harmonized IAM outputs and are rounded at the nearest 10 $GtCO_2$. Values show: median (25th to 75th percentile) across scenarios. "inf" indicates that net zero is not reached before 2100. Scenarios with year-2010 Kyoto-GHG emissions outside the range assessed by IPCC AR5 WGIII are excluded.

			Geophysical Characteristics at Peak Warming											**Geophysical Characteristics in 2100**										**Geophysical Characteristics of the Temperature Overshoot**				
Category	**# scenarios with climate assessment**	**Peak|Median warming**	**Peak|Year**	**Peak|CO_2 [ppm]**	**Peak|RF all [W m^{-2}]**	**Peak|RF CO_2 [W m^{-2}]**	**Peak|RF non CO_2 [W m^{-2}]**	**Net zero CO_2 | Year**	**Cumulative CO_2 emissions (2016 to peak, as submitted)**	**Cumulative CO_2 emissions (2016 to peak, harmonized)**	**Peak|Prob exceed 1.5°C [%]**	**peak|Prob exceed 2.0°C [%]**	**peak|Prob exceed 2.5°C [%]**	**2100| CO_2 [ppm]**	**2100|RF all [W m^{-2}]**	**2100|RF CO_2 [W m^{-2}]**	**2100|RF non-CO_2 [W m^{-2}]**	**Cumulative CO_2 emissions (2016-2100), as submitted**	**Cumulative CO_2 emissions (2016-2100), harmonized**	**2100|Prob exceed 1.5°C [%]**	**2100|prob exceed 2.0°C [%]**	**2100|prob exceed 2.5°C [%]**	**Overshoot|duration [years]|2.0°C**	**Overshoot|exceedance year|1.5°C**	**Overshoot|exceedance year|2.0°C**	**Overshoot|severity [temperature-years]|1.5°C**	**Overshoot|duration [years]|1.5°C**
Below-1.5°C	5	1.5 (1.4, 1.5)	2041 (2040, 2048)	423 (419, 430)	2.9 (2.7, 2.9)	2.3 (2.2, 2.3)	0.6 (0.4, 0.7)	2044 (2037, 2054)	480 (470, 590)	470 (450, 600)	45 (39, 49)	5 (4, 7)	1 (1, 1)	376 (367, 386)	1.8 (1.8, 2.1)	1.6 (1.5, 1.8)	0.3 (0.2, 0.4)	180 (10, 270)	150 (5, 260)	16 (12, 24)	3 (2, 6)	1 (0, 1)	NA	NA	NA	NA	NA
1.5°C-low-OS	37	1.6 (1.5, 1.6)	2048 (2039, 2062)	431 (424, 443)	3.0 (2.8, 3.2)	2.4 (2.3, 2.5)	0.6 (0.3, 0.8)	2050 (2038, 2082)	620 (530, 870)	630 (520, 880)	60 (51, 67)	10 (7, 14)	1 (1, 2)	380 (357, 418)	2.1 (1.8, 2.5)	1.7 (1.4, 2.2)	0.3 (0.1, 0.8)	250 (−120, 780)	260 (−130, 790)	28 (17, 45)	7 (4, 12)	1 (1, 3)	NA	2035 (2031, 2049)	NA	1 (0, 3)	27 (14, 54)
1.5°C-high-OS	38	1.7 (1.6, 1.9)	2051 (2043, 2058)	448 (433, 465)	3.2 (3.0, 3.5)	2.6 (2.4, 2.8)	0.6 (0.4, 0.8)	2052 (2044, 2066)	860 (610, 1050)	860 (620, 1070)	75 (67, 89)	18 (11, 34)	3 (1, 8)	385 (354, 419)	2.2 (1.8, 2.6)	1.8 (1.3, 2.2)	0.4 (0.2, 0.7)	330 (−100, 790)	340 (−90, 820)	34 (20, 50)	8 (4, 14)	2 (1, 4)	NA	2033 (2030, 2035)	NA	6 (2, 14)	52 (31, 68)
Lower-2°C	70	1.7 (1.5, 1.8)	2063 (2047, 2100)	453 (418, 475)	3.1 (2.7, 3.5)	2.6 (2.2, 2.9)	0.5 (0.2, 0.9)	2074 (2050, inf)	1000 (540, 1400)	990 (550, 1430)	78 (56, 86)	26 (12, 34)	7 (2, 10)	429 (379, 467)	2.8 (2.4, 3.2)	2.3 (1.7, 2.7)	0.4 (0.2, 0.9)	880 (180, 1400)	880 (190, 1420)	65 (51, 80)	20 (13, 34)	7 (3, 11)	NA	2033 (2030, 2043)	NA	NA	NA
Higher-2°C	59	1.9 (1.8, 2.0)	2075 (2051, 2100)	473 (444, 490)	3.4 (3.1, 3.6)	2.8 (2.5, 3.1)	0.5 (0.4, 1.0)	2082 (2051, inf)	1320 (880, 1690)	1340 (890, 1660)	87 (78, 93)	40 (31, 50)	13 (7, 19)	452 (401, 490)	3.1 (2.6, 3.5)	2.6 (1.0, 3.0)	0.5 (0.3, 1.0)	1270 (510, 1690)	1270 (520, 1660)	83 (59, 89)	38 (17, 50)	13 (6, 19)	NA	2033 (2030, 2039)	NA	NA	NA
Above-2°C	183	3.1 (2.0, 5.4)	2100 (2067, 2100)	651 (472, 1106)	5.4 (3.4, 9.0)	4.6 (2.8, 7.4)	0.8 (0.4, 1.9)	inf (2067, inf)	3510 (1360, 8010)	3520 (1380, 8010)	100 (89, 100)	96 (50, 100)	83 (17, 100)	651 (438, 1106)	5.4 (2.9, 9.0)	4.6 (2.4, 7.4)	0.8 (0.4, 1.9)	3510 (1090, 8010)	3520 (1090, 8010)	100 (76, 100)	96 (34, 100)	83 (12, 100)	35 (17, 39) [3]	2032 (2029, 2037)	2051 (2042, 2100)	NA	NA

2.SM.1.5 Mitigation and SDG Pathway Synthesis

The Chapter 2 synthesis assessment (see Figure 2.28) of interactions between 1.5°C mitigation pathways and sustainable development or Sustainable Development Goals (SDGs) is based on the assessment of interactions between mitigation measures and SDGs carried out by Chapter 5 (Section 5.4). To derive a synthesis assessment of the interactions between 1.5°C mitigation pathways and SDGs, a set of clear and transparent steps are followed, as described below.

- Table 5.2 is at the basis of all interactions considered between mitigation measures and SDGs.
- A condensed set of mitigation measures, selecting and combining mitigation measures from Table 5.2, is defined (see Table 2.SM.13).
- If a measure in the condensed Chapter 2 set is a combination of multiple mitigation measures from Table 5.2, the main interaction (synergies, synergy or trade-off, trade-off) is based on all interactions with three-star (★★★) and four-star (★★★★) confidence ratings in Table 5.2. If no three-star or four-star interactions are available, lower confidence interactions are considered if available.
- The resulting interaction is defined by the interaction of the majority of cells.
- If one cell shows a diverging interaction and this interaction has three-star or more confidence level, a "synergy or trade-off" interaction is considered.
- If all interactions for a given mitigation measure and SDG combination are the same, the resulting interaction is represented with a bold symbol.
- If all three-star and four-star interactions are of the same nature, but a lower-confidence interaction is opposite, the interaction is represented with a regular symbol.
- Confidence is defined by the rounded average of all available confidence levels of the predominant direction (rounded down; four-star confidence in Table 5.2 is also reported as three-star in the Chapter 2 synthesis)
- If a measure in Table 5.2 is assessed to result in either a neutral effect or a synergy or trade-off, the synergy or trade-off is reported in the Chapter 2 synthesis, but the confidence level is reduced by one notch.

To derive relative synergy–risk profiles for the four scenario archetypes used in Chapter 2 (S1, S2, S5, LED, see Sections 2.1 and 2.3), the relative deployment of the selected mitigation measures is used. For each mitigation measure, a proxy indicator is used (see Table 2.SM.14). The proxy indicator values are displayed on a relative scale from zero to one, where the value of the lowest pathway is set to the origin and the values of the other pathways scaled so that the maximum is one. The pathways with proxy indicator values that are neither 0 nor 1 receive a 0.5 weighting. These 0, 0.5, or 1 values are used to determine the relative achievement of specific synergies or trade-offs per SDG in each scenario, by summing each respective interaction type (synergy, trade-off, or synergy or trade-off) over all proxy indicators. Ultimately these sums are synthesized in one interaction based on the majority of sub-interactions (synergy, trade-off, or synergy or trade-off). In cases where both synergies and trade-offs are identified, the 'synergy or trade-off' interaction is attributed.

Table 2.SM.13: Mapping of mitigation measures assessed in Table 5.2 of Chapter 5 to the condensed set of mitigation measured used for the mitigation-SDG synthesis of Chapter 2.

Table 5.2 Mitigation Measures Set			Chapter 2 Condensed Set
Demand	Industry	Accelerating energy efficiency improvement	DEMAND: Accelerating energy efficiency improvements in end use sectors
		Low-carbon fuel switch	DEMAND: Fuel switch and access to modern low-carbon energy
		Decarbonization/CCS/CCU	Not included
	Buildings	Behavioural response	DEMAND: Behavioural response reducing Building and Transport demand
		Accelerating energy efficiency improvement	DEMAND: Accelerating energy efficiency improvements in end use sectors
		Improved access & fuel switch to modern low-carbon energy	DEMAND: Fuel switch and access to modern low-carbon energy
	Transport	Behavioural response	DEMAND: Behavioural response reducing Building and Transport demand
		Accelerating energy efficiency improvement	DEMAND: Accelerating energy efficiency improvements in end use sectors
		Improved access & fuel switch to modern low-carbon energy	DEMAND: Fuel switch and access to modern low-carbon energy
Supply	Replacing coal	Non-biomass renewables: solar, wind, hydro	SUPPLY: Non-biomass renewables: solar, wind, hydro
		Increased use of biomass	SUPPLY: Increased use of biomass
		Nuclear/advanced nuclear	SUPPLY: Nuclear/advanced nuclear
		CCS: Bio energy	SUPPLY: Bioenergy with carbon capture and storage (BECCS)
	Advanced coal	CCS: Fossil	SUPPLY: Fossil fuels with carbon capture and storage (fossil-CCS)
Land & Ocean	Agriculture & Livestock	Behavioural response: Sustainable healthy diets and reduced food waste	DEMAND: Behavioural response: Sustainable healthy diets and reduced food waste
		Land based greenhouse gas reduction and soil carbon sequestration	LAND: Land-based greenhouse gas reduction and soil carbon sequestration
		Greenhouse gas reduction from improved livestock production and manure management systems	LAND: Greenhouse gas reduction from improved livestock production and manure management systems
	Forest	Reduced deforestation, REDD+	LAND: Reduced deforestation, REDD+, afforestation and reforestation
		Afforestation and reforestation	LAND: Reduced deforestation, REDD+, afforestation and reforestation
		Behavioural response (responsible sourcing)	Not included
	Oceans	Ocean iron fertilization	Not included
		Blue carbon	Not included
		Enhanced Weathering	Not included

Table 2.SM.14: Mitigation measure and proxy indicators reflecting relative deployment of given measure across pathway archetypes. Values of Indicators 2, 3, and 4 are inversely related with the deployment of the respective measures.

Mitigation Measure		**Pathway Proxy**	
Group	*Description*	*Number*	*Description*
Demand	Accelerating energy efficiency improvements in end-use sectors	1	Compound annual growth rate of primary energy (PE) to final energy (FE) conversion from 2020 to 2050
	Behavioural response reducing Building and Transport demand	2	Percent change in FE between 2010 and 2050
	Fuel switch and access to modern low-carbon energy	3	Year-2050 carbon intensity of FE
	Behavioural response: Sustainable healthy diets and reduced food waste	4	Year-2050 share of non-livestock in food energy supply
Supply	Non-biomass renewables: solar, wind, hydro	5	Year-2050 PE from non-biomass renewables
	Increased use of biomass	6	Year-2050 PE from biomass
	Nuclear/advanced nuclear	7	Year-2050 PE from nuclear
	Bioenergy with carbon capture and storage (BECCS)	8	Year-2050 BECCS deployment in $GtCO_2$
	Fossil fuels with carbon capture and storage (fossil-CCS)	9	Year-2050 fossil-CCS deployment in $GtCO_2$
Land	Land based greenhouse gas reduction and soil carbon sequestration	10	Cumulative AFOLU CO_2 emissions over the 2020–2100 period
	Greenhouse gas reduction from improved livestock production and manure management systems	11	CH_4 and N_2O AFOLU emissions per unit of total food energy supply
	Reduced deforestation, REDD+, afforestation and reforestation	12	Change in global forest area between 2020 and 2050

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2.SM.2 Part 2

Contributing Modelling Framework Reference Cards

For each of the contributing modelling frameworks, a reference card has been created highlighting the key features of the model. These reference cards are either based on information received from contributing modelling teams upon submission of scenarios to the SR1.5 database, or alternatively are drawn from the ADVANCE IAM wiki documentation, available at http://www.fp7-advance.eu/content/model-documentation, and updated. These reference cards are provided in part 2 of this Supplementary Material.

2.SM.2.1 Reference Card – AIM/CGE

About

Name and version

AIM/CGE

Institution and users

National Institute for Environmental Studies (NIES), Japan

Model scope and methods

Objective

AIM/CGE is developed to analyse climate mitigation and impacts. The energy system is disaggregated to meet this objective on both the energy supply and demand sides. Agricultural sectors have also been disaggregated for the appropriate land-use treatment. The model is designed to be flexible in its use for global analysis.

Concept

General equilibrium with technology-explicit modules in power sectors

Solution method

Solving a mixed complementarity problem

Anticipation

Myopic

Temporal dimension

Base year: 2005
Time steps: Annual
Horizon: 2100

Spatial dimension

Number of regions: 17
Japan
China
India
Southeast Asia
Rest of Asia
Oceania
EU25
Rest of Europe
Former Soviet Union
Turkey
Canada
United States
Brazil
Rest of South America

Middle East
North Africa
Rest of Africa

Policy implementation

Climate policies such as emissions targets, emission permit trading and so on. Energy taxes and subsidies

Socio-economic drivers

Exogenous drivers

Total factor productivity
Note: GDP is endogenous, while TFP is exogenous; but TFP can be calibrated so as to reproduce a given GDP pathway

Endogenous drivers

GDP (Non-baseline scenarios that take into account either climate change mitigation or impacts.)

Development

GDP per capita

Macro economy

Economic sectors

Agriculture
Industry
Energy
Transport
Services

Cost measures

GDP loss
Welfare loss
Consumption loss

Trade

Coal
Oil
Gas
Electricity
Food crops
Emissions permits
Non-energy goods

Energy

Behaviour

-

Resource use

Coal
Oil
Gas
Biomass

Electricity technologies
Coal
Gas
Oil
Nuclear
Biomass
Wind
Solar PV
CCS

Conversion technologies
Oil to liquids
Biomass to liquids

Grid and infrastructure
-

Energy technology substitution
Discrete technology choices

Energy service sectors
Transportation
Industry
Residential and commercial

Land use

Land cover
Abandoned land
Cropland
Forest
Grassland
Extensive Pastures

Note: 6 AEZs (agro-ecological zones) by crop, pasture, forestry, other forest, natural grassland and others. There is a land competition under multinomial logit selection.

Other resources

-

Emissions and climate

Greenhouse gases
CO_2
CH_4
N_2O
HFCs
CFCs
SF_6

Pollutants
NO_X
SO_X
BC
OC
VOC

CO

Climate indicators

CO_2e concentration (ppm)
Radiative Forcing (W m^{-2})
Temperature change (°C)

2.SM.2.2 Reference Card – BET

About

Name and version

BET EMF33

Institution and users

CRIEPI

University of Tokyo

Role of end-use technologies in long-term GHG reduction scenarios developed with the BET model

doi: 10.1007/s10584-013-0938-6

Model scope and methods

Objective

The model is used for climate change studies on long-term mitigation scenarios. Typical application is to examine the role of electrification and advanced end-use technologies in climate change mitigation in a more systematic fashion, ranging from changes in usage of end-use technologies to power generation mix.

Concept

General equilibrium (closed economy)

Solution method

Optimization

Anticipation

Inter-temporal (foresight)

Temporal dimension

Base year: 2010**, time steps:** 10, **horizon:** 2010–2230

Spatial dimension

Number of regions: 13

BRA	Brazil
CAZ	Canada, Australia, and New Zealand
CHA	China incl. Hong Kong
EUR	EU27+3 (Switzerland, Norway, and Iceland)
IND	India
JPN	Japan
MNA	Middle East and North Africa
OAS	Other Asia
OLA	Other Latin America
ORF	Other Reforming Economies
RUS	Russia
SSA	Sub-Saharan Africa
USA	United States

Policy implementation

Emission tax/pricing, cap and trade

Socio-economic drivers

Exogenous drivers

Population

Total factor productivity

Autonomous energy efficiency improvements

Endogenous drivers
GDP
End-use service demand

Macro economy

Economic sectors
Aggregated representation (single-sector economy)

Cost measures
GDP loss
Consumption loss
Energy system costs

Trade
Coal
Oil
Gas
Hydrogen
Food crops (exogenous)
Emissions permits
Non-energy goods

Energy

Behaviour
-

Resource use
Coal
Conventional oil
Unconventional oil
Conventional gas
Unconventional gas
Uranium
Bioenergy

Electricity technologies
Coal w/o CCS
Coal w/ CCS
Gas w/o CCS
Gas w/ CCS
Oil w/o CCS
Bioenergy w/o CCS
Bioenergy w/ CCS
Geothermal power
Nuclear power
Solar power (central PV)
Wind power (onshore)
Wind power (offshore)
Hydroelectric power
Hydrogen fuel

Conversion technologies
Coal to hydrogen w/ CCS
Electrolysis
Coal to liquids w/o CCS
Bioliquids w/o CCS
Oil refining
Biomass to gas w/o CCS

Grid and infrastructure
Electricity. Note: Generalized transmission and distribution costs are included, but not modelled in a spatially explicit manner.
Gas.
Note: Generalized gas network costs are included, but not modelled in a spatially explicit manner.

Energy technology substitution
Linear choice (lowest cost, only for the supply side)
Expansion and decline constraints
System integration constraints

Energy service sectors
Transportation
Industry
Residential and commercial

Land use

Land cover
Cropland food crops
Cropland feed crops
Cropland energy crops
Managed forest
Natural forest
Pasture

Other resources

-

Emissions and climate

Greenhouse gases
CO_2

Pollutants
-

Climate indicators
CO_2 concentration (ppm)
Radiative forcing (W m^{-2})

2.SM.2.3 Reference Card – C-ROADS

About

Name and version

C-ROADS v5.005

Institution and users

Climate Interactive, US, https://www.climateinteractive.org/.

Model scope and methods

Objective

The purpose of C-ROADS is to improve public and decision-maker understanding of the long-term implications of international emissions and sequestration futures with a rapid-iteration, interactive tool as a path to effective action that stabilizes the climate.

Concept

C-ROADS takes future population, economic growth and GHG emissions as scenario inputs specified by the user and currently omits the costs of policy options and climate change damage.

Solution method

Recursive dynamic solution method (myopic)

Anticipation

Simulation modelling framework, without foresight.

Temporal dimension

Base year: 1850
Time steps: 0.25 year time step
Horizon: 2100

Spatial dimension

Number of regions: 20
USA
European Union (EU) 27 (EU27) (plus Iceland, Norway and Switzerland)
Russia (includes fraction of former USSR)
Other Eastern Europe
Canada
Japan
Australia
New Zealand
South Korea
Mexico
China
India
Indonesia
Philippines, Thailand, Taiwan, Hong Kong, Malaysia, Pakistan, Singapore
Brazil
Latin America excluding Mexico and Brazil
Middle East
South Africa
Africa excluding South Africa
Asia excluding China, India, Indonesia, and those included in Other Large Asia

Policy implementation

The model includes implicit representation of policies. For each well-mixed GHG, regionally specified socio-economic drivers, emissions per GDP, and emissions changes relative to a reference year or reference scenario determine emissions pathways.

Socioeconomic drivers

Exogenous drivers

Exogenous population

Exogenous GDP per capita rates and convergence times are used to model GDP over time.

Endogenous drivers

None

Development

None

Macro economy

Economic sectors

Not represented by the model

Cost measures

Not represented by the model

Trade

Not represented by the model

Energy

Behaviour

Not represented by the model

Resource use

Not represented by the model

Electricity technologies

Not represented by the model

Conversion technologies

Not represented by the model

Grid and infrastructure

Not represented by the model

Energy technology substitution

Not represented by the model

Energy service sectors

Not represented by the model

Land use

Land cover

Not represented by the model

Other resources
None

Emissions and climate
Greenhouse gases
CO_2
CH_4
N_2O
HFCs
CFCs
SF_6
PFCs

Pollutants
Not modelled
Covered by the model in terms of radiative forcing; uses projections of a specified SSP scenario

Climate indicators
The cycle of each well-mixed greenhouse gas is explicitly modelled.
CO_2 concentration (ppm)
CH_4 concentration (ppb)
N_2O concentration (ppb)
HFCs concentration (ppt)
SF_6 concentration (ppt)
PFCs concentration (ppt)
CO_2e concentration (ppm)
Radiative Forcing (W m^{-2})
The model uses the radiative efficiencies and explicitly-modelled concentration over time of each well-mixed greenhouse to determine its radiative forcing (RF). The model also uses a specified SSP scenario for exogenous values of other forcings, which includes those from aerosols, albedo, solar irradiance and volcanic activity. The total RF is the sum of these components.
Temperature change (°C)
Sea level rise
Ocean acidification

2.SM.2.4 Reference Card – DNE21+

About

Name and version

DNE21+ V.14C

Institution and users

Research Institute of Innovative Technology for the Earth (RITE), 9-2 Kizugawadai, Kizugawa-shi, Kyoto 619-0292

http://www.rite.or.jp/Japanese/labo/sysken/about-global-warming/download-data/RITE_GHGMitigationAssessmentModel_20150130.pdf

https://www.rite.or.jp/system/en/research/new-earth/dne21-model-analyses/climate/

Model scope and methods

Objective

-

Concept

Minimizing energy systems cost

Solution method

Optimization

Anticipation

Inter-temporal (foresight)

Temporal dimension

Base year: 2000,
Time steps: 5 year steps (2000 - 2030); 10 year-steps (2030 - 2050),
Horizon: 2000-2050

Spatial dimension

Number of regions: 54

ARG+	Argentina, Paraguay, Uruguay
AUS	Australia
BRA	Brazil
CAN	Canada
CHN	China
EU15	EU-15
EEU	Eastern Europe (Other EU-28)
IND	India
IDN	Indonesia
JPN	Japan
MEX	Mexico
RUS	Russia
SAU	Saudi Arabia
SAF	South Africa
ROK	South Korea
TUR	Turkey
USA	United States of America
OAFR	Other Africa
MEA	Middle East & North Africa
NZL	New Zealand
OAS	Other Asia

OFUE Other FUSSR (Eastern Europe)
OFUA Other FUSSR (Asia)
OLA Other Latin America
OWE Other Western Europe

Policy implementation
Emission tax/pricing, cap and trade; fuel taxes; fuel subsidies; feed-in-tariff; portfolio standard; capacity targets; emission standards; energy efficiency standards; land protection; pricing carbon stocks

Socio-economic drivers
Exogenous drivers
Population
Population age structure
Education level
Urbanization rate
GDP
Income distribution
Labour participation rate
Labour productivity

Macro economy
Economic sectors
Agriculture
Industry
Energy
Services

Cost measures
Energy system costs

Trade
Coal
Oil
Gas
Electricity
Emissions permits

Energy
Behaviour
Transportation
Industry
Residential & Commercial
Technology Adoption

Resource use
Coal
Conventional oil
Unconventional oil
Conventional gas
Unconventional gas

Electricity technologies
Coal w/o CCS
Coal w/ CCS

Gas w/o CCS
Gas w/ CCS
Oil w/o CCS
Oil w/ CCS
Bioenergy w/o CCS
Bioenergy w/ CCS
Geothermal power
Nuclear power
Solar power
Wind power
Hydroelectric power

Conversion technologies
Coal to hydrogen w/o CCS
Coal to hydrogen w/ CCS
Natural gas to hydrogen w/o CCS
Natural gas to hydrogen w/ CCS
Biomass to hydrogen w/o CCS
Biomass to hydrogen w/ CCS
Electrolysis
Coal to liquids w/o CCS
Bioliquids w/o CCS
Oil refining
Coal to gas w/o CCS

Grid and infrastructure
Electricity
Gas
CO_2
H_2

Energy technology substitution
Linear choice (lowest cost)
System integration constraints

Energy service sectors
Transportation
Industry
Residential and commercial

Land use

Land cover
Cropland food crops
Cropland feed crops
Cropland energy crops
Managed forest
Natural forest
Pasture

Other resources

Other resources
Water

Emissions and climate

Greenhouse gases

CO_2
CH_4
N_2O
HFCs
CFCs
SF6

Pollutants

NO_X
SO_X
BC
OC

Climate indicators

CO_2e concentration (ppm)
Radiative forcing (W m^{-2})
Temperature change (°C)

2.SM.2.5 Reference Card – FARM 3.2

About

Name and version

Future Agricultural Resources Model 3.2

Institution and users

United States Department of Agriculture, Economic Research Service; Öko-Institut, Germany – https://www.ers.usda.gov/webdocs/publications/81903/err-223.pdf?v=42738

Model scope and methods

Objective

The Future Agricultural Resources Model (FARM) was originally designed as a static computable general equilibrium (CGE) model to simulate land use and climate impacts at a global scale. It has since been extended to simulate energy and agricultural systems through 2100 to enable participation in the energy modelling forum (EMF) and the agricultural modelling intercomparison project (AgMIP) model comparison studies.

Concept

FARM models land-use shifts among crops, pasture, and forests in response to population growth; changes in agricultural productivity; and policies such as a renewable portfolio standard or greenhouse gas cap-and-trade.

Solution method

General equilibrium recursive-dynamic simulation

Anticipation

Myopic

Temporal dimension

Base year: 2011
Time steps: 5 years
Horizon: 2101

Spatial dimension

Number of regions: 15
United States
Japan
European Union west (EU-15)
European Union east
Other OECD90
Russian Federation
Other Reforming Economies
China region
India
Indonesia
Other Asia
Middle East and North Africa
Sub-Saharan Africa
Brazil
Other Latin America

Policy implementation

Emissions tax/pricing, cap and trade, fuel taxes and subsidies, portfolio standards, agricultural producer, subsidies, agricultural consumer subsidies, land protection

Socio economic drivers

Exogenous drivers

Population
Labour productivity
Land productivity
Autonomous energy efficiency improvements
Other input-specific productivity

Endogenous drivers

None

Development

None

Macro economy

Economic sectors

Agriculture
Industry
Energy
Services

Cost measures

GDP loss
Welfare loss
Equivalent variation
Consumption loss

Trade

Coal
Oil
Gas
Electricity
Food crops
Non-energy goods

Energy

Behaviour

Substitution between energy and non-energy inputs in response to changes in relative prices

Resource use

Coal (supply curve)
Conventional oil (supply curve)
Conventional gas (supply curve)
Biomass (supply curve)

Electricity technologies

Coal (w/o and w/ CCS)
Gas (w/o and w/ CCS)
Oil (w/o and w/ CCS)

Nuclear
Biomass (w/o and w/ CCS)
Wind
Solar PV

Conversion technologies
Fuel to liquid, oil refining

Grid and infrastructure
Electricity (aggregate)
Gas (aggregate)
CO_2 (aggregate)

Energy technology substitution
Discrete technology choices with mostly high substitutability through production functions

Energy service sectors
Transportation (land, water, air)
Buildings

Land use

Land cover
Crop Land
Food Crops
Feed Crops
Energy Crops
Managed Forest
Pastures

Other resources
Other resources
None

Emissions and climate
Greenhouse gases
CO_2
Fossil Fuels
Cement
Land Use

Pollutants
None

Climate indicators
None

2.SM.2.6 Reference Card – GCAM 4.2

About

Name and version

Global Change Assessment Model 4.2

Institution and users

Joint Global Change Research Institute – http://jgcri.github.io/gcam-doc/v4.2/toc.html

Model scope and methods

Objective

GCAM is a global integrated assessment model that represents the behaviour of, and complex interactions between five systems: the energy system, water, agriculture and land use, the economy, and the climate.

Concept

The core operating principle for GCAM is that of market equilibrium. Representative agents in GCAM use information on prices, as well as other information that might be relevant, and make decisions about the allocation of resources. These representative agents exist throughout the model, representing, for example, regional electricity sectors, regional refining sectors, regional energy demand sectors, and land users who have to allocate land among competing crops within any given land region. Markets are the means by which these representative agents interact with one another. Agents pass goods and services along with prices into the markets. Markets exist for physical flows such as electricity or agricultural commodities, but they also can exist for other types of goods and services, for example tradable carbon permits.

Solution method

Partial equilibrium (price elastic demand) recursive-dynamic

Anticipation

Myopic

Temporal dimension

Base year: 2010
Time steps: 5 years
H**orizon:** 2100

Spatial dimension

Number of regions: 32 (For CD-Links scenarios, GCAM included 82 regions)
USA (For CD-Links scenarios, the USA was subdivided into 50 states plus the District of Columbia)
Eastern Africa
Northern Africa
Southern Africa
Western Africa
Australia and New Zealand
Brazil
Canada
Central America and Caribbean
Central Asia
China
EU-12
EU-15
Eastern Europe
Non-EU Europe
European Free Trade Association

India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
Northern South America
Southern South America
South Asia
South Korea
Southeast Asia
Taiwan
Argentina
Colombia

Policy implementation
Climate Policies
Emission tax/pricing
Cap and trade
Energy Policies
Fuel taxes
Fuel subsidies
Portfolio standard
Energy Technology Policies
Capacity targets
Energy efficiency standards
Land-Use Policies
Land protection
Afforestation

Socio-economic drivers
Exogenous drivers
Population
GDP
Labour participation rate
Labour productivity

Endogenous drivers
None

Development
None

Macro economy
Economic sectors
Agriculture
Industry
Energy
Transport
Services
Residential and Commercial

Cost measures
Area under marginal abatement cost (MAC) curve

Trade
Coal
Oil
Gas
Uranium
Bioenergy crops
Food crops
Emissions permits

Energy

Behaviour
None

Resource use
Coal (supply curve)
Conventional oil (supply curve)
Unconventional oil (supply curve)
Conventional gas (supply curve)
Unconventional gas (supply curve)
Uranium (supply curve)
Biomass (process model)
Land

Electricity technologies
Coal (w/ o and w/ CCS)
Gas (w/o and w/ CCS)
Oil (w/o and w/ CCS)
Nuclear
Biomass (w/o and w/ CCS)
Wind (onshore)
Solar PV (central PV, distributed PV, and concentrating solar power)
CCS
Conversion technologies

CHP
Hydrogen from coal, oil, gas, and biomass, w/o and w/ CCS
Nuclear and solar thermochemical
Fuel to gas
Coal to gas w/o CCS
Biomass (w/o and w/ CCS)
Fuel to liquid
Coal to liquids (w/o and w/ CCS)
Gas to liquids (w/o and w/ CCS)
Biomass to Liquids (w/o and w/ CCS)

Grid and infrastructure
None

Energy technology substitution
Discrete technology choices with usually high substitutability through logit-choice model

Energy service sectors
Transportation
Residential and commercial
Industry

Land use
Land cover
Cropland
Food crops
Feed crops
Energy crops
Forest
Managed forest
Natural forest
Pasture
Shrubland
Tundra
Urban
Rock, Ice, Desert

Other resources
Other resources
Water
Cement

Emissions and climate
Greenhouse gases
CO_2 (fossil fuels, cement, land use)
CH_4 (energy, land use, other)
N_2O (energy, land use, other)
HFCs
CFCs
SF6

Pollutants
NO_X (energy, land use)
SO_X (energy, land use)
BC (energy, land use)
OC (energy, land use)
NH_3 (energy, land use)

Climate indicators
Kyoto-gases concentration
Radiative forcing ($W\ m^{-2}$)
Temperature change (°C)

2.SM.2.7 Reference Card – GEM-E3

About

Name and version
GEM-E3

Institution and users
Institute of Communication and Computer Systems (ICCS), Greece
https://ec.europa.eu/jrc/en/gem-e3

Model scope and methods

Objective
The model puts emphasis on: (i) the analysis of market instruments for energy-related environmental policy, such as taxes, subsidies, regulations, emission permits etc., at a degree of detail that is sufficient for national, sectoral and world-wide policy evaluation; and (ii) the assessment of distributional consequences of programmes and policies, including social equity, employment and cohesion for less-developed regions.

Concept
General equilibrium

Solution method
The model is formulated as a simultaneous system of equations with an equal number of variables. The system is solved for each year following a time-forward path. The model uses the GAMS software and is written as a mixed non-linear complementarity problem solved by using the PATH algorithm with the standard solver options.

Anticipation
Myopic

Temporal dimension
Base year: 2011
Time steps: Five year time steps
Horizon: 2050

Spatial dimension
Different spatial dimension depending on application. Main applications feature one of the two regional disaggregation below.

Number of regions: 38
Austria
Belgium
Bulgaria
Croatia
Cyprus
Czech Republic
Germany
Denmark
Spain
Estonia
Finland
France
United Kingdom
Greece
Hungary

Ireland
Italy
Lithuania
Luxembourg
Latvia
Malta
Netherlands
Poland
Portugal
Slovakia
Slovenia
Sweden
Romania
USA
Japan
Canada
Brazil
China
India
Oceania
Russian federation
Rest of Annex I
Rest of the World

Or

Number of regions: 19
EU28
USA
Japan
Canada
Brazil
China
India
South Korea
Indonesia
Mexico
Argentina
Turkey
Saudi Arabia
Oceania
Russian federation
Rest of energy producing countries
South Africa
Rest of Europe
Rest of the World

Policy implementation
Taxes, permits trading, subsidies, energy efficiency standards, CO_2 standards, emission-reduction targets, trade agreements, R&D, adaptation.

Socio-economic drivers
Exogenous drivers
Total factor productivity

Labour productivity
Capital technical progress
Energy technical progress
Materials technical progress
Active population growth
Endogenous drivers
Learning-by-doing
Development
GDP per capita
Labour participation rate

Macro economy
Economic sectors
Agriculture
Industry
Energy
Transport
Services
Other
Note: GEM-E3 represents the following sectors: Agriculture, coal, crude oil, oil, gas, electricity supply, ferrous metals, non-ferrous metals, chemical products, paper & pulp, non-metallic minerals, electric goods, conventional transport equipment, other equipment goods, consumer goods industries, construction, air transport, land transport – passenger, land transport – freight, water transport – passenger, water transport – freight, biofuel feedstock, biomass, ethanol, biodiesel, advanced electric appliances, electric vehicles, equipment for wind, equipment for PV, equipment for CCS, market services, non-market services, coal fired, oil fired, gas fired, nuclear, biomass, hydroelectric, wind, PV, CCS coal, CCS gas

Cost measures
GDP loss
Welfare loss
Consumption loss

Trade
Coal
Oil
Gas
Electricity
Emissions permits
Non-energy goods
Agriculture
Ferrous and non-ferrous metals
Chemical products
Other energy intensive
Electric goods
Transport equipment
Other equipment goods
Consumer goods industries

Energy
Behaviour
The GEM-E3 model endogenously computes energy consumption, depending on energy prices, realized energy efficiency expenditures and autonomous energy efficiency improvements. Each agent decides how much energy it will consume in order to optimize its behaviour (i.e., to maximize profits for firms and utility for households) subject to technological constraints (i.e., a production function). At a sectoral level, energy

consumption is derived from profit maximization under a nested CES (constant elasticity of substitution) specification. Energy enters the production function together with other production factors (capital, labour, materials). Substitution of energy and the rest of the production factors is imperfect (energy is considered an essential input to the production process) and it is induced by changes in the relative prices of each input. Residential energy consumption is derived from the utility maximization problem of households. Households allocate their income between different consumption categories and savings to maximize their utility subject to their budget constraint. Consumption is split between durable (e.g., vehicles, electric appliances) and non-durable goods. For durable goods, stock accumulation depends on new purchases and scrapping. Durable goods consume (non-durable) goods and services, including energy products. The latter are endogenously determined depending on the stock of durable goods and on relative energy prices.

Resource use
Coal
Oil
Gas
Biomass

Electricity technologies
Coal
Gas
Oil
Nuclear
Biomass
Wind
Solar PV
CCS

Conversion technologies
None

Grid and infrastructure
Electricity

Energy technology substitution
Discrete technology choices

Energy service sectors
Transportation
Industry
Residential and commercial

Land use

Land cover
No land use is simulated in the current version of GEM-E3.

Other resources

Other resources

Emissions and climate

Greenhouse gases
CO_2
CH_4
N_2O
HFCs

CFCs
SF_6

Pollutants
NO_X
SO_X

Climate indicators
None

2.SM.2.8 Reference Card – GENeSYS-MOD 1.0

About

Name and version

GENeSYS-MOD 1.0

Institution and users

Technische Universität (TU) Berlin, Germany / German Institute for Economic Research (DIW Berlin), Germany

Model scope and methods

Objective

The Global Energy System Model (GENeSYS-MOD) is an open-source energy system model, based on the Open-Source Energy Modelling System (OSeMOSYS). The aim is to analyse potential pathways and scenarios for the future energy system, for example, for an assessment of climate targets. It incorporates the power, heat, and transportation sectors and specifically considers sector-coupling aspects between these traditionally segregated sectors.

Concept

The model minimizes the total discounted system costs by choosing the cost-optimal mix of generation and sector-coupling technologies for the power, heat, and transportation sectors.

Solution method

Linear program optimization (minimizing total discounted system costs)

Anticipation

Perfect foresight

Temporal dimension

Base year: 2015, **time steps:** 2015, 2020, 2030, 2035, 2040, 2045, 2050, **horizon:** 2015–2050

Spatial dimension

Number of regions: 10
Europe
Africa
North America
South America
Oceania
China and Mongolia
India
Middle East
Former Soviet Union
Remaining Asian countries (mostly Southeast-Asia)

Policy implementation

Emission tax/pricing, emissions budget, fuel taxes, fuel subsidies, capacity targets, emission standards, energy efficiency standards

Socio-economic drivers

Exogenous drivers

Technical progress (such as efficiency measures)
GDP per capita
Population

Endogenous drivers
None

Development
-

Macro economy

Economic sectors
-
Cost measures
-
Trade

Energy

Behaviour
-
Resource use
Coal
Oil
Gas
Uranium
Biomass
Electricity technologies
Coal
Gas
Oil
Nuclear
Biomass
Wind (onshore & offshore)
Solar PV (utility PV & rooftop PV)
CSP
Geothermal
Hydropower
Wave & tidal power

Conversion technologies
CHP
Hydrogen (electrolysis & fuel cells)
Electricity & gas storages

Grid and infrastructure
Electricity

Energy technology substitution
Discrete technology choices
Expansion and decline constraints
System integration constraints

Energy service sectors
Transportation (split up in passenger & freight)
Total power demand
Heat (divided up in warm water / space heating & process heat)

Land use

Land cover

-

Other resources

Other resources

-

Emissions and climate

Greenhouse gases

CO_2

Pollutants

-

Climate indicators

-

2.SM.2.9 Reference Card – GRAPE-15 1.0

About

Name and version

GRAPE-15 1.0

Institution and users

The Institute of Applied Energy, Japan – https://doi.org/10.5547/ISSN0195-6574-EJ-VolSI2006-NoSI3-13

Model scope and methods

Objective

GRAPE is an integrated assessment model with an inter-temporal optimization model, which consists of modules for energy, macro economy, climate, land use and environmental impacts.

Concept

-

Solution method

Partial equilibrium (fixed demand) inter-temporal optimization

Anticipation

Perfect foresight

Temporal dimension

Base year: 2005**, time steps:** 5 years, **horizon:** 2110

Spatial dimension

Number of regions: 15

Canada
USA
Western Europe
Japan
Oceania
China
Southeast Asia
India
Middle East
Sub-Sahara Africa
Brazil
Other Latin America
Central Europe
Eastern Europe
Russia

Policy implementation

Emissions taxes/pricing, cap and trade, land protection

Socio-economic drivers

Exogenous drivers

Population
Population age structure
Education level
Urbanization rate
GDP
Income distribution

Total factor productivity
Autonomous energy efficiency improvements

Endogenous drivers
None

Development
Income distribution in a region (exogenous)
Urbanization rate (exogenous)
Education level (exogenous)

Macro economy

Economic sectors
Agriculture
Industry
Energy
Transport
Services

Cost measures
GDP loss
Welfare loss
Consumption loss
Energy system costs

Trade
Coal
Oil
Gas
Electricity
Bioenergy crops
Food crops
Non-energy goods
Hydrogen

Energy

Behaviour
None

Resource use
Coal (supply curve)
Conventional oil (supply curve)
Unconventional oil (supply curve)
Conventional gas (supply curve)
Unconventional gas (supply curve)
Uranium (supply curve)
Biomass (supply curve)
Water (process model)
Land

Electricity technologies
Coal (w/o and w/ CCS)
Gas (w/o and w/ CCS)
Oil (w/o and w/ CCS)
Nuclear

Biomass (w/o and w/ CCS)
Wind (onshore and offshore)
Solar PV (central and distributed)
Geothermal
Hydroelectric
Hydrogen

Conversion technologies
CHP
Coal/Oil/Gas/Biomass-to-Heat
Hydrogen
Coal to H_2 (w/o and w/ CCS)
Oil to H_2 (w/o and w/ CCS)
Gas to H_2 (w/o and w/ CCS)
Biomass to H_2 (w/o CCS)
Nuclear and solar thermochemical
Electrolysis
Fuel to gas
Coal to gas (w/o and w/ CCS)
Fuel to liquid
Coal to liquids (w/o and w/ CCS)
Gas to liquids (w/o and w/ CCS)
Biomass to liquids (w/o and w/ CCS)
Oil Refining

Grid and infrastructure
Electricity
Gas
Heat
CO_2
H_2

Energy technology substitution
Discrete technology choices with mostly high substitutability through linear choice (lowest cost)
Expansion and decline constraints

Energy service sectors
Transportation
Industry
Residential and commercial

Land use
Land cover
Energy cropland
Forest
Pastures
Built-up area

Other resources
Other resources
Water

Emissions and climate
Greenhouse gases
CO_2

Fossil fuels
Land use
CH_4
Energy
Land use
N_2O
Energy
HFCs
CFCs
SF6
CO
Energy use

Pollutants
Only for energy
NO_X
SO_X
BC
OC
Ozone

Climate indicators
CO_2e concentration (ppm)
Radiative Forcing (W m^{-2})
Temperature change (°C)

2.SM.2.10 Reference Card – ETP Model

About

Name and version

ETP Model, version 3

Institution and users

International Energy Agency – http://www.iea.org/etp/etpmodel/

Model scope and methods

Objective

The analysis and modelling aim to identify an economical way for society to reach the desired outcomes of reliable, affordable and clean energy. For a variety of reasons, the scenario results do not necessarily reflect the least-cost ideal. The ETP analysis takes into account those policies that have already been implemented or decided. In the short term, this means that deployment pathways may differ from what would be most cost-effective. In the longer term, the analysis emphasizes a normative approach, and fewer constraints governed by current political objectives apply in the modelling. The objective of this methodology is to provide a model for a cost-effective transition to a sustainable energy system.

Concept

Partial equilibrium (fixed energy service and material demands), with the exception for the transport sector, where "avoid and shift" policies are being considered.

Solution method

Optimization for power, other transformation and industry sectors; simulation for agriculture, residential, services and transport sectors

Anticipation

Inter-temporal (foresight)

Temporal dimension

Base year: 2014
Time steps: 5 years
Horizon: 2060

Spatial dimension

Number of regions: differs between energy sectors (28-39 model regions)
Asian countries except Japan
Countries of the Middle East and Africa
Latin American countries
OECD90 and EU (and EU candidate) countries
Countries from the Reforming Economies of the Former Soviet Union
World
OECD countries
Non-OECD countries
Brazil
China
South Africa
Russia
India
ASEAN region countries
USA
European Union (28 member countries)
Mexico

Policy implementation
Emission tax/pricing, cap and trade, fuel taxes, fuel subsidies, feed-in-tariff, portfolio standards, capacity targets, emission standards, energy efficiency standards

Socio economic drivers
Exogenous drivers
Population
Urbanization rate
GDP
Autonomous energy efficiency improvements

Endogenous drivers
None

Development
None

Macro economy
Economic sectors
Agriculture
Industry
Residential
Services
Transport
Power
Other transformation
Cost measures
None
Trade
Coal
Oil
Gas
Electricity

Energy
Behaviour
None

Resource use
Coal (supply curve)
Conventional oil (process model)
Unconventional oil (supply curve)
Conventional gas (process model)
Unconventional gas (supply curve)
Bioenergy (supply curve)

Electricity technologies
Coal (w/o and w/ CCS)
Gas (w/o and w/ CCS)
Oil (w/o and w/ CCS)
Nuclear
Biomass (w/o and w/ CCS)
Solar Power (central PV, distributed PV, and CSP)
Wind power (onshore and offshore)

Hydroelectric power
Ocean power

Conversion technologies
Coal to hydrogen (w/o CCS and w/ CCS)
Natural gas to hydrogen (w/o CCS and w/ CCS)
Oil to hydrogen (w/o CCS)
Biomass to hydrogen (w/o CCS and w/ CCS)
Coal to liquids (w/o CCS and w/ CCS)
Gas to liquids (w/o CCS and w/ CCS)
Bioliquids (w/o CCS and w/ CCS)
Oil refining
Coal to gas (w/o CCS and w/ CCS)
Oil to gas (w/o CCS and w/ CCS)
Biomass to gas (w/o CCS and w/ CCS)
Coal heat
Natural gas heat
Oil heat
Biomass heat
Geothermal heat
Solarthermal heat
CHP (coupled heat and power)

Grid and infrastructure
Electricity (spatially explicit)
Gas (aggregate)
Heat (aggregate)
Hydrogen (aggregate)
CO_2 (spatially explicit)
Gas spatially explicit for gas pipelines and LNG infrastructure between model regions

Energy technology substitution
Lowest cost with adjustment penalties. Discrete technology choices with mostly high substitutability in some sectors and mostly low substitutability in other sectors
Expansion and decline constraints
System integration constraints

Energy service sectors
Transportation
Industry
Residential and commercial

<u>Land use</u>
Land cover
Not represented by the model

<u>Other resources</u>
Other resources
None

<u>Emissions and climate</u>
Greenhouse gases
CO_2 fossil fuels (endogenous & controlled)
CO_2 cement (endogenous & controlled)

Pollutants

None

Climate indicators

None

2.SM.2.11 Reference Card – IEA World Energy Model

About

Name and version

IEA World Energy Model (version 2016)

Institution and users

International Energy Agency - https://www.iea.org/weo/
http://www.iea.org/media/weowebsite/2016/WEM_Documentation_WEO2016.pdf

Model scope and methods

Objective

The model is a large-scale simulation model designed to replicate how energy markets function and is the principal tool used to generate detailed sector-by-sector and region-by-region projections for the World Energy Outlook (WEO) scenarios.

Concept

Partial equilibrium (price elastic demand)

Solution method

Simulation

Anticipation

Mix of "Inter-temporal (foresight)" and "Recursive-dynamic (myopic)"

Temporal dimension

Base year: 2014
Time steps: 1 year steps
Horizon: 2050

Spatial dimension

Number of regions: 25
United States
Canada
Mexico
Chile
Japan
Korea
OECD Oceania
Other OECD Europe
France, Germany, Italy, United Kingdom
Europe 21 excluding EUG4
Europe 7
Eurasia
Russia
Caspian
China
India
Indonesia
South East Asia (excluding Indonesia)
Rest of Other Developing Asia
Brazil
Other Latin America
North Africa
Other Africa

South Africa
Middle East

Policy implementation
Emission tax/pricing, cap and trade (global and regional), fuel taxes, fuel subsidies, feed-in-tariff, portfolio standard, capacity targets, emission standards, energy efficiency standards

Socio economic drivers

Exogenous drivers
Population (exogenous)
Urbanization rate (exogenous)
GDP (exogenous)

Endogenous drivers
Autonomous energy efficiency improvements (endogenous)

Development
-

Macro economy

Economic sectors
Agriculture (economic)
Industry (physical & economic)
Services (economic)
Energy (physical & economic)

Cost measures
Energy system cost mark-up

Trade
Coal
Oil
Gas
Bioenergy crops
Emissions permits

Energy

Behaviour
Price elasticity

Resource use
Coal (process model)
Conventional oil (process model)
Unconventional oil (process model)
Conventional gas (process model)
Unconventional gas (process model)
Bioenergy (process model)

Electricity technologies
Coal
Gas
Oil
Nuclear
Geothermal
Bioenergy

Wind (onshore and offshore)
Solar PV (central and distributed)
CCS
CSP
Hydropower
Ocean power
Note: CCS can be combined with coal, gas and biomass power generation technologies

Conversion technologies
Natural gas to hydrogen w/o CCS
Coal to liquids w/o CCS
Coal to gas w/o CCS
Coal heat
Natural gas heat
Oil heat
Bioenergy heat
Geothermal heat
Solarthermal heat
CHP (coupled heat and power)

Grid and infrastructure
Electricity (aggregate)
Gas (aggregate)

Energy technology substitution
Logit choice model
Weibull function
Discrete technology choices with mostly high substitutability in some sectors and mostly low substitutability in other sectors
Expansion and decline constraints
System integration constraints

Energy service sectors
Transportation
Industry
Residential
Commercial

Land use
Land cover
Not covered by the model

Other resources
Other resources

Emissions and climate
Greenhouse gases*
CO_2
CH_4
N_2O
HFCs (exogenous)
CFCs (exogenous)
SF_6 (exogenous)

Pollutants*
NO_x

SO_x
BC
OC
CO
NH_3
VOC

*NOTE: Non-energy CO_2, non-energy CH_4, non-energy N_2O, CFC, HFC, SF_6, CO, NO_x, VOC, SO_2, are assumptions-based and not disaggregated (only total emissions are available).

Climate indicators
CO_2e concentration (ppm)
Radiative Forcing (W m^{-2})
Temperature change (°C)

2.SM.2.12 Reference Card – IMACLIM

About

Name and version

IMACLIM 1.1 (Advance), IMACLIM-NLU 1.0 (EMF33)

Institution and users

Centre International de Recherche sur l'Environnement et le Développement (CIRED), France, http://www.centre-cired.fr.
Société de Mathématiques Appliquées et de Sciences Humaines (SMASH), France, http://www.smash.fr.

Model scope and methods

Objective

Imaclim-R is intended to study the interactions between energy systems and the economy to assess the feasibility of low-carbon development strategies and the transition pathway towards a low-carbon future.

Concept

Hybrid: general equilibrium with technology explicit modules. Recursive dynamics: each year the equilibrium is solved (system of non-linear equations), in between years the parameters for the equilibrium evolve according to specified functions.

Solution method

Imaclim-R is implemented in Scilab and uses the function fsolve from a shared C++ library to solve the static equilibrium system of non-linear equations.

Anticipation

Recursive dynamics: each year the equilibrium is solved (system of non-linear equations), in between years, the parameters for the equilibrium evolve according to specified functions.

Temporal dimension

Base year: 2001
Time steps: annual
H**orizon:** 2050 or 2100

Spatial dimension

Number of regions: 12
USA
Canada
Europe
China
India
Brazil
Middle East
Africa
Commonwealth of Independent States
OECD Pacific
Rest of Asia
Rest of Latin America

Policy implementation

Baseline does not include explicit climate policies. Climate/energy policies can be implemented in a number of ways, depending on the policy. A number of general or specific policy choices can be modelled, including: emissions or energy taxes, permit trading, specific technology subsidies, regulations, technology and/or resource constraints

Socio economic drivers

Exogenous drivers

Labour productivity
Energy technical progress
Population
Active population
Note: Our model growth engine is composed of exogenous trends of active population growth and exogenous trends of labour productivity growth. The two sets of assumptions on demography and labour productivity, although exogenous, only prescribe natural growth. Effective growth results endogenously from the interaction of these driving forces with short-term constraints: (i) available capital flows for investments and (ii) rigidities, such as fixed technologies, immobility of the installed capital across sectors or rigidities in real wages, which may lead to partial utilization of production factors (labour and capital).

Endogenous drivers

-

Development

GDP per capita

Macro economy

Economic sectors

Agriculture
Industry
Energy
Transport
Services
Construction
Note: The energy sector is divided into five sub-sectors: oil extraction, gas extraction, coal extraction, refinery, power generation. The transport sector is divided into three sub-sectors: terrestrial transport, air transport, water transport. The industry sector has one sub-sector: Energy intensive industry.

Cost measures

GDP loss
Welfare loss
Consumption loss
Energy system costs

Trade

Coal
Oil
Gas
Electricity
Bioenergy crops
Capital
Emissions permits
Non-energy goods
Refined liquid fuels

Energy

Behaviour

Price response (via elasticities), and non-price drivers (infrastructure and urban forms conditioning location choices, different asymptotes on industrial goods consumption saturation levels with income rise, speed of personal vehicle ownership rate increase, speed of residential area increase).

Resource use

Coal

Oil
Gas
Biomass

Electricity technologies
Coal
Gas
Oil
Nuclear
Biomass
Wind
Solar PV
CCS

Conversion technologies
Fuel to liquid

Grid and infrastructure
Electricity

Energy technology substitution
Discrete technology choices
Expansion and decline constraints
System integration constraints

Energy service sectors
Transportation
Industry
Residential and commercial
Agriculture

Land use

Land cover
Cropland
Forest
Extensive pastures
Intensive pastures
Inaccessible pastures
Urban areas
Unproductive land
Note:
IMACLIM 1.1 (Advance): Bioenergy production is determined by the fuel and electricity modules of Imaclim-R using supply curves from Hoogwijk et al. (2009) (bioelectricity) and IEA (biofuel).
IMACLIM-NLU 1.0 (EMF33): In this version the Imaclim-R model is linked to the land-use mode Nexus Land use. Bioenergy demand level is determined by the fuel and electricity modules of Imaclim-R. The Nexus Land use gives the corresponding price of biomass feedstock, taking into account the land constraints and food production The production of biomass for electricity and ligno-cellulosic fuels is located on marginal lands (i.e., less fertile or accessible lands). By increasing the demand for land, and spurring agricultural intensification, Bioenergy propels land and food prices.

Other resources

Other resources

-

Emissions and climate

Greenhouse gases

CO_2

Pollutants

-

Climate indicators

-

2.SM.2.13 Reference Card – IMAGE

About

Name and version

IMAGE framework 3.0

Institution and users

Utrecht University (UU), Netherlands, http://www.uu.nl.
PBL Netherlands Environmental Assessment Agency (PBL), Netherlands, http://www.pbl.nl.

Model scope and methods

Objective

IMAGE is an ecological–environmental model framework that simulates the environmental consequences of human activities worldwide. The objective of the IMAGE model is to explore the long- term dynamics and impacts of global changes that result. More specifically, the model aims to analyse interactions between human development and the natural environment to gain better insight into the processes of global environmental change, to identify response strategies to global environmental change based on assessment of options, and to indicate key inter-linkages and associated levels of uncertainty in processes of global environmental change.

Concept

The IMAGE framework can best be described as a geographically explicit integrated assessment simulation model, focusing on a detailed representation of relevant processes with respect to human use of energy, land and water in relation to relevant environmental processes.

Solution method

Recursive dynamic solution method

Anticipation

Simulation modelling framework, without foresight. However, a simplified version of the energy/climate part of the model (called FAIR) can be run prior to running the framework to obtain data for climate policy simulations.

Temporal dimension

Base year: 1970
Time steps: 1-5 year time step
Horizon: 2100

Spatial dimension

Number of regions: 26
Canada
USA
Mexico
Rest of Central America
Brazil
Rest of South America
Northern Africa
Western Africa
Eastern Africa
South Africa
Western Europe
Central Europe
Turkey
Ukraine +
Asian-Stan

Russia +
Middle East
India +
Korea
China +
Southeastern Asia
Indonesia +
Japan
Oceania
Rest of South Asia
Rest of Southern Africa

Policy implementation

Key areas where policy responses can be introduced in the model are:
Climate policy
Energy policies (air pollution, access and energy security)
Land use policies (food)
Specific policies to project biodiversity
Measures to reduce the imbalance of the nitrogen cycle

Socio-economic drivers

Exogenous drivers

Exogenous GDP
GDP per capita
Population

Endogenous drivers

Energy demand
Renewable price
Fossil fuel prices
Carbon prices
Technology progress
Energy intensity
Preferences
Learning by doing
Agricultural demand
Value added

Development

GDP per capita
Income distribution in a region
Urbanization rate
Note: GDP per capita and income distribution are exogenous

Macro economy

Economic sectors

Note: No explicit economy representation in monetary units. Explicit economy representation in terms of energy is modelled (for the agriculture, industry, energy, transport and built environment sectors)

Cost measures

Area under MAC
Energy system costs

Trade

Coal

Oil
Gas
Uranium
Bioenergy crops
Food crops
Emissions permits
Non-energy goods
Bioenergy products
Livestock products

Energy

Behaviour

In the energy model, substitution among technologies is described in the model using the multinomial logit formulation. The multinomial logit model implies that the market share of a certain technology or fuel type depends on costs relative to competing technologies. The option with the lowest costs gets the largest market share, but in most cases not the full market. We interpret the latter as a representation of heterogeneity in the form of specific market niches for every technology or fuel.

Resource use

Coal
Oil
Gas
Uranium
Biomass
Note: Distinction between traditional and modern biomass

Electricity technologies

Coal w/ CCS
Coal w/o CCS
Gas w/ CCS
Gas w/o CCS
Oil w/ CCS
Oil w/o CCS
Nuclear
Biomass w/ CCS
Biomass w/o CCS
Wind
Solar PV
CSP
Hydropower
Geothermal
Note: wind: onshore and offshore; coal: conventional, IGCC, IGCC + CCS, IGCC + CHP, IGCC + CHP + CCS; oil: conventional, OGCC, OGCC + CCS, OGCC + CHP, OGCC + CHP + CCS); natural gas: conventional, CC, CC + CCS, CC + CHP, CC + CHP + CCS; biomass: conventional, CC, CC + CCS, CC + CHP, CC + CHP + CCS
hydropower and geothermal: exogenous

Conversion technologies

CHP
Hydrogen

Grid and infrastructure

Electricity

Energy technology substitution

Discrete technology choices
Expansion and decline constraints

System integration constraints

Energy service sectors
Transportation
Industry
Residential and commercial

Land use
Land cover
Forest
Cropland
Grassland
Abandoned land
Protected land

Other resources
Other resources
Water
Metals
Cement

Emissions and climate
Greenhouse gases
CO_2
CH_4
N_2O
HFCs
CFCs
SF_6
PFCs

Pollutants
NO_X
SO_X
BC
OC
Ozone
VOC
NH3
CO

Climate indicators
CO_2e concentration (ppm)
Radiative Forcing (W m^{-2})
Temperature change (°C)

2.SM.2.14 Reference Card – MERGE-ETL 6.0

About

Name and version

MERGE-ETL 6.0

Institution and users

Paul Scherrer Institut

https://www.psi.ch/eem/ModelsEN/2012MergeDescription.pdf

https://www.psi.ch/eem/ModelsEN/2014MergeCalibration.pdf

Model scope and methods

Objective

MERGE (Model for Evaluating Regional and Global Effects of GHG reductions policies) is an integrated assessment model originally developed by Manne et al. (1995). It divides the world in geopolitical regions, each one represented by two coupled submodels describing the energy and economic sectors, respectively. MERGE acts as a global social planner with perfect foresight and determines the economic equilibrium in each region that maximizes global welfare, defined as a linear combination of the current and future regional welfares. Besides these regional energy–economic submodels, and linked to them, MERGE includes global submodels of greenhouse gas emissions and the climate to allow the analysis of the effectiveness and impacts of climate policies and the role of technologies to realize climate targets. The model is sufficiently flexible to explore views on a wide range of contentious issues: costs of abatement, damages of climate change, valuation and discounting.

Concept

The MERGE-ETL model is a hard-linked hybrid model as the energy sectors are fully integrated with the rest of the economy. The model combines a bottom-up description of the energy system disaggregated into electric and non-electric sectors, a top-down economic model based on macroeconomic production functions, and a simplified climate cycle model. The energy sectors endogenously account for technological change with explicit representation of two-factor learning curves.

Solution method

General equilibrium (closed economy). Two different solutions can be produced: a cooperative globally optimal solution and a non-cooperative solution equivalent to Nash equilibrium. It is programmed in GAMS and uses the CONOPT solver.

Anticipation

Inter-temporal (foresight) or myopic.

Temporal dimension

Base year: 2015
Time steps: 10 years
Horizon: 2015-2100

Spatial dimension

Number of regions: 10

EUP European Union
RUS Russia
MEA Middle East
IND India
CHI China
JPN Japan
CANZ Canada, Australia and New Zealand

USA United States of America
ROW Rest of the World
SWI Switzerland

Policy implementation
Emission tax/pricing, cap and trade, fuel taxes, fuel subsidies, feed-in-tariff, portfolio standard, capacity targets

Socio economic drivers
Exogenous drivers
Population, population age structure, autonomous energy efficiency improvements

Development
GDP

Macro economy
Economic sectors
One final good
Electric and non-electric demand sectors

Cost measures
GDP loss
Welfare loss
Consumption loss
Area under MAC
Energy system costs

Trade
Non-Energy goods
Coal
Oil
Gas
Uranium
Bioenergy crops
Emissions permits

Energy
Behaviour
Considered in side-constraints controlling technology deployment rates

Resource use
Coal
Conventional oil
Unconventional oil
Conventional gas
Unconventional gas
Uranium
Bioenergy
Note: Cost-supply curves for the different resources are considered

Electricity technologies
Coal
Gas
Oil
Nuclear

Biomass
Wind
Solar PV
Hydrogen
Note: CCS can be combined with coal, gas and biomass power generation technologies

Conversion technologies
Hydrogen
Fuel to liquids
Note: CCS can be combined with coal, gas and biomass technologies

Grid and infrastructure
Electricity
Gas
CO_2
H_2

Energy technology substitution
Expansion and decline constraints
System integration constraints
Early technology retirement

Energy service sectors
Electric and non-electric demand that is further disaggregated to seven energy sectors/fuels, namely coal, oil, gas, biofuels, hydrogen, solar and heat

Land use
Land cover

Other resources
Other resources

Emissions and climate
Greenhouse gases
CO_2
CH_4
N_2O
HFCs
SF_6

Pollutants
-

Climate indicators
CO_2e concentration (ppm)
Radiative Forcing ($W\ m^{-2}$)
Temperature change (°C)
Climate damages $ or equivalent

2.SM.2.15 Reference Card – MESSAGE(ix)-GLOBIOM

About

Name and version

MESSAGE-GLOBIOM 1.0 and MESSAGE*ix*-GLOBIOM 1.0

Institution and users

International Institute for Applied Systems Analysis (IIASA), Austria, global model description: http://data.ene.iiasa.ac.at/message-globiom/. Model documentation and code (MESSAGE*ix*) http://messageix.iiasa.ac.at

Main users: IIASA, the MESSAGE model is distributed via the International Atomic Energy Agency (IAEA) to member countries, the new MESSAGE*ix* model is available as an open source tool via GitHub (https://github.com/iiasa/message_ix)

Model scope and methods

Objective

MESSAGE-GLOBIOM is an integrated assessment framework designed to assess the transformation of the energy and land systems vis-a-vis the challenges of climate change and other sustainability issues. It consists of the energy model MESSAGE, the land use model GLOBIOM, the air pollution and GHG model GAINS, the aggregated macroeconomic model MACRO and the simple climate model MAGICC.

Concept

Hybrid model (energy engineering and land use partial equilibrium models soft-linked to macroeconomic general equilibrium model)

Solution method

Hybrid model (linear program optimization for the energy systems and land use modules, non-linear program optimization for the macroeconomic module)

Anticipation

Myopic/Perfect Foresight (MESSAGE can be run both with perfect foresight and myopically, while GLOBIOM runs myopically)

Temporal dimension

Base year: 2010
Time steps: 1990, 1995, 2000, 2005, 2010, 2020, 2030, 2040, 2050, 2060, 2070, 2080, 2090, 2100, 2110
Horizon: 1990-2110

Spatial dimension

Number of regions: 11+1
AFR (Sub-Saharan Africa)
CPA (Centrally Planned Asia & China)
EEU (Eastern Europe)
FSU (Former Soviet Union)
LAM (Latin America and the Caribbean)
MEA (Middle East and North Africa)
NAM (North America)
PAO (Pacific OECD)
PAS (Other Pacific Asia)
SAS (South Asia)
WEU (Western Europe)
GLB (international shipping)

Policy implementation

GHG and energy taxes; GHG emission cap and permits trading; energy taxes and subsidies; micro-financing (for energy access analysis); regulation: generation capacity, production and share targets

Socio economic drivers

Exogenous drivers

Labour Productivity
Energy technical progress
GDP per capita
Population

Endogenous drivers

-

Development

GDP per capita
Income distribution in a region
Number of people relying on solid cooking fuels

Macro economy

Economic sectors

Note: MACRO represents the economy in a single sector with the production function including capital, labour and energy nests

Cost measures

GDP loss
Consumption loss
Area under marginal abatement cost (MAC) curve
Energy system costs

Trade

Coal
Oil
Gas
Uranium
Electricity
Food crops
Emissions permits
Note: bioenergy is only traded after processing to a secondary fuel (e.g., liquid biofuel)

Energy

Behaviour

Non-monetary factors of decision making (e.g., behavioural impacts) are represented in MESSAGE via so-called inconvenience costs. These are generally included in the consumer-dominated energy end-use sectors (transportation sector, residential and commercial sector) and are particularly relevant in the modelling of energy access in developing countries.

Resource use

Coal
Oil
Gas
Uranium
Biomass
Note: modern and traditional applications of biomass are distinguished

Electricity technologies

Coal w /o CCS

Coal w/ CCS
Gas w/o CCS
Gas w/ CCS
Oil w/o CCS
Biomass w/o CCS
Biomass w/ CCS
Nuclear
Wind onshore
Wind offshore
Solar PV
CSP
Geothermal
Hydropower
Note: CCS can be combined with coal, gas and biomass power generation technologies

Conversion technologies
CHP
Hydrogen
Fuel to gas
Fuel to liquid
Note: CHP can be combined with all thermal power plant types; hydrogen can be produced from coal, gas and biomass feedstocks and electricity; fuel to liquids is represented for coal, gas and biomass feedstocks; and fuel to gas is represented for coal and biomass feedstocks

Grid and infrastructure
Electricity
Gas
Heat
CO_2
Hydrogen

Energy technology substitution
Discrete technology choices
Expansion and decline constraints
System integration constraints

Energy service sectors
Transportation
Industry
Residential and commercial
Note: non-energy use (feedstock) of energy carriers is separately represented, but generally reported under industry

Land use
Land cover
Forest (natural/managed)
Short-rotation plantations
Cropland
Grassland
Other natural land

Other resources
Other resources
Water
Cement
Note: cement is not modelled as a separate commodity, but process emissions from cement production are

represented

Emissions and climate

Greenhouse gases

CO_2
CH_4
N_2O
HFCs
CFCs
SF_6

Pollutants

NO_x
SO_x
BC
OC
CO
NH_3
VOC

Climate indicators

CO_2e concentration (ppm)
Radiative Forcing (W m^{-2})
Temperature change (°C)

2.SM.2.16 Reference Card – POLES

About

Name and version

POLES ADVANCE (other versions are in use in other applications)

Institution and users

JRC - Joint Research Centre - European Commission (EC-JRC), Belgium, http://ec.europa.eu/jrc/en/poles.
Main users: - European Commission JRC; Université de Grenoble UPMF, France - Enerdata

Model scope and methods

Objective

POLES was originally developed to assess energy markets, combining a detailed description of energy demand, transformation and primary supply for all energy vectors. It provides full energy balances on a yearly basis using frequent data updates so as to deliver robust forecasts for both short- and long-term horizons. It has quickly been used, since the late 90s, to assess energy-related CO_2 mitigation policies. Over time, other GHG emissions have been included (energy and industry non-CO_2 from the early 2000s), and linkages with agricultural and land use models have been progressively implemented.

Concept

Partial equilibrium

Solution method

Recursive simulation

Anticipation

Myopic

Temporal dimension

Base year: 1990-2015 (data up to current time −1/−2)
Time steps: yearly
Horizon: 2050–2100

Spatial dimension

Number of regions: 66

Policy implementation

Energy taxes per sector and fuel, carbon pricing, feed-in-tariffs, green certificates, low interest rates, investment subsidies, fuel efficiency standards in vehicles and buildings, white certificates

Socio economic drivers

Exogenous drivers

Exogenous GDP
Population

Endogenous drivers

Value added
Mobility needs
Fossil fuel prices
Buildings surfaces

Development

GDP per capita
Urbanization rate

Macro economy

Economic sectors

Agriculture
Industry
Services

Cost measures

Area under MAC
Energy system costs
Note: Investments: supply-side only

Trade

Coal
Oil
Gas
Bioenergy crops
Liquid biofuels

Energy

Behaviour

Activity drivers depend on income per capita and energy prices via elasticities. Energy demand depends on activity drivers, energy prices and technology costs. Primary energy supply depends on remaining resources, production cost and price effects.

Resource use

Coal
Oil
Gas
Uranium
Biomass

Electricity technologies

Coal
Gas
Oil
Nuclear
Biomass
Wind
Solar PV
CCS
Hydropower
Geothermal
Solar CSP
Ocean

Conversion technologies

CHP
Hydrogen
Fuel to liquid

Grid and infrastructure

Gas
H_2

Energy technology substitution

-

Energy service sectors

Transportation
Industry
Residential and commercial

Land use

Land cover

Cropland
Forest
Grassland
Urban areas
Desert

Other resources

Other resources

Metals
Note: Steel tons

Emissions and climate

Greenhouse gases

CO_2
CH_4
N_2O
HFCs
SF_6
PFCs

Pollutants

-

Climate indicators

-

2.SM.2.17 Reference Card – REMIND - MAgPIE

About

Name and version

REMIND 1.7 – MAgPIE 3.0

Institution and users

Potsdam Institut für Klimafolgenforschung (PIK), Germany,
https://www.pik-potsdam.de/research/sustainable-solutions/models/remind
https://www.pik-potsdam.de/research/projects/activities/land-use-modelling/magpie

Model scope and methods

Objective

REMIND (Regionalized Model of Investment and Development) is a global multiregional model incorporating the economy, the climate system and a detailed representation of the energy sector. It allows analysing technology options and policy proposals for climate mitigation, and models regional energy investments and interregional trade in goods, energy carriers and emissions allowances.
MAgPIE (Model of Agricultural Production and its Impacts on the Environment) is a global multiregional economic land-use optimization model designed for scenario analysis up to the year 2100. MAgPIE provides a holistic framework to explore future transformation pathways of the land system, including multiple trade-offs with ecosystem services and sustainable development.

Concept

REMIND: Hybrid model that couples an economic growth model with a detailed energy system model and a simple climate model.
MAgPIE: Gridded land-use optimization model with 10 socio-economic world regions. MAgPIE takes regional economic conditions, such as demand for agricultural commodities, technological development, and production costs, as well as spatially explicit data on potential crop yields, carbon stocks and water constraints (from the dynamic global vegetation model LPJmL), under current and future climatic conditions into account.

Solution method

REMIND: Inter-temporal optimization that maximizes cumulated discounted global welfare: Ramsey-type growth model with Negishi approach to regional welfare aggregation.
MAgPIE: Partial equilibrium model of the agricultural sector with recursive-dynamic optimization. The objective function of MAgPIE is the fulfilment of agricultural demand for 10 world regions at minimum global costs under consideration of biophysical and socio-economic constraints. Major cost types in MAgPIE are factor requirement costs (capital, labor, fertilizer), land conversion costs, transportation costs to the closest market, investment costs for yield-increasing technological change (TC) and costs for GHG emissions in mitigation scenarios.
REMIND and MAgPIE are coupled by exchanging greenhouse gas prices and bioenergy demand from REMIND to MAgPIE, and bioenergy prices and AFOLU greenhouse gas emissions from MAgPIE to REMIND, and iterating until an equilibrium of prices and quantities is established.

Anticipation

REMIND: Perfect Foresight
MAgPIE: Myopic

Temporal dimension

REMIND:
Base year: 2005
Time steps: flexible time steps, default is 5-year time steps until 2050 and 10-year time steps until 2100; period from 2100–2150 is calculated to avoid distortions due to end effects, but typically only the time span 2005–2100 is used for model applications.

MAgPIE:
Base year: 1995
Time steps: 5 and/or 10 years
Horizon: 1995–2100

Spatial dimension
Number of regions: 11
AFR - Sub-Saharan Africa (excluding South Africa)
CHN - China
EUR - European Union
JPN - Japan
IND - India
LAM - Latin America
MEA - Middle East, North Africa, and Central Asia
OAS - other Asian countries (mainly Southeast Asia)
RUS - Russia
ROW - rest of the World (Australia, Canada, New Zealand, Non-EU Europe, South Africa)
USA - United States of America
Note: MAgPIE operates on 10 socio-economic world regions which are mapped into REMIND-defined regions.

Policy implementation
REMIND: Pareto-optimal achievement of policy targets on temperature, radiative forcing, GHG concentration, or cumulative carbon budgets. Alternatively, calculation of Nash equilibrium without internalized technology spillovers. Possibility to ana lyse changes in expectations about climate policy goals as well as pre-specified policy packages until 2030/2050, including, for example, energy capacity and efficiency targets, renewable energy quotas, carbon and other taxes, and energy subsidies
MAgPIE: 1st- and 2nd-generation bioenergy, pricing of GHG emissions from land-use change (CO_2) and agricultural land use (CH_4, N_2O), land-use regulation, REDD+ policies, afforestation, agricultural trade policies

Socio economic drivers

Exogenous drivers
REMIND: Labour productivity, energy efficiency parameters of the production function, population
MAgPIE: Demand for bioenergy, food, feed, and material demand from the agricultural sector

Endogenous drivers
REMIND: Investments in industrial capital stock and specific energy technology capital stocks. Endogenous learning-by-doing for wind and solar power as well as electric and fuel cell vehicle technologies (global learning curve, internalized spillovers).
MAgPIE: Investments in agricultural productivity, land conversion and (re)allocation of agricultural production.

Development
REMIND: GDP per capita
MAgPIE: GDP per capita

Macro economy (REMIND)

Economic sectors
Note: The macroeconomic part contains a single sector representation of the entire economy. A generic final good is produced from capital, labour, and different final energy types

Cost measures
GDP loss
Welfare loss

Consumption loss

Trade
Coal
Oil
Gas
Uranium
Bioenergy crops
Capital
Emissions permits
Non-energy goods

Energy (REMIND)
Behaviour
Price response through CES production function. No explicit modelling of behavioural change. Baseline energy demands are calibrated in such a way that the energy demand patterns in different regions slowly converge when displayed as per capita energy demand over per capita GDP.

Resource use
Coal
Oil
Gas
Uranium
Biomass

Electricity technologies
Coal (with and w/o CCS)
Gas (with and w/o CCS)
Oil (with and w/o CCS)
Nuclear
Biomass (with and w/o CCS)
Wind
Solar PV
CCS
Solar CSP
Hydropower
Geothermal

Conversion technologies
CHP
Heat pumps
Hydrogen (from fossil fuels and biomass with and w/o CCS; electrolytic hydrogen)
Fuel to gas
Fuel to liquid (from fossil fuels and biomass with and w/o CCS)
Heat plants

Grid and infrastructure
Electricity
Gas
Heat
CO_2
H_2
Note: Generalized transmission and distribution costs are included, but not modelled on an explicit spatial level. Regionalized additional grid and storage costs for renewable integration are included.

Energy technology substitution
Discrete technology choices
Expansion and decline constraints
System integration constraints
Note: Expansion and decline, and system integration are influenced though cost mark-ups rather than constraints.

Energy service sectors
Transportation
Industry
Residential and commercial
Note: In older versions of REMIND (REMIND 1.6 and earlier), the industry and residential and commercial sectors are not treated separately but represented jointly by one stationary sector (referred to as 'Other Sector').

Land use (MAgPIE)
MAgPIE allocates land use to fulfil competing demands for commodities, feed, carbon storage, land conservation and environmental protection. Land use is broadly categorized in cropland, forest land, pasture land, and other natural land. Regional food energy demand is defined for an exogenously given population in 16 food energy categories, based on regional diets. Future trends in food demand are derived from a cross-country regression analysis, based on future scenarios on GDP and population growth. MAgPIE takes technological development and production costs as well as spatially explicit data on potential crop yields, land and water constraints (from LPJmL) into account. It includes agricultural trade with different levels of regional self-sufficiency constraints. Changes in soil and plant carbon from land conversion are accounted for. MAgPIE models the full suite of AFOLU emissions.

Other resources
Other resources
Cement
Note: Cement production is not explicitly modelled, but emissions from cement production are accounted for.

Emissions and climate
Greenhouse gases
CO_2
CH_4
N_2O
HFCs
CFCs
SF_6

Pollutants
NO_X
SO_X
BC
OC
Ozone
CO
VOC
Note: Ozone is not modelled as emission but is an endogenous result of atmospheric chemistry.

Climate indicators
CO_2e concentration (ppm)
Radiative Forcing (W m^{-2})

Temperature change (°C)
Note: Different emissions are accounted for with different levels of detail depending on the types and sources of emissions (directly by source, via marginal abatement cost (MAC) curves, by econometric estimates, exogenous).

2.SM.2.18 Reference Card – Shell - World Energy Model

About

Name and version

Shell World Energy Model 2018
2018 Edition (Version 2.10 series)

Institution and users

Shell Corporation B.V., www.shell.com/scenariosenergymodels

Model scope and methods

Objective

Exploratory simulations of plausible scenarios, covering both short-term drivers and momentum, together with the capability for long-term transformation of the energy system.

Concept

Partial equilibrium (price elastic demand)

Solution method

Simulation

Anticipation

Recursive-dynamic (myopic)

Temporal dimension

Base year: 2017, time steps: 1 year steps, horizon: 2100

Spatial dimension

Number of regions: 100 (= 82 top countries + 18 rest of the world regions)

Policy implementation

Emission tax/pricing, cap and trade, fuel taxes, fuel subsidies, energy efficiency standards

Socio economic drivers

Exogenous drivers

Population
Autonomous Energy Efficiency Improvements

Endogenous drivers

-

Development

-

Macro economy

Economic sectors

Number of sectors: 14
Industry
Services
Energy
Energy service (sector-specific) and energy demand (in EJ) for each sector

Cost measures
-

Trade
Coal
Oil
Gas
Bioenergy crops

Energy
Behaviour
-

Resource use
Coal
Conventional oil (process model)
Unconventional oil (process model)
Conventional gas (process model)
Unconventional gas (process model)
Bioenergy (fixed)

Electricity technologies
Coal (w/o CCS and w/ CCS)
Gas (w/o CCS and w/ CCS)
Oil (w/o CCS and w/ CCS)
Bioenergy (w/o CCS and w/ CCS)
Geothermal power
Nuclear power
Solar power (central PV, distributed PV, CSP)
Wind power
Hydroelectric power
Ocean power

Conversion technologies
Coal to hydrogen (w/o CCS and w/ CCS)
Natural gas to hydrogen (w/o CCS and w/ CCS)
Oil to hydrogen (w/o CCS and w/ CCS)
Biomass to hydrogen (w/o CCS and w/ CCS)
Nuclear thermochemical hydrogen
Electrolysis
Coal to liquids (w/o CCS and w/ CCS)
Gas to liquids (w/o CCS and w/ CCS)
Bioliquids (w/o CCS and w/ CCS)
Oil refining
Coal to gas (w/o CCS and w/ CCS)
Oil to gas (w/o CCS and w/ CCS)
Biomass to gas (w/o CCS and w/ CCS)
Coal heat
Natural gas heat
Oil heat
Biomass heat
Geothermal heat
Solarthermal heat

Grid and infrastructure
-

Energy technology substitution
Logit choice model
Discrete technology choices with mostly high substitutability
Mostly a constrained logit model; some derivative choices (e.g., refinery outputs) have pathway dependent choices
Constraints are imposed both endogenously and after off-model analysis
Energy service sectors
Transportation
Industry
Residential and commercial

Land use
Land cover
-

Other resources
Other resources

Emissions and climate
Greenhouse gases
CO_2 fossil fuels (endogenous & uncontrolled)

Pollutants
-

Climate indicators
-

2.SM.2.19 Reference Card – WITCH

About

Name and version

WITCH

Institution and users

Fondazione Eni Enrico Mattei (FEEM), Italy, http://www.feem.it.
Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), Italy, http://www.cmcc.it.
http://www.witchmodel.org/

Model scope and methods

Objective

WITCH evaluates the impacts of climate policies on global and regional economic systems and provides information on the optimal responses of these economies to climate change. The model considers the positive externalities from leaning-by-doing and learning-by-researching in the technological change.

Concept

Hybrid: Economic optimal growth model, including a bottom-up energy sector and a simple climate model, embedded in a 'game theory' framework.

Solution method

Regional growth models solved by non-linear optimization and game theoretic setup solved by tatonnement algorithm (cooperative solution: Negishi welfare aggregation, non-cooperative solution: Nash equilibrium)

Anticipation

Perfect foresight

Temporal dimension

Base year: 2005
Time steps: 5
Horizon: 2150

Spatial dimension

Number of regions: 14
cajaz: Canada, Japan, New Zealand
china: China, including Taiwan
easia: South East Asia
india: India
kosau: South Korea, South Africa, Australia
laca: Latin America, Mexico and Caribbean
indo: Indonesia
mena: Middle East and North Africa
neweuro: EU new countries + Switzerland + Norway
oldeuro: EU old countries (EU-15)
sasia: South Asia
ssa: Sub Saharan Africa
te: Non-EU Eastern European countries, including Russia
usa: United States of America

Policy implementation

Quantitative climate targets (temperature, radiative forcing, concentration), carbon budgets, emissions profiles as optimization constraints. Carbon taxes. Allocation and trading of emission permits, banking and borrowing. Subsidies, taxes and penalty on energies sources.

Socio economic drivers

Exogenous drivers

Total factor productivity
Labour productivity
Capital technical progress

Development

-

Macro economy

Economic sectors

Energy
Other
Note: A single economy sector is represented. Production inputs are capital, labour and energy services, accounting for the energy sector split into 8 energy technologies sectors (coal, oil, gas, wind and solar, nuclear, electricity and biofuels).

Cost measures

GDP loss
Welfare loss
Consumption loss
Energy system costs

Trade

Coal
Oil
Gas
Emissions permits

Energy

Resource use

Coal
Oil
Gas
Uranium
Biomass

Electricity technologies

Coal
Gas
Oil
Nuclear
Biomass
Wind
Solar PV
CCS

Conversion technologies

-

Grid and infrastructure

Electricity
CO_2

Energy technology substitution
Expansion and decline constraints
System integration constraints

Energy service sectors
Transportation

Land use
Land cover
Cropland
Forest
Note: Bioenergy related cost and emissions are obtained by soft linking with the GLOBIOM model.

Other resources
Other resources
Water

Emissions and climate
Greenhouse gases
CO_2
CH_4
N_2O
HFCs
CFCs
SF_6

Pollutants
NO_X
SO_X
BC
OC

Climate indicators
CO_2e concentration (ppm)
Radiative Forcing (W m^{-2})
Temperature change (°C)
Climate damages $ or equivalent

3SM - Impacts of 1.5ºC Global Warming on Natural and Human Systems
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3.SM.1 Supplementary information to Section 3.2

3.SM.1.1 Climate Models and Associated Simulations Available for the Present Assessment

Climate models allow for policy-relevant calculations such as the assessment of the levels of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions compatible with a specified climate stabilization target, such as the 1.5°C or 2°C global warming scenarios. Climate models are numerical models that can be of varying complexity and resolution (e.g., Le Treut et al. 2007). Presently, global climate models are typically Earth System Models (ESMs), in that they entail a comprehensive representation of Earth system processes, including biogeochemical processes.

In order to assess the impact and risk of projected climate changes on ecosystems or human systems, typical ESM simulations have a resolution that is too coarse – 100 km or more in many cases. Different approaches can be used to derive higher-resolution information. In some cases, ESMs can be run globally with very-high resolution; however, such simulations are cost-intensive and thus very rare. Another approach is to use regional climate models (RCM) to dynamically downscale the ESM simulations. RCMs are limited-area models with representations of climate processes comparable to those in the atmospheric and land surface components of the global models but with a higher resolution than 100 km – generally down to 10–50 km (e.g., Coordinated Regional Climate Downscaling Experiment, CORDEX; Giorgi and Gutowski 2015; Jacob et al. 2014; Cloke et al. 2013; Erfanian et al. 2016; Barlow et al. 2016) and in some cases even higher (convection permitting models, i.e., less than 4 km, e.g., Kendon et al. 2014; Ban et al. 2014; Prein et al. 2015). Statistical downscaling is another approach for downscaling information from global climate models to higher resolution. Its underlying principle is to develop statistical relationships that link large-scale atmospheric variables with local/regional climate variables, and to apply them to coarser-resolution models (Salameh et al. 2009; Su et al. 2016). Nonetheless, at the time of writing, there are only very few studies for 1.5°C climate that use regional climate models or statistical downscaling. One exception is an extension of the IMPACT2C project for Europe (see below).

There are various sources of climate model information available for the present assessment. There are global simulations that have been used in previous IPCC assessments and which were computed as part of the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project (CMIP). The IPCC Fourth Assessment Report (AR4) and Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) were mostly based on simulations from the CMIP3 experiment, while the AR5 was mostly based on simulations from the CMIP5 experiment. Simulations of the CMIP3 and CMIP5 experiments were found to be very similar (e.g., Knutti and Sedláček 2012; Mueller and Seneviratne 2014).

In addition to the CMIP3 and CMIP5 experiments, there are results from CORDEX which are available for different regions (Giorgi and Gutowski 2015). For instance, assessments based on publications from an extension of the IMPACT2C project (Vautard et al. 2014; Jacob and Solman 2017) have recently become available for projections associated with global warming of 1.5°C.

Simulations from the Half a degree Additional warming, Prognosis and Projected Impacts (HAPPI) multimodel experiment have also been run to specifically assess climate changes at 1.5°C versus 2°C global warming (Mitchell et al. 2017). The HAPPI protocol consists of coupled land-atmosphere initial condition ensemble simulations with prescribed sea surface temperatures (SSTs), sea ice, GHG and aerosol concentrations and solar and volcanic activity that coincide with three forced climate states: present-day (2006–2015), future (2091–2100) and either with 1.5°C or 2°C global warming (prescribed from the modified SST conditions).

Beside climate models, other models are available to assess changes in regional and global climate systems (e.g., models for sea level rise, models for floods, droughts and freshwater input to oceans, cryosphere/snow models, models for sea ice, as well as models for glaciers and ice sheets). Analyses of impacts in 1.5°C and 2°C warmer climates (relative to the pre-industrial period) using such models include, for example, Schleussner et al. (2016) and publications from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) (Warszawski et al. 2014), which have recently derived new analyses dedicated to assessments for responses to 1.5ºC and 2ºC global warming.

3.SM.1.2 Methods for the Attribution of Observed Changes in Climate and Their Relevance for Assessing Projected Changes at 1.5°C or 2°C Global Warming

As highlighted in previous IPCC reports, detection and attribution is an approach which is typically applied to assess impacts of GHG forcing on observed changes in climate (e.g., Hegerl et al. 2007; Seneviratne et al. 2012; Bindoff et al. 2013). For more background on this topic, the reader is referred to these past IPCC reports, as well as to the IPCC Good Practice Guidance Paper on Detection and Attribution related to Anthropogenic Climate Change (Hegerl et al. 2010). It is noted that in the IPCC Working Group I (WGI) framework, 'attribution' is focused on the 'attribution to anthropogenic greenhouse gas forcing' (e.g., Bindoff et al. 2013b). In past IPCC Working Groups II (WGII) reports, attribution of observed impacts were also made to regional changes in climate, but without consideration of whether the patterns of changes in regional climate had had a detectable influence from GHG forcing. As noted in Section 3.2.2, a recent study (Hansen and Stone 2016) shows that most of the detected temperature-related impacts that were reported in AR5 (Cramer et al. 2014) can be attributed to anthropogenic climate change, while the signals for precipitation-induced responses are more ambiguous.

Attribution to anthropogenic GHG forcing is an important field of research for the assessments of projected changes at 1.5°C and 2°C global warming in this report (see Section 3.3, and in particular Table 3.2). Indeed, observed global warming compared to the pre-industrial conditions up to the 2006–2015 decade was 0.87°C, and approximately 1ºC at around 2017 (Chapter 1; Section 3.2). Thus, 'climate at 1.5°C global warming' corresponds to the addition of approximately half a degree of global warming compared to present-day temperatures, and observed regional climate changes and impacts associated with a ca. 0.5°C global warming can be inferred from the historical record (although there could be non-linear changes at higher levels of warming, see Sections 3.2.1 and 3.2.2). This means that methods applied in the attribution of climate changes to human influences can be relevant for assessments of changes in climate with 1.5°C global warming, especially in cases where no climate model simulations or analyses are available for the conducted assessments. Indeed, impacts at 1.5°C global warming can be assessed in part from regional and global climate changes that have already been detected and attributed to human influence (e.g., Schleussner et al. 2017). This is because changes that could already be ascribed to anthropogenic GHG forcing pinpoint components of the climate system which are most responsive to this forcing, and thus will continue to be under 1.5°C or 2°C global warming. For this reason, when specific projections are missing for 1.5°C global warming, some of the assessments provided in Section 3.3 (in particular in Table 3.2) build upon joint assessments of (i) changes that were observed and attributed to human influence up to present, that is, for 1°C global warming or less, and (ii) projections for higher levels of warming (e.g., 2°C, 3°C or 4°C) to assess the most likely changes at 1.5°C. Such assessments are for transient changes only (Section 3.2.1). Evidence from attribution analyses can also be considered in the assessment of the reliability of climate projections for 1.5°C and 2°C global warming.

3.SM.1.3 The Propagation of Uncertainties from Climate Forcings to Impacts on the Ecosystems

The uncertainties associated with future projections of climate change are calculated using ensembles of model simulations (Flato et al. 2013). However, models are not fully independent, and the use of model spread as an estimator of uncertainty has been called into question (Annan and Hargreaves 2017). Many studies have been devoted to this issue, which is highly relevant to policymakers. The sources of uncertainty are diverse (Rougier and Goldstein 2014), and they must be identified to better determine the limits of predictions. The following list includes several key sources of uncertainty:

1. Input uncertainties include a lack of knowledge about the boundary conditions and the noise affecting the forcing variables;
2. Parametric and structural uncertainties are related to the lack of knowledge about some processes (i.e., those that are highly complex or operate at very fine scales) and the lack of clear information about the parameterisations used in models and the differences among the models. It has also been shown that different combinations of parameters can yield plausible simulations (Mauritsen et al. 2012);
3. Observational errors include noise and the unknown covariance structure in the data used;
4. Scale uncertainty originates from the fact that impact studies require a finer scale than ESM outputs can provide (Khan and Coulibaly 2010);
5. The offline coupling of climate-impact models introduces uncertainty because this coupling permits only a limited number of linkage variables and does not allow the representation of key feedbacks. This procedure may cause a lack of coherence between the linked climate and impact models (Meinshausen et al. 2011);
6. Important biases also include the consequences of tuning using a restricted range of climate states, that is, the periods from which climate data are available. Large biases in projections may be produced when future forcings are very different to those used for tuning; and
7. It is also assumed that ESMs yield adequate estimates of climate, except for an unknown translation (Rougier and Goldstein 2014). Usually this translation is estimated by performing an anomaly correction (the difference between the control simulation and the observed field). Such correction represents an additional uncertainty that is often ignored in the final estimate of the error bars.

Due to these uncertainties in the formulation, parametrisation and initial states of models, any individual simulation represents only one step in the pathway followed by the climate system (Flato et al. 2013). The assessment of these uncertainties must therefore be done in a probabilistic way. It is particularly important when the signal to noise ratio is weak, as it could be when assessing the difference of risks between 1.5°C and 2°C global warming.

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3.SM.2 Supplementary Information to Section 3.3

3.SM.2.1 Change in Global Climate

The Global Mean Surface Temperature (GMST) increase reached approximately 1°C above pre-industrial levels in 2017 (Haustein et al. 2017; see also Chapter 1). At the time of writing the AR5 WGI report (i.e., for time frames up to 2012; Stocker et al. 2013), Hartmann et al. (2013) assessed that the globally averaged combined land and ocean surface temperature data as calculated by a linear trend showed a warming of 0.85°C (0.65°C–1.06°C) over the period 1880–2012, when multiple independently produced datasets existed, and about 0.72°C (0.49°C –0.89°C) over the period 1951–2012. Hence most of the global warming has occurred since 1950, and it has continued substantially in recent years. The above values are for global mean warming; however, regional trends can be much more varied (Figure S3.1). With few exceptions, most land regions display stronger trends in the global mean warming, and by 2012, that is, with a warming of about 0.85°C (see above), some land regions already displayed warming higher than 1.5°C (Figure 3.SM.1).

It should be noted that more recent evaluations of the observational record suggest that the estimates of global warming at the time of the AR5 may have been underestimated (Cowtan and Way, 2014; Richardson et al., 2016). Indeed, as highlighted in Section 3.3.1 and also discussed in Chapter 1, sampling biases and different approaches to estimate GMST (e.g., using water versus air temperature over oceans) can sensibly impact estimates of GMST increase as well as differences between model simulations and observations-based estimates (Richardson et al., 2016). It should be noted that studies analyzing projected changes in extremes as a function of GMST generally use surface air temperature on both land and oceans (e.g., Fischer and Knutti, 2015; Seneviratne et al., 2016; Mitchell et al., 2017; Wartenburger et al., 2017; Kharin et al., 2018) rather than a blend of ocean surface temperature and surface air temperature over land (Chapter 1).

As highlighted in Chapter 1, an area in which substantial new literature has become available since the AR5 is the GMST trend over the period 1998–2012, which has been referred to by some as the 'global warming hiatus' (Stocker et al., 2013; Karl et al., 2015; Lewandowsky et al., 2016; Medhaug et al., 2017). This term was used to refer to an apparent slowdown of GMST increase over that time period (although other climate variables continued to display unabated changes during that period, including a particular intense warming of hot extremes over land; Seneviratne et al. 2014). Medhaug et al. (2017) noted that from a climate point of view, with 2015 and 2016 being the two warmest years on record in early 2017 (based on GMST), the question of whether 'global warming has stopped' was no longer present in the public debate. Nonetheless, the related literature is relevant for the assessment of changes in climate at 1.5°C global warming, since this event illustrates the possibility that the global temperature response may be decoupled from the radiative forcing over short time periods. While this may be associated with cooler global temperatures as experienced during the incorrectly labeled hiatus period, this implies that there could also be time periods with global warming higher than 1.5°C even if the radiative forcing would be consistent with a global warming of 1.5°C in the long-term average. Recent publications have highlighted that the 'slow down' in global temperature warming that occurred in the time frame of the hiatus episode was possibly overestimated at the time of the AR5 due to issues with data corrections, in particular related to coverage (Cowtan and Way 2014; Karl et al. 2015; Figure 3.SM.2). This has some relevance for the definition of a '1.5°C climate' (see Chapter 1 and Cross-Chapter Box 8 in Chapter 3 on 1.5°C warmer worlds). Overall, the issue of internal climate variability is the reason why a 1.5°C warming level needs to be determined in terms of 'human-induced warming' (see Chapter 1 for additional background on this issue).

A large fraction of the detected global warming has been attributed to anthropogenic forcing (Bindoff et al., 2013b). The AR5 (Bindoff et al., 2013b) assessed that it is *virtually certain* that human influence has warmed the global climate system and that it is *extremely likely* that human activities caused more than half of the observed increase in GMST from 1951 to 2010 (supplementary Figure 3.SM.3). The AR5 (Bindoff et al., 2013b) assessed that GHGs contributed a GMST increase *likely* to be between

0.5°C and 1.3°C over the period 1951–2010, with the contributions from other anthropogenic forcings *likely* to lie between –0.6°C and 0.1°C, from natural forcings *likely* to be between –0.1°C and 0.1°C, and from internal variability *likely* to be between –0.1°C and 0.1°C. Regarding observed global changes in temperature extremes, reports from the AR5 cycle assessed that since 1950 it is *very likely* that there has been an overall decrease in the number of cold days and nights and an overall increase in the number of warm days and nights at the global scale, that is, for land areas with sufficient data (Seneviratne et al., 2012; Hartmann et al., 2013). This assessment is confirmed as part of the present report and highlights that further decreases in cold extremes and increases in hot extremes are projected for a global warming of 1.5°C.

Observed global changes in the water cycle, including precipitation, are more uncertain than observed changes in temperature (Hartmann et al., 2013; Stocker et al., 2013). The AR5 assessed that it is *very likely* that global near surface and tropospheric air specific humidity have increased since the 1970s (Hartmann et al., 2013). However, AR5 also highlighted that during recent years the near surface moistening over land has abated (*medium confidence*), and that as a result, there have been fairly widespread decreases in relative humidity near the surface over the land in recent years (Hartmann et al., 2013). With respect to precipitation, some regional precipitation trends appear to be robust (Stocker et al., 2013), but when virtually all the land area is filled in using a reconstruction method, the resulting time series of global mean land precipitation shows little change since 1900. Hartmann et al. (2013) highlight that confidence in precipitation change averaged over global land areas since 1901 is low for years prior to 1951 and medium after 1951. However, for averages over the mid-latitude land areas of the Northern Hemisphere, Hartmann et al. (2013) assessed that precipitation had likely increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudinal zones, area-averaged long-term positive or negative trends have *low confidence* due to data quality, data completeness or disagreement amongst available estimates (Hartmann et al., 2013). For heavy precipitation, the AR5 assessed that in land regions where observational coverage was sufficient for assessment, there was *medium confidence* that anthropogenic forcing had contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century (Bindoff et al., 2013b).

Figures 3.SM.4 and 3.SM.5 display the same analyses as the left-hand panels of Figures 3.3 and 3.4 in the main text, but based on Representative Concentration Pathway (RCP)2.6 simulations instead of RCP8.5.

3.SM.2.2 Regional Temperature on Land, Including Extremes

3.SM.2.2.1 Observed and Attributed Changes in Regional Temperature Means and Extremes

While the quality of temperature measurements obtained through ground observational networks tend to be high compared to that of measurements for other climate variables (Seneviratne et al., 2012), it should be noted that some regions are undersampled. Cowtan and Way (2014) highlighted issues regarding undersampling being concentrated at the Poles and over Africa, which may lead to biases in estimated changes in GMST (see also Section 3.3.2 and Chapter 1). This undersampling also affects the confidence of assessments regarding regional observed and projected changes in both mean and extreme temperature.

Despite this partly limited coverage, the attribution chapter of the AR5 (Bindoff et al., 2013b) and recent papers (e.g., Sun et al. 2016; Wan et al. 2018) assessed that over every continental region and in many sub-continental regions, anthropogenic influence has made a substantial contribution to surface temperature increases since the mid-20th century. For Antarctica, while changes are occurring, statistical assessment (presumably to 95% confidence) has not been achieved due primarily to the large natural variability in the weather that occurs there and the comparatively short observational record.

Regarding observed regional changes in temperature extremes, the AR5 (Hartmann et al. 2013) provided the following assessment based in part on the IPCC Special Report on Managing the Risks of

Extreme Events and Disasters to Advance Climate Change Adaptation (SREX - Seneviratne et al., 2012):

- *Likely (high confidence)* overall increases in warm days and warm nights, and decreases in cold days and cold nights in North America and Central America, Europe and Mediterranean region, in Asia, in Southeast Asia and Oceania (including Australia), and in southern Africa
- *Medium confidence* overall increases in warm days and warm nights, and decreases in cold days and cold nights in South America, and North Africa and Middle East
- *Low to medium confidence* in some African regions lacking observations, but locations with observations display increases in warm days and warm nights, and decreases in cold days and cold nights.

Further, the IPCC SREX (Seneviratne et al. 2012) assessed that globally, in many (but not all) regions with sufficient data there is *medium confidence* that the length and the number of warm spells or heat waves has increased since the middle of the 20th century, and that it is *likely* that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures at the global scale.

Hence, observed and attributed changes in both mean and extreme temperature consistently point to a widespread influence of human-induced warming in most land regions. Also, there are new publications regarding observed trends in temperature and precipitation means and extremes in Africa (e.g., Ringard et al. 2016; Moron et al. 2016; Omondi et al. 2013; MacKellar et al. 2014), which may allow an increase in the confidence regarding observed changes on this continent.

Specific attribution statements for changes associated with a global warming of 0.5°C are currently not available on a regional scale from the literature, unlike global assessments (Schleussner et al. 2017), although preliminary results suggest that a 0.5°C global warming can also be identified for temperature extremes in a few large regions (Europe, Asia, Russia, North America; see supplementary material of Schleussner et al. 2017).

As highlighted in Section 3.2, the observational record can be used to assess past changes associated with a global warming of 0.5°C, with this type of assessment being considered as an analogue for the difference between a scenario at 1.5°C and at 2°C global warming. This approach has its limitations. For example, the methodology does not account for non-linearity in responses, including possible regional or global tipping points. Nonetheless, it can provide a first assessment of aspects of the climate system that have been identified as being sensitive to a global warming change of this magnitude. Schleussner et al. (2017), using this approach, assessed observed changes in extreme indices for the 1991–2010 versus the 1960–1979 period, which corresponds to about 0.5°C GMST difference in the observed record (based on the Goddard Institute for Space Studies Surface Temperature Analysis GISTEMP dataset, Hansen et al. 2010). They found that substantial changes due to 0.5°C warming are apparent for indices related to hot and cold extremes, as well as for the Warm Spell Duration Indicator (WSDI). Some results are displayed in Figures S3.6 and S3.7. Using two well-established observational datasets – Hadley Centre Global Climate Extremes Index 2 (HadEX2) and Global Historical Climatology Network (GHCN)-Daily climate Extremes (GHCNDEX); Donat et al. (2013a,b) – these analyses show that one quarter of the land has experienced an intensification of hot extremes (annual maximum value of daily maximum temperature; TXx) by more than 1°C and a reduction of the intensity of cold extremes by at least 2.5°C (annual minimum value of daily minimum temperature; TNn). Half of the global land mass has experienced changes in WSDI of more than six days, and the emergence of extremes outside the range of natural variability is particularly pronounced for this duration-based indicator (Figure 3.7). Results for TXx based on reanalysis products are similar for the 20th century reanalysis (20CR) product, but even more pronounced for the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalyses (referred to as "ERA"), as noted by Schleussner et al. 2017; however, results based on reanalysis products need to be considered with caution since they are partly a modelling product, and also assimilate datasets of different length. Overall, based on the analysis of Schleussner et al. (2017), the observational record suggests that a 0.5°C change in global warming has noticeable global impacts on temperature extremes.

3.SM.2.2.2 Projected Changes at 1.5°C versus 2°C in Regional Temperature Means and Extremes

This supplementary information provides more detailed material as background for the assessment of Section 3.3.2.2.

As noted in Section 3.3.2.2., there is a stronger warming of the regional land-based hot extremes compared to the mean global temperature warming in most land regions (also discussed in Seneviratne et al. 2016). The regions displaying the stronger contrast are central North America, eastern North America, Central Europe, southern Europe/Mediterranean, western Asia, Central Asia and southern Africa. As highlighted in Vogel et al. (2017), these regions are characterized by transitional climate regimes between dry and wet climates, which are associated with strong soil-moisture–temperature coupling (related to a transitional soil-moisture regime; Koster et al. 2004; Seneviratne et al. 2010). Several of these regions display enhanced drying under enhanced GHG forcing (see Section 3.3.4), which leads to a decrease of evaporative cooling and an additional regional warming compared to the global temperature response. In a recent study, Karmalkar and Bradley (2017) also found consistent results for the contiguous United States, with all subregions projected to reach 2°C approximately between 10 and 20 years before the global mean temperature.

In general, these transitional climate regions also show the largest spread in temperature extremes response, likely related to the impact of the soil-moisture–temperature coupling for the overall response. This spread is due to both intermodel variations in the representation of drying trends (see also Section 3.3.4; Orlowsky and Seneviratne 2013; Greve and Seneviratne 2015) and to differences in soil-moisture–temperature coupling in climate models (Seneviratne et al., 2013; Stegehuis et al., 2013; Sippel et al., 2016), whereby feedbacks with clouds and surface radiation are also relevant (Cheruy et al., 2014). Furthermore, in some regions internal climate variability can also explain the spread in projections (Deser et al., 2012). Regions with the most striking spread in projections of hot extremes include Central Europe, with projected regional TXx warming at 1.5°C, ranging from 1°C to 5°C warming, and central North America, which displays projected changes at 1.5°C global warming, ranging from no warming to 4°C warming.

Regarding results from regional studies, Vautard et al. (2014) report that most of Europe will experience higher warming than the global average with strong distributional patterns across Europe for global warming of 2°C, which is consistent with the present assessment for 1.5°C warming (Jacob et al., 2018). For instance, a north–south (west–east) warming gradient is found for summer (winter) along with a general increase and summer extreme temperatures.

It should be noted that recent evidence suggests that climate models overestimate the strength of soil-moisture–temperature coupling in transitional climate regions, although it is not clear if this behaviour would lead to an overestimation of projected changes in hot temperatures (Sippel et al., 2016). In addition, there are discrepancies in projections from regional versus global climate models in Europe, possibly due to differences in prescribed aerosol concentrations (Bartók et al., 2017).

While the above-mentioned hot spots of changes in temperature extremes are located in transitional climate regimes between dry and wet climates, a recent study has also performed a separate analysis of changes in temperature extremes between 'drylands' and 'humid' lands, defining the first category based on mean precipitation lower than 600 mm and the ratio of mean Precipitation to Potential Evapo-Transpiration (P/PET) being lower than 0.65 (Huang et al., 2017). This study identifies that warming is much greater in 'drylands' compared to 'humid lands' (by 44%), although the latter are mostly responsible for GHG emissions that underlie this change.

Figure 3.5 in Chapter 3 displays projected changes in the TXx as a function of GMST for the main regions as specified in the IPCC SREX (see Figure 3.2 for a description of the regions) using Empirical Scaling Relationships (ESR; Section 3.2). The underlying model projections include

Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodel global climate simulations (based on the analyses of Wartenburger et al. 2017 and Seneviratne et al. 2016) and simulations from the 'Half a degree Additional warming, Prognosis and Projected Impacts' (HAPPI) multimodel experiments (Mitchell et al. 2017; based on analyses presented in Seneviratne et al. 2018). The CMIP5 analyses provide continuous estimates of the dependency of the analysed climate extremes as functions of GMST, while the HAPPI-derived estimates are only available for the estimation of responses at two global warming levels, 1.5°C and 2°C. The CMIP5-based ESR analyses are computed from historical and RCP8.5 simulations from 26 CMIP5 global climate models (including up to 10 ensemble members per model). For the HAPPI analyses, changes in the indices and in the corresponding global mean temperatures (as indicated in the map and in the bar plots shown in the figures) are based on the 100 first ensemble members (#1 to #100) from five models (following Seneviratne et al. 2018): Canadian 4th generation Atmospheric global climate Model (CanAM4); Community Atmosphere Model version 4 (CAM4); European Center Hamburg model version 6-3-Default (Low) Resolution (ECHAM6-3-LR); Model for Interdisciplinary Research On Climate version 5 (MIROC5); and Norwegian Earth System Model version 1-HAPPI (NorESM1-HAPPI). For each of the HAPPI models and the two experiments considered (1.5°C relative to pre-industrial and 2°C relative to pre-industrial), differences were computed of the indices (scenario period – reference period, consisting of 10 years of data each per ensemble member); the reader is referred to the referenced publications for more background on the analyses and databases. Note that the ESR analyses are based on land data only for all of the considered regions, that is, with a mask being applied to ocean data within the considered regions. (Ocean datapoints are, however, included for analyses for island regions provided in this Supplementary Material, i.e., a subset of the regions indicated asterisks (*) in Figure 3.2; see e.g., Figure 3.SM.9 and similar).

Figure 3.SM.8 displays similar analyses as Figure 3.5 but for TNn. The mean response of these cold extremes displays less discrepancy with the global levels of warming (often close to the 1:1 line in many regions), however, there is a clear amplified warming in regions with snow and ice cover. This is expected given the Arctic warming amplification (Serreze and Barry 2011; see also AR5 overview on 'polar amplification': Masson-Delmotte et al. 2013; IPCC 2013) which is to a large extent due to snow-albedo-temperature feedbacks (Hall and Qu, 2006). In some regions and for some model simulations, the warming of TNn at 1.5°C global warming can reach up to 8°C regionally (e.g., northern Europe, Figure 3.SM.8), and thus be much larger than the global temperature warming.

Figures 3.SM.9 and 3.SM.10 display the same analyses as Figures 3.5 (main text) and 3.SM.8 for the regions indicated with asterisks in Figure 3.2. It should be noted that for the island regions, the land fraction is often too small to be resolved by standard global climate models. For this reason, as mentioned above, the analyses for island regions (indicated with # sign) are based on both land and ocean air temperatures and are representative of average climate conditions in the areas in which they are located.

Figure 3.SM.13 displays maps of changes in the number of hot days (NHD) and number of frost days (NFD) at 1.5°C and 2°C GMST increase. These analyses reveal clear patterns of changes between the two warming levels, with decreases in frost days in many regions.

3.SM.2.3 Regional Precipitation on Land, Including Heavy Precipitation and Monsoons

3.SM.2.3.1 Observed and Attributed Changes in Regional Precipitation

There is overall *low confidence* in observed trends for monsoons because of insufficient evidence (consistent with a previous assessment in the IPCC SREX, Seneviratne et al. 2012). There are, nonetheless, a few new assessments available, although they do not report consistent trends in different monsoon regions (Singh et al., 2014; Taylor et al., 2017; Bichet and Diedhiou, 2018). For instance, Singh et al. (2014) use precipitation observations (1951–2011) of the South Asian summer monsoon and show that there have been significant decreases in peak-season precipitation over the core-monsoon region and significant increases in daily-scale precipitation variability. Furthermore, Taylor et al. (2017) showed that over the west African Sahel, the frequency of extreme storms tripled since 1982 in satellite observations and Bichet and Diedhiou (2018) confirm that the region has been wetter during the last 30 years but dry spells are shorter and more frequent with a decreasing precipitation intensity in the western part (over Senegal). However, there is not sufficient evidence to provide higher than *low confidence* in the assessment of observations in overall trends in monsoons.

3.SM.2.3.2 Projected Changes at 1.5°C and 2°C in Regional Precipitation

The AR5 assessed that the global monsoon, aggregated over all monsoon systems, is likely to strengthen (Christensen et al., 2013). There are a few publications that provide more recent evaluations on projections of changes in monsoons for high-emissions scenarios. Jiang and Tian (2013), who compared the results of 31 and 29 reliable climate models under the Special Report on Emissions Scenarios (SRES) A1B scenario or the RCP4.5 scenario, respectively, found weak projected changes in the East Asian winter monsoon as a whole relative to the reference period (1980–1999). Regionally, they found a weakening north of about 25°N in East Asia and a strengthening south of this latitude, which resulted from atmospheric circulation changes over the western north Pacific Ocean and northeast Asia. This is linked to the weakening and northward shift of the Aleutian Low, and from decreased northwest–southeast thermal and sea level pressure differences across northeast Asia. In summer, Jiang and Tian (2013) found a projected strengthening (albeit, slight) of monsoon in east China over the 21st century as a consequence of an increased land–sea thermal contrast between the East Asian continent and the adjacent western north Pacific Ocean and South China Sea. Using six CMIP5 model simulations of the RCP8.5 high-emissions scenario, Jones and Carvalho (2013) found a 30% increase in the amplitude of the South American Monsoon System (SAMS) from the current level by 2045–2050. They also found an ensemble mean onset date of the SAMS which was 17 days earlier, and a demise date 17 days later, by 2045–2050. The most consistent CMIP5 projections analysed confirmed the increase in the total precipitation over southern Brazil, Uruguay and northern Argentina. Given that scenarios at 1.5°C or 2°C would include a substantially smaller radiative forcing than those assessed in the studies of Jiang and Tian (2013) and Jones and Carvalho (2013), there is *low confidence* regarding changes in monsoons at these low global warming levels, as well as regarding differences in responses at 1.5°C versus 2°C.

Several analyses of global circulation models (GCM-RCM) simulations in the framework of the Coordinated Regional Climate Downscaling Experiment for Africa (CORDEX-AFRICA) were performed to capture changes in the African climate system in a warmer climate. Sylla et al. (2015, 2016) analysed the response of the annual cycle of high-intensity daily precipitation events over West Africa to anthropogenic GHG for the late 21st century. The late-21st-century projected changes in mean precipitation exhibit a delay of the monsoon season and a decrease in frequency, but an increase in intensity of very wet events, particularly in the pre-monsoon and early mature monsoon stages, more pronounced in RCP8.5 over the Sahel and in RCP4.5 over the Gulf of Guinea. The pre-monsoon season also experiences the largest changes in daily precipitation statistics, with increased risk of drought associated with a decrease in mean precipitation and frequency of wet days and an increased risk of flood associated with very wet events. Weber et al. (2018) assessed the changes in temperature- and rainfall-related climate change indices in a 1.5°C, 2°C and 3°C global warming world for the Africa continent. The results showed the daily rainfall intensity is also projected to increase for higher global warming scenarios, especially for the sub-Saharan coastal regions.

Figure 3.SM.14 displays the same analyses as Figure 3.9 for the regions indicated with asterisks in Figure 3.2. For the underlying methodology, a similar approach was used as for Figure 3.5 (see Section 3.3.2.2).

3.SM.2.4 Drought and Dryness

Figure 3.SM.15 displays the same analyses as Figure 3.12 for the regions indicated with asterisks in Figure 3.2. For the underlying methodology, a similar approach was used as for Figure 3.5 (see Section 3.SM.3.2.2).

Supplementary Figures

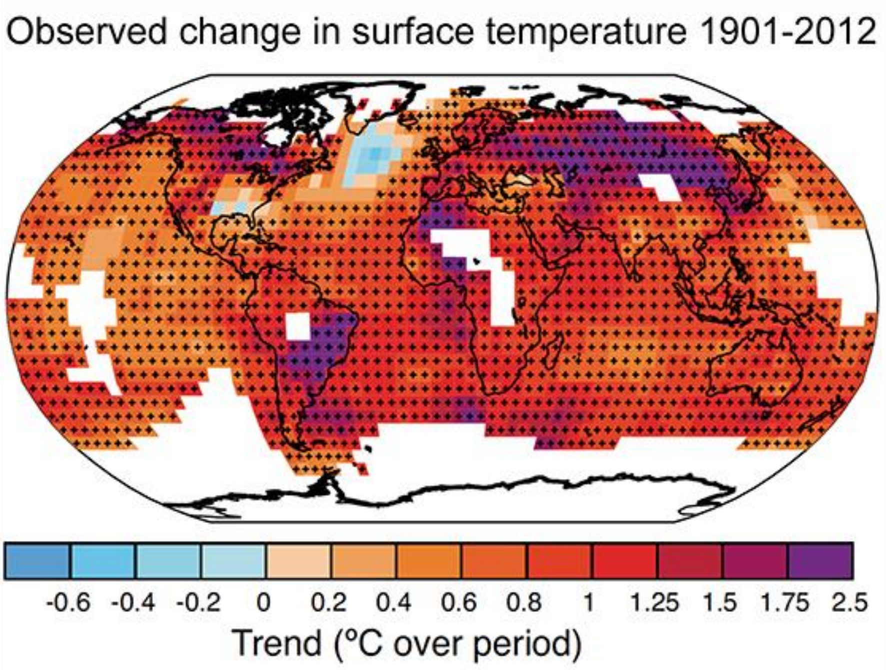


Figure 3.SM.1: Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset. Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign. From Stocker et al. (2013).

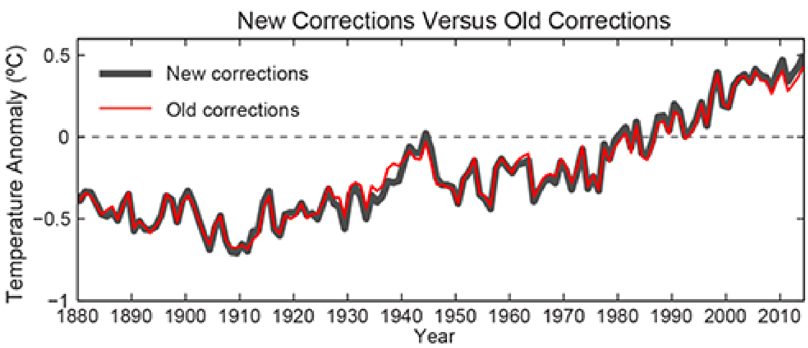
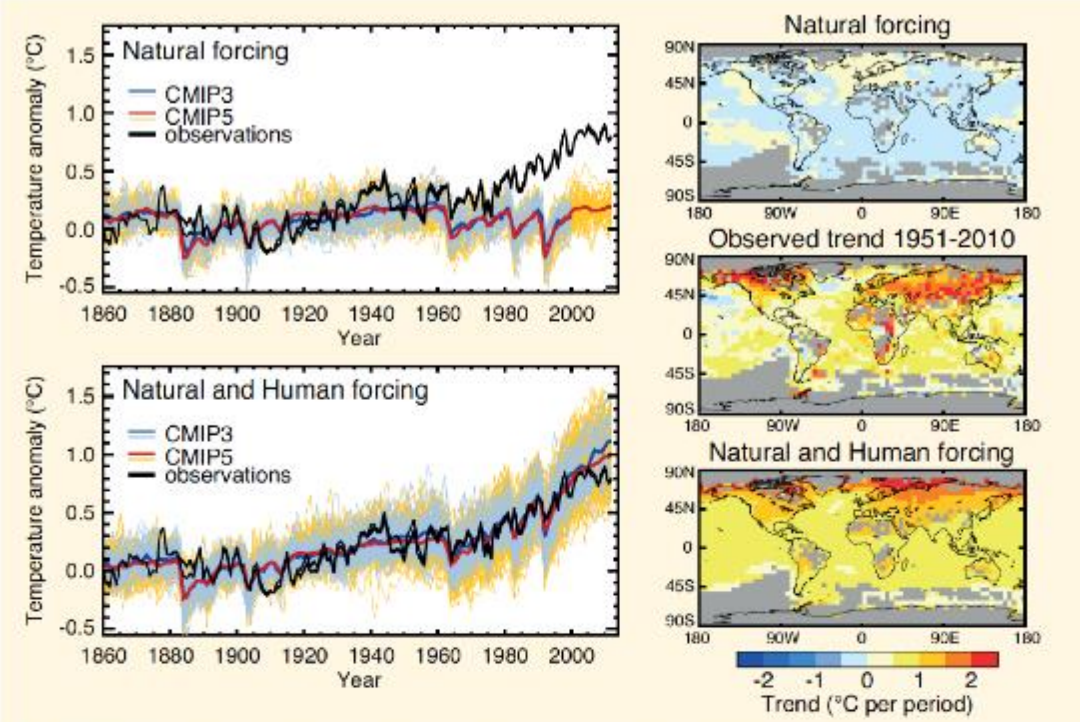


Figure 3.SM.2: Global temperature warming using older and newer corrections (Karl et al., 2015).



FAQ 10.1, Figure 1 | (Left) Time series of global and annual-averaged surface temperature change from 1860 to 2010. The top left panel shows results from two ensemble of climate models driven with just natural forcings, shown as thin blue and yellow lines; ensemble average temperature changes are thick blue and red lines. Three different observed estimates are shown as black lines. The lower left panel shows simulations by the same models, but driven with both natural forcing and human-induced changes in greenhouse gases and aerosols. (Right) Spatial patterns of local surface temperature trends from 1951 to 2010. The upper panel shows the pattern of trends from a large ensemble of Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations driven with just natural forcings. The bottom panel shows trends from a corresponding ensemble of simulations driven with natural + human forcings. The middle panel shows the pattern of observed trends from the Hadley Centre/Climatic Research Unit gridded surface temperature data set 4 (HadCRUT4) during this period.

Figure 3.SM.3: Attribution of global warming change (from IPCC AR5, Bindoff et al., 2013)

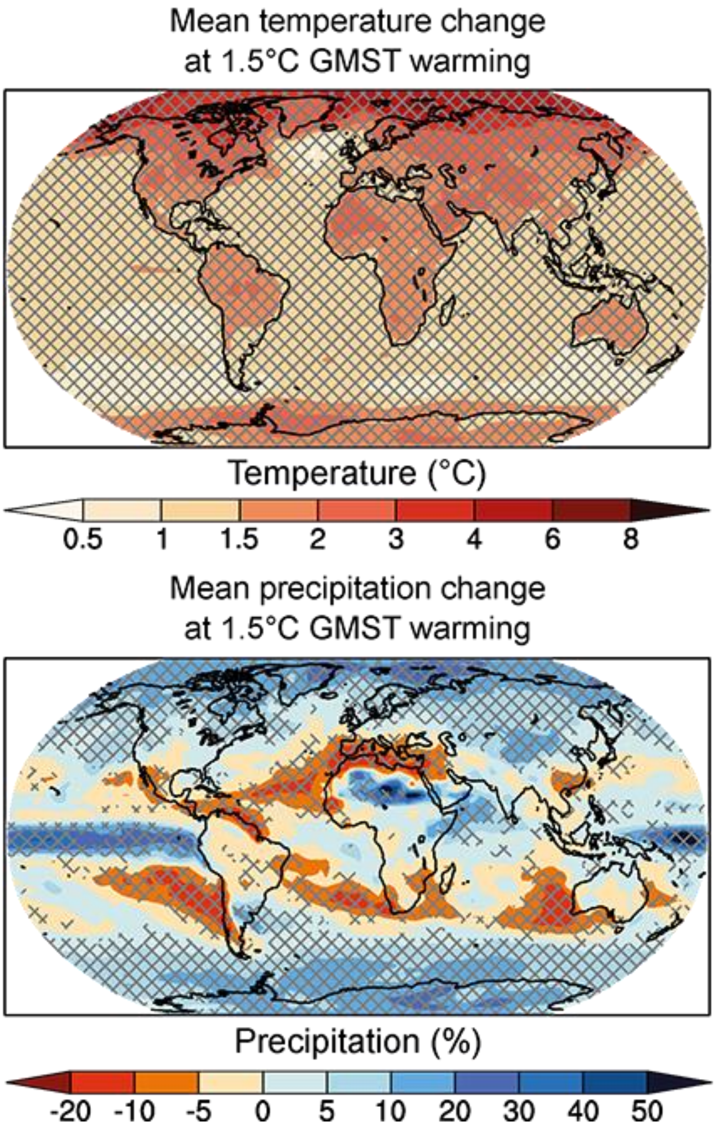


Figure 3.SM.4: Same as left-hand plots of Figure 3.3, but based on Representative Concentration Pathway (RCP)2.6 scenarios.

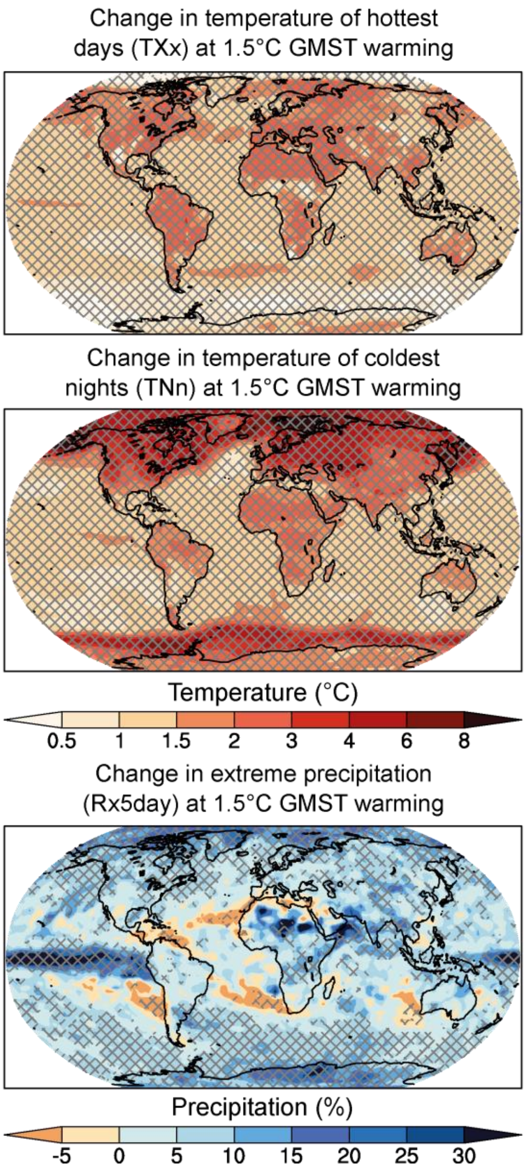


Figure 3.SM.5: Same as left-hand plot of Figure 3.4, but based on the Representative Concentration Pathway (RCP)2.6 scenarios.

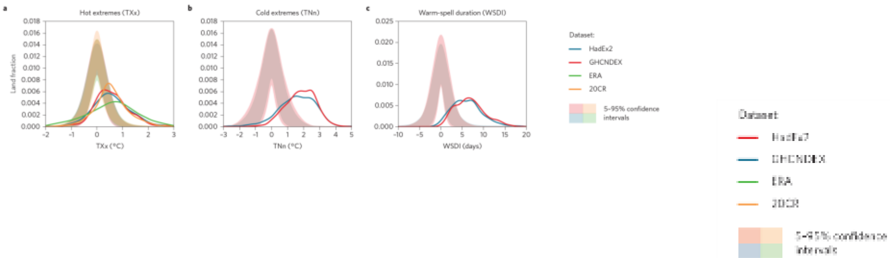


Figure 3.SM.6: Difference in extreme temperature event indices for 0.5°C warming over the observational record. Probability density functions show the globally aggregated land fraction that experienced a certain change between the 1991–2010 and 1960–1979 periods for the Hadley Centre Global Climate Extremes Index 2 (HadEX2) and Global Historical Climatology Network (GHCN)-Daily

climate Extremes (GHCNDEX) datasets. For annual maximum value of daily maximum temperature (TXx), the analysis also includes reanalysis data from the European Centre for Medium-Range Forecasts (ECMWF) (ECMWF Reanalysis 40 (ERA-40) and Interim (ERA-Interim), used as a combined dataset including ERA-40 until 1979 and ERA-Interim from 1979 onward) and the Twentieth Century Reanalysis (20CR) ERA and 20CR over the global land area. Light-coloured envelopes illustrate the changes expected by internal variability alone, estimated by statistically resampling individual years. From Schleussner et al. (2017).

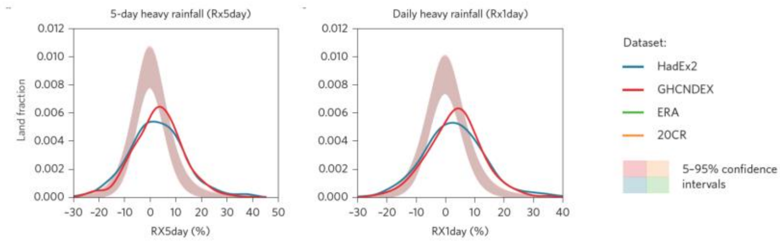


Figure 3.SM.7: Differences in extreme precipitation event indices for 0.5°C warming over the observational record. Probability density functions show the globally aggregated land fraction that experienced a certain change between the 1991–2010 and 1960–1979 periods for the HadEX2 and GHCNDEX datasets. Light-coloured envelopes illustrate the changes expected by internal variability alone, estimated by statistically resampling individual years. From Schleussner et al. (2017).

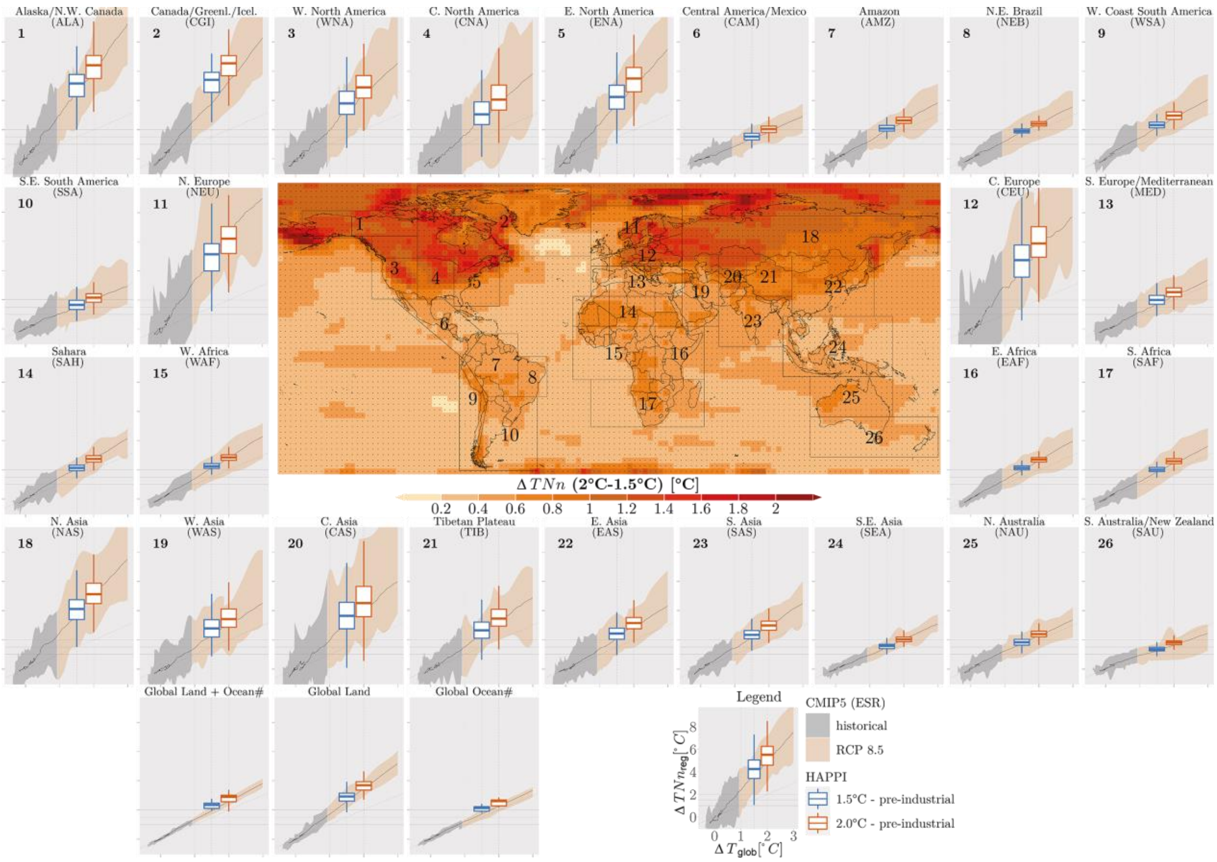


Figure 3.SM.8: Same analysis as Figure 3.5, but for the annual minimum value of daily minimum temperature (TNn). For more details on computation, see description of computation of Figure 3.5 in the present Annex, as well as Wartenburger et al. (2017), Seneviratne et al. (2016) and Seneviratne et al. (2018).

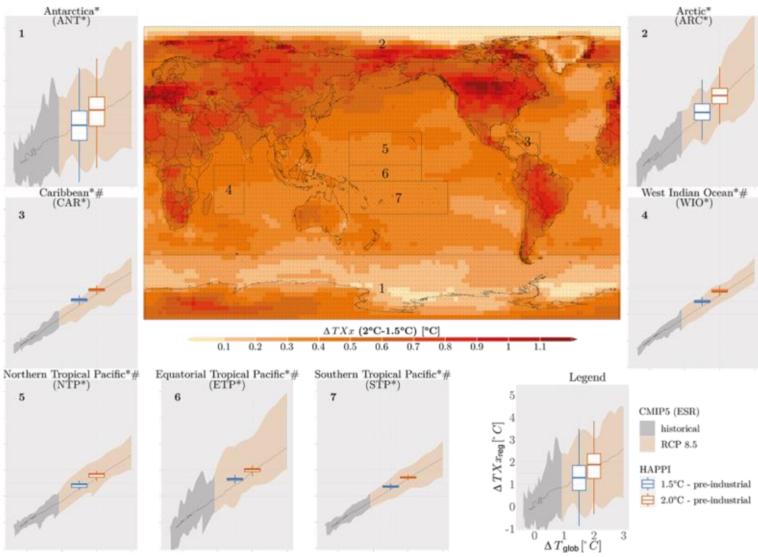


Figure 3.SM.9: Same analysis as Figure 3.5 (projected changes in annual maximum value of daily maximum temperature, TXx, as function of global temperature warming) for additional regions displayed with asterisks in Figure 3.2 (island regions, polar regions). Asterisks (*) indicate non-SREX reference regions (http://www.ipcc-data.org/guidelines/pages/ar5_regions.html). Hashtag (#) indicates island regions; for these regions, the ocean area was not masked out in the analyses. See description of computation of Figure 3.5 in the present Annex for more details.

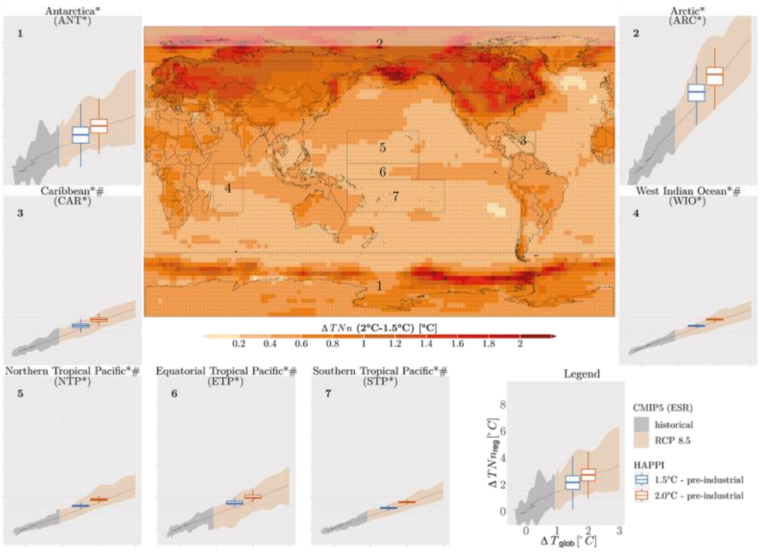


Figure 3.SM.10: Same analysis as Figure S3.8 (projected changes in TNn as function of global temperature warming) for additional regions displayed with asterisks in Figure 3.2 (island regions, polar regions). Asterisks (*) indicate non-SREX reference regions (http://www.ipcc-data.org/guidelines/pages/ar5_regions.html). Hashtag (#) indicates island regions; for these regions, the ocean area was not masked out in the analyses.

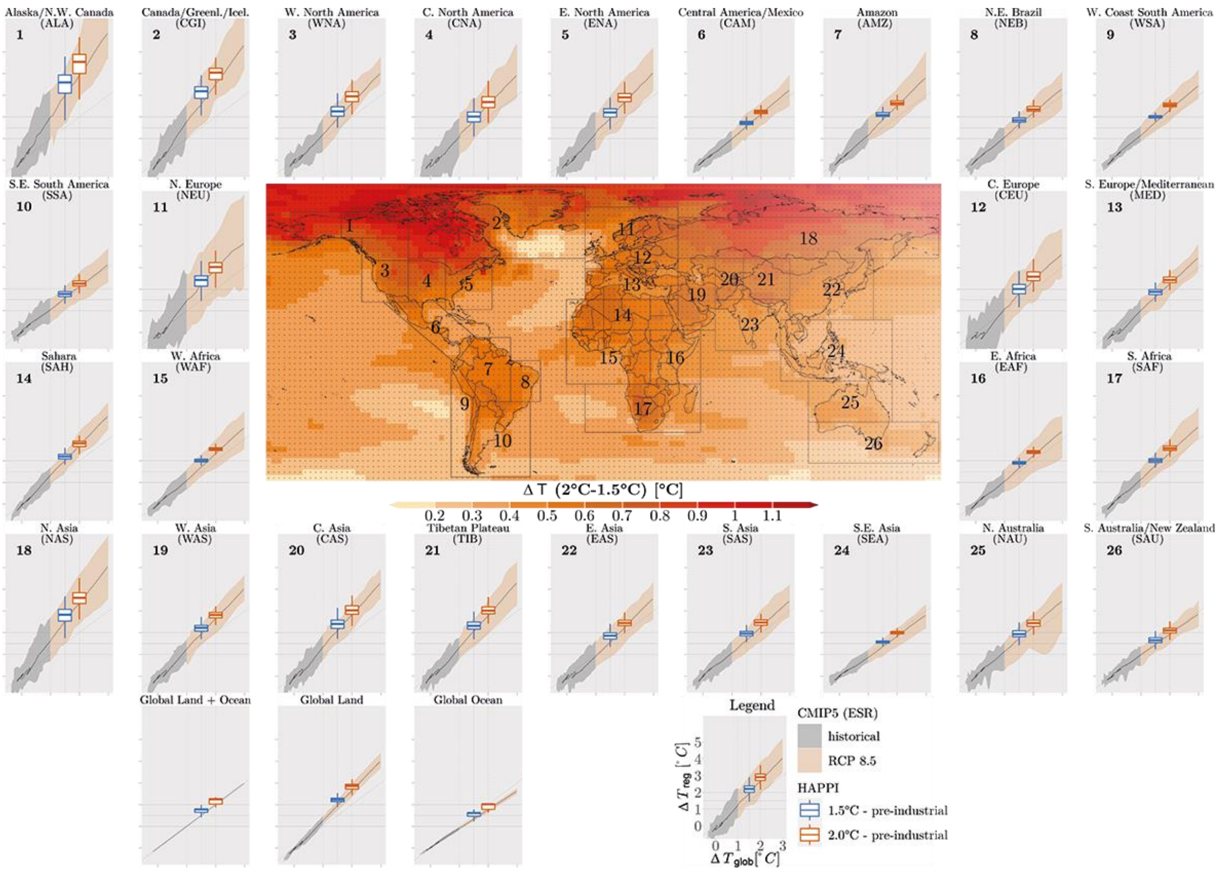


Figure 3.SM.11: Same analysis as Figure 3.5, but for the mean surface temperature (Tmean).

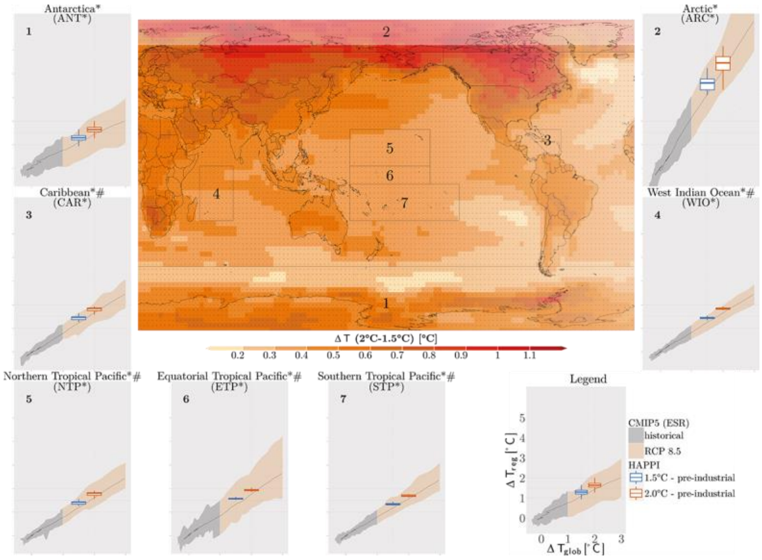


Figure 3.SM.12: Same analysis as Figure 3.SM.11 (projected in the changes in Tmean as function of the mean global temperature) for additional regions displayed with asterisks in Figure 3.2 (island regions, polar regions). Asterisks (*) indicate non-SREX reference regions (http://www.ipcc-data.org/guidelines/pages/ar5_regions.html). Hashtag (#) indicates island regions; for these regions, the ocean area was not masked out in the analyses.

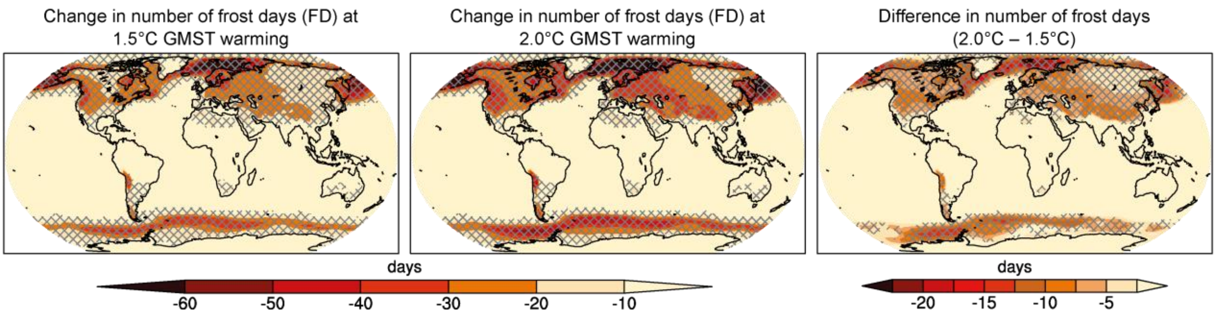


Figure 3.SM.13: Projected changes in number of frost days (days with T<0°C, bottom) at 1.5°C (left) and 2°C (middle) GMST increase, and their difference (right). Cross-hatching highlights areas in which at least 2/3rds of the models agree on the sign of change as a measure of robustness (18 or more out of 26). Adapted from Wartenburger et al. (2017).

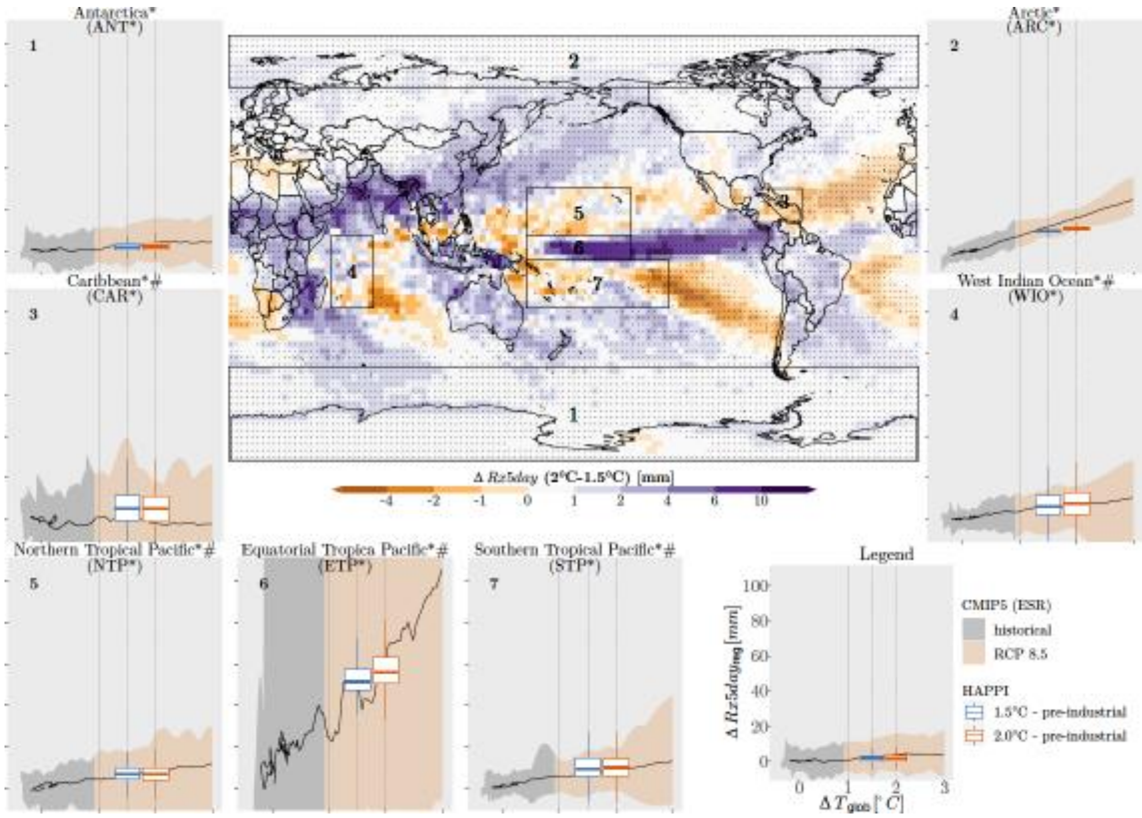


Figure 3.SM.14: Same analysis as Figure 3.9 for additional regions displayed with asterisks in Figure 3.2 (island regions, polar regions). Asterisks (*) indicate non-SREX reference regions (http://www.ipcc-data.org/guidelines/pages/ar5_regions.html). Hashtag (#) indicates island regions; for these regions, the ocean area was not masked out in the analyses.

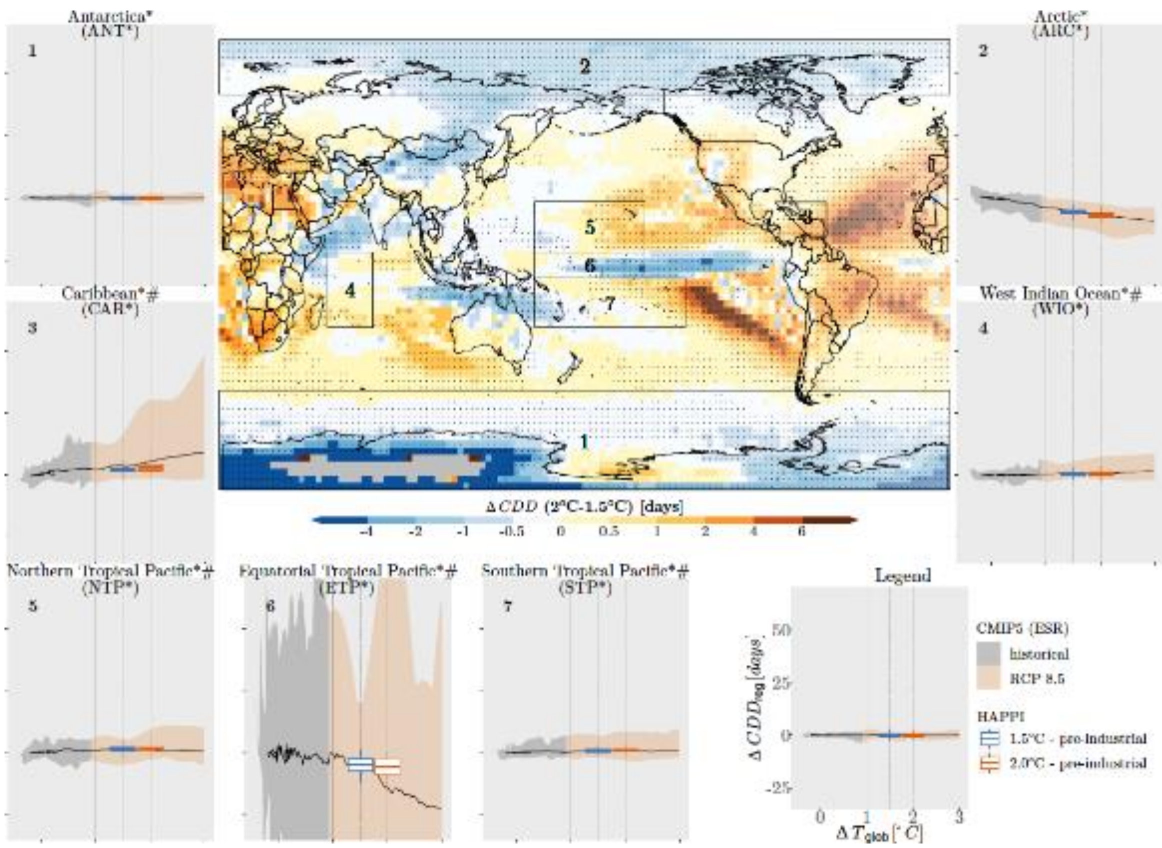


Figure 3.SM.15: Same analysis as Figure 3.12 for additional regions displayed with asterisks in Figure 3.2 (island regions, polar regions). Asterisks (*) indicate non-SREX reference regions (http://www.ipcc-data.org/guidelines/pages/ar5_regions.html). Hashtag (#) indicates island regions; for these regions, the ocean area was not masked out in the analyses.

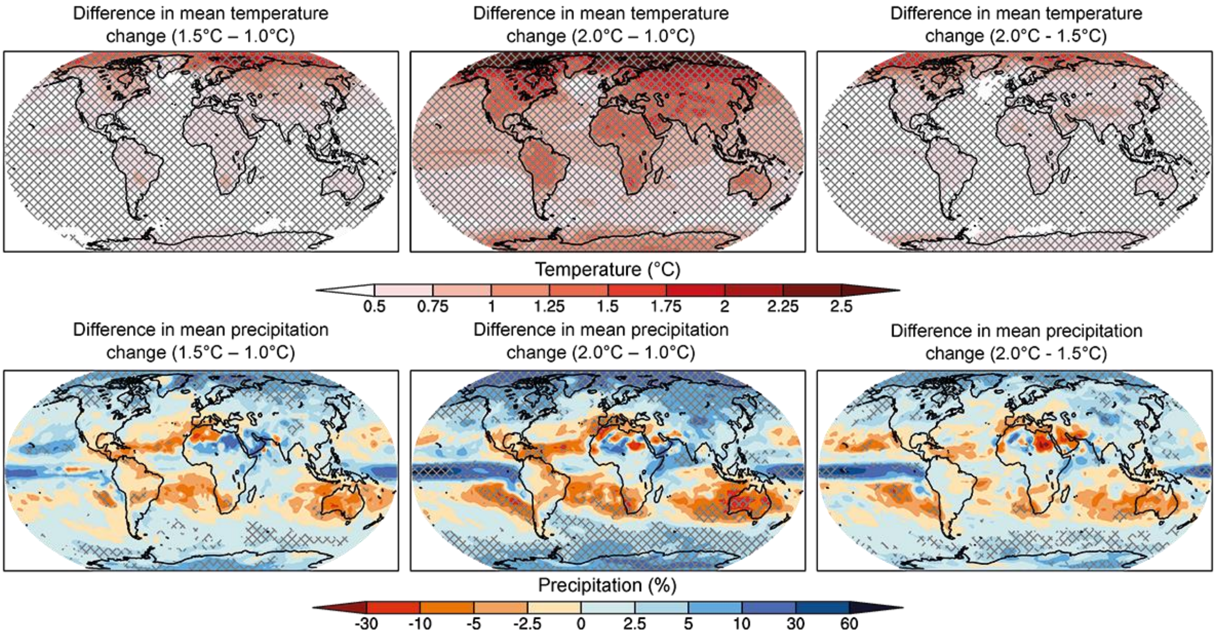


Figure 3.SM.16: Same as Figure 3.3 but for differences to 1°C global warming instead of pre-industrial conditions (left and middle plots).

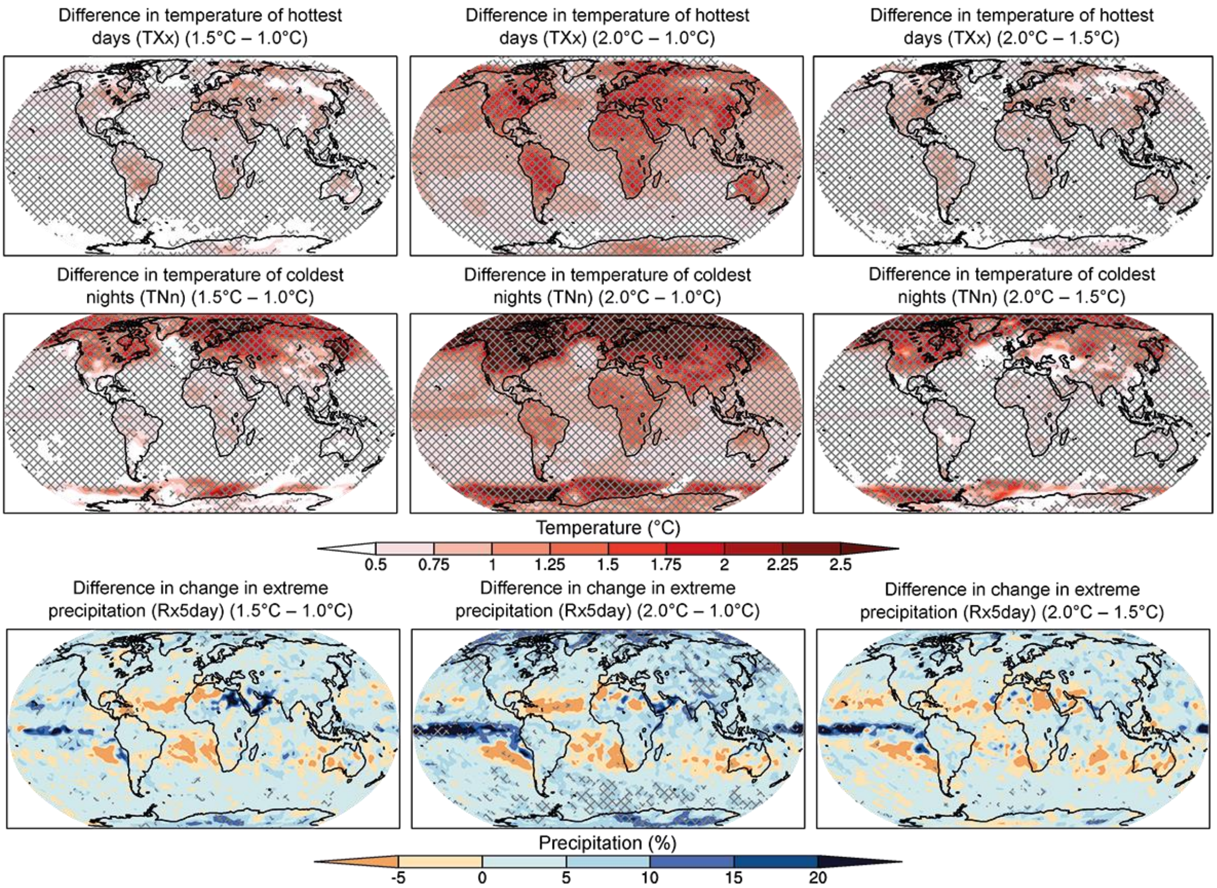


Figure 3.SM.17: Same as Figure 3.4 but for differences to 1°C global warming instead of pre-industrial conditions (left and middle plots).

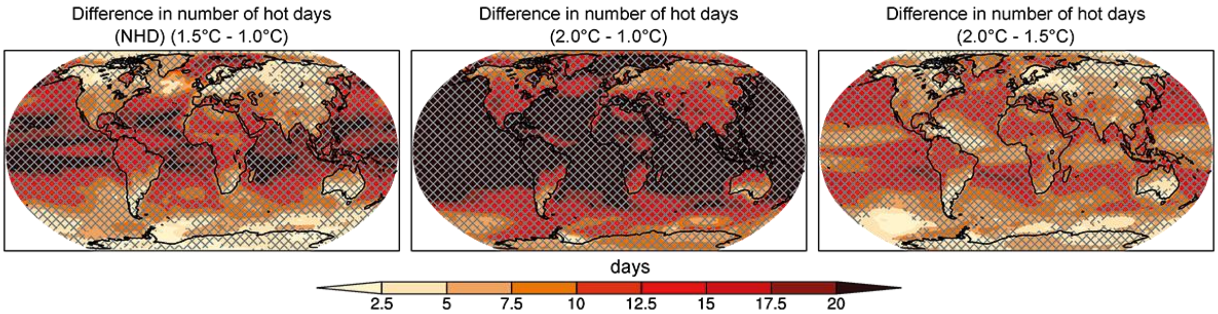


Figure 3.SM.18: Same as Figure 3.7 but for differences to 1°C global warming instead of pre-industrial conditions (left and middle plots).

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3.SM.3_ Supplementary information to Section 3.4

These tables document some of the quantitative projections of projected climate change impacts that are to be found in the literature cited in this report. They do not necessarily contain all of the quantitative projections that could be found in the literature, in particular where a single publication contains a large number of projections.

Table 3.SM.1: 3.4.2 Freshwater resources

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Water scarcity	Global	%	1980-2009	N/A	N/A	19GCM from the CMIP3 archive, MAGICC6, SRES A1F1, RCP8.5, 2086–2115	N/A	Y	N/A	8	N/A	N/A	8	2	N/A	N/A	Million people	Gerten et al., 2013	19GCM from the CMIP3 archive	N/A	2086–2115	Table 1, Fig.4 (a)
Water scarcity	Global	Million people (<1000m3cap-1y-1)	1980-2009	N/A	N/A	19GCM from the CMIP3 archive, MAGICC6, SRES A1F1, RCP8.5, 2086–2115	N/A	Y	N/A	1397	N/A	N/A	1397	2	N/A	Total 6012, affected 1267	Million people	Gerten et al., 2013	19GCM from the CMIP3 archive	N/A	2086–2115	Table 1
Water scarcity	Europe	Million people (<1000m3cap-1y-1)	1980-2009	N/A	N/A	19GCM from the CMIP3 archive, MAGICC6, SRES A1F1, RCP8.5, 2086–2115	N/A	Y	N/A	118	N/A	N/A	118	2	N/A	Total 505, affected 110	Million people	Gerten et al., 2013	19GCM from the CMIP3 archive	N/A	2086–2115	Table 1
Water scarcity	Asia	Million people (<1000m3cap-1y-1)	1980-2009	N/A	N/A	19GCM from the CMIP3 archive, MAGICC6, SRES A1F1, RCP8.5, 2086–2115	N/A	Y	N/A	Y	N/A	N/A	988	2	N/A	Total 3879, affected 870	Million people	Gerten et al., 2013	19GCM from the CMIP3 archive	N/A	2086–2115	Table 1
Water scarcity	Africa	Million people (<1000m3cap-1y-1)	1980-2009	N/A	N/A	19GCM from the CMIP3 archive, MAGICC6, SRES A1F1, RCP8.5, 2086–2115	N/A	Y	N/A	115	N/A	N/A	115	2	N/A	Total 775, affected 115	Million people	Gerten et al., 2013	19GCM from the CMIP3 archive	N/A	2086–2115	Table 1
Water scarcity	North America	Million people (<1000m3cap-1y-1)	1980-2009	N/A	N/A	19GCM from the CMIP3 archive, MAGICC6, SRES A1F1, RCP8.5, 2086–2115	N/A	Y	N/A	81	N/A	N/A	81	2	N/A	Total 479, affected 83	Million people	Gerten et al., 2013	19GCM from the CMIP3 archive	N/A	2086–2115	Table 1
Water scarcity	South America	Million people (<1000m3cap-1y-1)	1980-2009	N/A	N/A	19GCM from the CMIP3 archive, MAGICC6, SRES A1F1, RCP8.5, 2086–2115	N/A	Y	N/A	82	N/A	N/A	82	2	N/A	Total 345, affected 77	Million people	Gerten et al., 2013	19GCM from the CMIP3 archive	N/A	2086–2115	Table 1
Water scarcity	Oceania	Million people (<1000m3cap-1y-1)	1980-2009	N/A	N/A	19GCM from the CMIP3 archive, MAGICC6, SRES A1F1, RCP8.5, 2086–2115	N/A	Y	N/A	13	N/A	N/A	13	2	N/A	Total 29, affected 13	Million people	Gerten et al., 2013	19GCM from the CMIP3 archive	N/A	2086–2115	Table 1
Water resources	Global	%	1980-2010	SSP2	0,7	Transition of RCP8.5, 2080, 11 GHMs by 5 GCMs	T	Y	N/A	N/A	N/A	N/A	8	1,7	1	N/A	N/A	Schewe et al., 2014	HadGEM2-ES,IPSL-CM5A LR,MIROC-ESM-CHEM,GFDL-ESM2M, NorESM1-M	N/A	2090	Fig.2,p3247 Table S1 (GCM) Table S2 (GHM)
Water resources	Global	%	1980-2010	SSP2	0,7	Transition of RCP8.5, 2080, 11 GHMs by 5 GCMs	T	Y	N/A	N/A	N/A	N/A	14	2,7	2	N/A	N/A	Schewe et al., 2014	HadGEM2-ES,IPSL-CM5A LR,MIROC-ESM-CHEM,GFDL-ESM2M, NorESM1-M	N/A	2090	Fig.2,p3247 Table S1 (GCM) Table S2 (GHM)
Water scarcity, Increased water resources stress	Global	Million people	1961–1990	SSP1	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	E	N/A	1330	N/A	N/A	N/A	1330 (379-2997)	Around 1.6	Around 1.3	Population in 2050, total 8411, water stressed 3286	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3,NorESM1-M,NorESM1-ME, bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1 Supplementary Table 1 (GCM)
Water scarcity, Increased water resources stress	Global	Million people (<1000m3cap-1y-1)	1961–1990	SSP1	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	1514	N/A	N/A	1514 (810-2845)	Around 2	Around 1.7	Population in 2050, total 8411, water stressed 3286	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3,NorESM1-M,NorESM1-ME, bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1
Water scarcity, Increased water resources stress	Global	Million people (<1000m3cap-1y-1)	1961–1990	SSP2	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	E	N/A	1575	N/A	N/A	N/A	1575 (473-3434)	Around 1.6	Around 1.3	Population in 2050, total 9245, water stressed 4079	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3,NorESM1-M,NorESM1-ME, bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1
Water scarcity, Increased water resources stress	Global	Million people (<1000m3cap-1y-1)	1961–1990	SSP2	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	1794	N/A	N/A	1794 (881-3239)	Around 2	Around 1.7	Population in 2050, total 9245, water stressed 4079	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3,NorESM1-M,NorESM1-ME, bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Water scarcity, increased water resources stress	Global	Million people (<1000m3cap-1yr-1)	1961–1990	SSP3	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	E	N/A	1887	N/A	N/A	N/A	1887 (626-4088)	Around 1.6	Around 1.3	Population in 2050, total 10233, water-stressed 4774	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1
Water scarcity, increased water resources stress	Global	Million people (<1000m3cap-1yr-1)	1961–1990	SSP3	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	2157	N/A	N/A	2157 (1037-3975)	Around 2	Around 1.7	Population in 2050, total 10233, water-stressed 4774	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1
Water scarcity, increased water resources stress	Global	Million people (<1000m3cap-1yr-1)	1961–1990	SSP4	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	E	N/A	1666	N/A	N/A	N/A	1666 (508-3481)	Around 1.6	Around 1.3	Population in 2050, total 9368, water-stressed 4236	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1
Water scarcity, increased water resources stress	Global	Million people (<1000m3cap-1yr-1)	1961–1990	SSP4	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	1867	N/A	N/A	1867 (884-3444)	Around 2	Around 1.7	Population in 2050, total 9368, water-stressed 4236	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1
Water scarcity, increased water resources stress	Global	Million people (<1000m3cap-1yr-1)	1961–1990	SSP5	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	T	N/A	1375	N/A	N/A	N/A	1375 (418-3033)	Around 1.6	Around 1.3	Population in 2050, total 8508, water-stressed 3350	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1
Water scarcity, increased water resources stress	Global	Million people (<1000m3cap-1yr-1)	1961–1990	SSP5	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	1566	N/A	N/A	1566 (854-2879)	Around 2	Around 1.7	Population in 2050, total 8508, water-stressed 3350	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 a) Fig.1
Freshwater stress	Bahamas	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,27	N/A	N/A	N/A	1,27	1,5	0,9	0,34	Million people (2010)	Karnauskas et al., 2018	access1-0, access1-3, bcc-csm1-1, csm1-1-m, cesm1-cam5, cnrm-cm5, csiro-mk3-6-0, gfdl-cm3, gfdl-esm2g, gfdl-esm2m, giss-e2-r, hadgem2-cc, hadgem2-es, inmcm4, ipsl-cm5a-lr, ipsl-cm5a-mr, miroc-esm, miroc-esm-chem, miroc5, mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Bahamas	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,27	N/A	N/A	1,27	2	1.4	0,34	Million people (2010)	Karnauskas et al., 2018	access1-0, access1-3, bcc-csm1-1, csm1-1-m, cesm1-cam5, cnrm-cm5, csiro-mk3-6-0, gfdl-cm3, gfdl-esm2g, gfdl-esm2m, giss-e2-r, hadgem2-cc, hadgem2-es, inmcm4, ipsl-cm5a-lr, ipsl-cm5a-mr, miroc-esm, miroc-esm-chem, miroc5, mri-cgcm3	N/A	2100	Table 1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Freshwater stress	Belize	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,4	N/A	N/A	N/A	1,4	1,5	0,9	0,31	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Belize	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,41	N/A	N/A	1,41	2	1,4	0,31	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Cabo Verde	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,18	N/A	N/A	N/A	1,18	1,5	0,9	0,5	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Cabo Verde	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,2	N/A	N/A	1,2	2	1,4	0,5	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Comoros	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,43	N/A	N/A	N/A	1,43	1,5	0,9	0,73	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Comoros	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,44	N/A	N/A	1,44	2	1,4	0,73	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Cuba	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	0,98	N/A	N/A	N/A	0,98	1,5	0,9	11,26	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Cuba	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	0,99	N/A	N/A	0,99	2	1,4	11,26	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Freshwater stress	Dominican Republic	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,28	N/A	N/A	N/A	1,28	1,5	0,9	9,93	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Dominican Republic	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,36	N/A	N/A	1,36	2	1,4	9,93	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Fiji	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,13	N/A	N/A	N/A	1,13	1,5	0,9	0,86	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Fiji	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,16	N/A	N/A	1,16	2	1,4	0,86	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Grenada	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,16	N/A	N/A	N/A	1,16	1,5	0,9	0,1	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Grenada	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,21	N/A	N/A	1,21	2	1,4	0,1	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Guinea-Bissau	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,51	N/A	N/A	N/A	1,51	1,5	0,9	1,52	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Guinea-Bissau	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,5	N/A	N/A	1,5	2	1,4	1,52	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Freshwater stress	Guyana	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,11	N/A	N/A	N/A	1,11	1,5	0,9	0,75	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Guyana	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0.6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,12	N/A	N/A	1,12	2	1,4	0,75	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Haiti	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,25	N/A	N/A	N/A	1,25	1,5	0,9	9,99	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Haiti	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0.6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,31	N/A	N/A	1,31	2	1,4	9,99	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Jamaica	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,09	N/A	N/A	N/A	1,09	1,5	0,9	2,74	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Jamaica	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0.6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,13	N/A	N/A	1,13	2	1,4	2,74	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Maldives	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,25	N/A	N/A	N/A	1,25	1,5	0,9	0,32	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Maldives	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0.6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,22	N/A	N/A	1,22	2	1,4	0,32	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Freshwater stress	Mauritius	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP85, SSP2	T	Y	1,13	N/A	N/A	N/A	1,13	1,5	0,9	1,3	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Mauritius	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP85, SSP2	T	Y	N/A	1,17	N/A	N/A	1,17	2	1,4	1,3	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Micronesia	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP85, SSP2	T	Y	1,03	N/A	N/A	N/A	1,03	1,5	0,9	0,11	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Micronesia	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP85, SSP2	T	Y	N/A	1,03	N/A	N/A	1,03	2	1,4	0,11	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Papua New Guinea	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP85, SSP2	T	Y	1,37	N/A	N/A	N/A	1,37	1,5	0,9	6,86	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Papua New Guinea	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP85, SSP2	T	Y	N/A	1,37	N/A	N/A	1,37	2	1,4	6,86	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	St. Lucia	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP85, SSP2	T	Y	1,23	N/A	N/A	N/A	1,23	1,5	0,9	0,17	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	St. Lucia	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP85, SSP2	T	Y	N/A	1,27	N/A	N/A	1,27	2	1,4	0,17	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Freshwater stress	St. Vincent & Grenadines	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,06	N/A	N/A	N/A	1,06	1,5	0,9	0,11	Million people (2010)	Karnaustas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm,-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	St. Vincent & Grenadines	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,11	N/A	N/A	1,11	2	1,4	0,11	Million people (2010)	Karnaustas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm,-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Samoa	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,02	N/A	N/A	N/A	1,02	1,5	0,9	0,18	Million people (2010)	Karnaustas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm,-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Samoa	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,06	N/A	N/A	1,06	2	1,4	0,18	Million people (2010)	Karnaustas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm,-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Sao Tome & Principe	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,17	N/A	N/A	N/A	1,17	1,5	0,9	0,17	Million people (2010)	Karnaustas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm,-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Sao Tome & Principe	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,17	N/A	N/A	1,17	2	1,4	0,17	Million people (2010)	Karnaustas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm,-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Singapore	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,25	N/A	N/A	N/A	1,25	1,5	0,9	5,09	Million people (2010)	Karnaustas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm,-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Singapore	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,26	N/A	N/A	1,26	2	1,4	5,09	Million people (2010)	Karnaustas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm,-chem,miroc5,mri-cgcm3	N/A	2100	Table 1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Freshwater stress	Solomon Islands	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,45	N/A	N/A	N/A	1,45	1,5	0,9	0,54	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Solomon Islands	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,47	N/A	N/A	1,47	2	1,4	0,54	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Suriname	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,25	N/A	N/A	N/A	1,25	1,5	0,9	0,52	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Suriname	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,25	N/A	N/A	1,25	2	1,4	0,52	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Timor-Leste	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,52	N/A	N/A	N/A	1,52	1,5	0,9	1,12	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Timor-Leste	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,54	N/A	N/A	1,54	2	1,4	1,12	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Tonga	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,07	N/A	N/A	N/A	1,07	1,5	0,9	0,1	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Tonga	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,07	N/A	N/A	1,07	2	1,4	0,1	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Freshwater stress	Trinidad & Tobago	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,1	N/A	N/A	N/A	1,1	1,5	0,9	1,34	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Trinidad & Tobago	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,14	N/A	N/A	1,14	2	1,4	1,34	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Vanuatu	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	1,5	N/A	N/A	N/A	1,5	1,5	0,9	0,24	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Freshwater stress	Vanuatu	FSI (freshwater stress index) = PCI (population change index) × ACI (aridity change index)	1986–2005 (climatology), 2010 (population)	SSP1–5	0,6	20GCM, CMIP5, 2030, RCP8.5, SSP2	T	Y	N/A	1,52	N/A	N/A	1,52	2	1,4	0,24	Million people (2010)	Karnauskas et al., 2018	access1-0,access1-3,bcc-csm1-1,csm1-1-m,cesm1-cam5,cnrm-cm5,csiro-mk3-6-0,gfdl-cm3,gfdl-esm2g,gfdl-esm2m,giss-e2-r,hadgem2-cc,hadgem2-es,inmcm4,ipsl-cm5a-lr,ipsl-cm5a-mr,miroc-esm,miroc-esm-chem,miroc5,mri-cgcm3	N/A	2100	Table 1
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2011–2040, MIROC-ESM-CHEM, H08	T	Y	N/A	1,4	N/A	N/A	1,4	2,1	1,7	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2011–2040	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2041–2070, MIROC-ESM-CHEM, H08	E	Y	N/A	N/A	N/A	N/A	0,8	2,8	2,4	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2071–2100, MIROC-ESM-CHEM, H08	E	Y	N/A	N/A	N/A	N/A	1,6	2,8	2,4	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2071–2100	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2011–2040, HadGEM2-ES, H08	T	Y	N/A	N/A	N/A	N/A	0,9	2,2	1,8	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2011–2040	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2041–2070, HadGEM2-ES, H08	E	Y	N/A	N/A	N/A	N/A	-0,0	2,8	2,4	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2071–2100, HadGEM2-ES, H08	E	Y	N/A	N/A	N/A	N/A	-0,2	2,7	2,3	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2071–2100	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2011–2040, GFDL-ESM2M, H08	T	Y	1,8	N/A	N/A	N/A	1,8	1,5	1,1	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2011–2040	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2041–2070, GFDL-ESM2M, H08	E	Y	N/A	N/A	N/A	N/A	2	1,7	1,3	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP2.6, 2071–2100, GFDL-ESM2M, H08	E	Y	1,1	N/A	N/A	N/A	1,1	1,6	1,2	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2071–2100	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2011–2040, MIROC-ESM-CHEM, H08	T	Y	N/A	1,4	N/A	N/A	1,4	1,9	1,5	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2011–2040	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2041–2070, MIROC-ESM-CHEM, H08	T	Y	N/A	N/A	N/A	N/A	2,4	3,3	2,9	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2071–2100, MIROC-ESM-CHEM, H08	T	Y	N/A	N/A	N/A	2,8	2,8	4	3,6	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2071–2100	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2011–2040, HadGEM2-ES, H08	T	Y	N/A	0,6	N/A	N/A	0,6	2,1	1,7	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2011–2040	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2041–2070, HadGEM2-ES, H08	T	Y	N/A	N/A	N/A	N/A	1,7	3,5	3,1	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2071–2100, HadGEM2-ES, H08	T	Y	N/A	N/A	N/A	N/A	1,9	4,3	3,9	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2071–2100	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2011–2040, GFDL-ESM2M, H08	T	Y	2,3	N/A	N/A	N/A	2,3	1,6	1,2	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2011–2040	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2041–2070, GFDL-ESM2M, H08	T	Y	N/A	N/A	N/A	N/A	2,3	2,2	1,8	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP4.5, 2071–2100, GFDL-ESM2M, H08	T	Y	N/A	N/A	N/A	N/A	2,4	2,4	2	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2071–2100	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2011–2040, MIROC-ESM-CHEM, H08	T	Y	N/A	2	N/A	N/A	2	2,1	1,7	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2011–2040	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2041–2070, MIROC-ESM-CHEM, H08	T	Y	N/A	N/A	N/A	N/A	4,8	4,2	3,8	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2071–2100, MIROC-ESM-CHEM, H08	T	Y	N/A	N/A	N/A	N/A	10	6,7	6,3	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	MIROC-ESM-CHEM	N/A	2071–2100	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2011–2040, HadGEM2-ES, H08	T	Y	N/A	N/A	N/A	N/A	0,9	2,3	1,9	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2011–2040	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2041–2070, HadGEM2-ES, H08	T	Y	N/A	N/A	N/A	N/A	2,9	4,4	4	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2071–2100, HadGEM2-ES, H08	T	Y	N/A	N/A	N/A	N/A	6,7	6,8	6,4	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	HadGEM2-ES	N/A	2071–2100	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2011–2040, GFDL-ESM2M, H08	T	Y	1,7	N/A	N/A	N/A	1,7	1,6	1,2	3214	$km^3\ y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2011–2040	Table 6, Table 9

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2041–2070, GFDL-ESM2M, H08	T	Y	N/A	N/A	N/A	N/A	3,8	2,8	2,4	3214	$km^3 y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2041–2070	Table 6, Table 9
Water scarcity, water withdrawal	Global	%	1971–2000	SSP1–5	0,4	RCP8.5, 2071–2100, GFDL-ESM2M, H08	T	Y	N/A	N/A	N/A	N/A	7,1	4,2	3,8	3214	$km^3 y^{-1}$	Hanasaki et al., 2013	GFDL-ESM2M	N/A	2071–2100	Table 6, Table 9
Impacts on hydropower production	Greece, Portugal, Spain	% (power change)	1971–2000	N/A	N/A	3 GCMs and 3 RCMs, RCP4.5, 8.5, 2004–2043	N/A	N/A	Decrease 5% or less	N/A	N/A	N/A	Decrease 5% or less	1,5	N/A	N/A	N/A	Tobin et al., 2018	MPI-ESM-LR-r1,HadGEM2-ES-r1,EC-EARTH(-r1,-r12)	CSC-REMO,SMHI-RCA4,KNMI-RACMO22E	N/A	p5, Fig.1c
Impacts on hydropower production	Greece, Portugal, Spain	% (power change)	1971–2000	N/A	N/A	3 GCMs and 3 RCMs, RCP4.5, 8.5, 2016–2059	N/A	N/A	N/A	Decrease below 10%	N/A	N/A	Decrease below 10%	2	N/A	N/A	N/A	Tobin et al., 2018	MPI-ESM-LR-r1,HadGEM2-ES-r1,EC-EARTH(-r1,-r12)	CSC-REMO,SMHI-RCA4,KNMI-RACMO22E	N/A	p5, Fig.1c
Impacts on hydropower production	Greece, Portugal, Spain	% (power change)	1971–2000	N/A	N/A	3 GCMs and 3 RCMs, RCP4.5, 8.5, 2037–2084	N/A	N/A	N/A	N/A	Decrease between 15–20%	N/A	Decrease between 15–20%	3	N/A	N/A	N/A	Tobin et al., 2018	MPI-ESM-LR-r1,HadGEM2-ES-r1,EC-EARTH(-r1,-r12)	CSC-REMO,SMHI-RCA4,KNMI-RACMO22E	N/A	p5, Fig.1c
Impacts on thermoelectric power production	Europe	% (power change)	1971–2000	N/A	N/A	3 GCMs and 3 RCMs, RCP4.5, 8.5, 2004–2043	N/A	N/A	Decrease about 5%	N/A	N/A	N/A	Decrease about 5%	1,5	N/A	N/A	N/A	Tobin et al., 2018	MPI-ESM-LR-r1,HadGEM2-ES-r1,EC-EARTH(-r1,-r12)	CSC-REMO,SMHI-RCA4,KNMI-RACMO22E	N/A	p5, Fig.1d
Impacts on thermoelectric power production	Europe	% (power change)	1971–2000	N/A	N/A	3 GCMs and 3 RCMs, RCP4.5, 8.5, 2016–2059	N/A	N/A	N/A	Decrease about 10%	N/A	N/A	Decrease about 10%	2	N/A	N/A	N/A	Tobin et al., 2018	MPI-ESM-LR-r1,HadGEM2-ES-r1,EC-EARTH(-r1,-r12)	CSC-REMO,SMHI-RCA4,KNMI-RACMO22E	N/A	p5, Fig.1d
Impacts on thermoelectric power production	Europe	% (power change)	1971–2000	N/A	N/A	3 GCMs and 3 RCMs, RCP4.5, 8.5, 2037–2084	N/A	N/A	N/A	N/A	Decrease abut 15% (Bulgaria, Greece, Spain; 15–20% decrease)	N/A	Decrease about15% (Bulgaria, Greece, Spain; 15–20% decrease)	3	N/A	N/A	N/A	Tobin et al., 2018	MPI-ESM-LR-r1,HadGEM2-ES-r1,EC-EARTH(-r1,-r12)	CSC-REMO,SMHI-RCA4,KNMI-RACMO22E	N/A	p5, Fig.1d
Increased flooding, population affected	Global	%	1976–2005	N/A	N/A	Transition, 7 GCMs, EC-EARTH3-HR v3.1, RCP8.5	T	N/A	100	N/A	N/A	N/A	100	15	N/A	N/A	N/A	Alfieri et al., 2017	IPSL-CM5A-LR, GFDL-ESM2M , HadGEM2-ES, EC-EARTH, GISS-E2-H, IPSL-CM5A-MR, HadCM3LC	N/A	2100	p 176-179 Fig4-Fig6
Increased flooding, population affected	Global	%	1976–2005	N/A	N/A	Transition, 7 GCMs, EC-EARTH3-HR v3.1, RCP8.5	T	N/A	N/A	170	N/A	N/A	170	2	N/A	N/A	N/A	Alfieri et al., 2017	IPSL-CM5A-LR, GFDL-ESM2M , HadGEM2-ES, EC-EARTH, GISS-E2-H, IPSL-CM5A-MR, HadCM3LC	N/A	2100	p 176-179 Fig4-Fig6
Increased flooding, population affected	Global	%	1976–2005	N/A	N/A	Transition, 7 GCMs, EC-EARTH3-HR v3.1, RCP8.5	T	N/A	N/A	N/A	N/A	580	580	4	N/A	N/A	N/A	Alfieri et al., 2017	IPSL-CM5A-LR, GFDL-ESM2M , HadGEM2-ES, EC-EARTH, GISS-E2-H, IPSL-CM5A-MR, HadCM3LC	N/A	2100	p 176-179 Fig4-Fig6
River flood risk	38 European countries	Population affected (1000pp/year)	1976–2005	N/A	N/A	7 JRC-EU, 5 ISIMIP, 7 JRC-GL, RCP8.5, SWLs (specific warming levels)	N/A	N/A	650	N/A	N/A	N/A	650	1,5	N/A	350	Population affected (1000pp/year)	Alfieri et al., 2018	3 JRC-EU(EC-EARTH,HadGEM2-ES,MPI-ESM-LR),5 ISIMIP(GFDL-ESM2M,HadGEM2-ES,IPSL-CM5A-LR,MIROC-ESM-CHEM,NorESM1-M),7 JRC-GL(IPSL-CM5A-LR,GFDL-ESM2M,HadGEM2-ES,EC-EARTH,GISS-E2-H,IPSL-CM5A-MR,HadCM3LC)	4 JRC-EU(RACMO22E,REMO2009,CCLM4-8-17,RCA4),JRC-GL(EC-EARTH3-HR)	N/A	Table 3
River flood risk	38 European countries	Population affected (1000pp/year)	1976–2005	N/A	N/A	7 JRC-EU, 5 ISIMIP, 7 JRC-GL, RCP8.5, SWLs (specific warming levels)	N/A	N/A	N/A	674	N/A	N/A	674	2	N/A	350	Population affected (1000pp/year)	Alfieri et al., 2018	3 JRC-EU(EC-EARTH,HadGEM2-ES,MPI-ESM-LR),5 ISIMIP(GFDL-ESM2M,HadGEM2-ES,IPSL-CM5A-LR,MIROC-ESM-CHEM,NorESM1-M),7 JRC-GL(IPSL-CM5A-LR,GFDL-ESM2M,HadGEM2-ES,EC-EARTH,GISS-E2-H,IPSL-CM5A-MR,HadCM3LC)	4 JRC-EU(RACMO22E,REMO2009,CCLM4-8-17,RCA4),JRC-GL(EC-EARTH3-HR)	N/A	Table 3
River flood risk	38 European countries	Population affected (1000pp/year)	1976–2005	N/A	N/A	7 JRC-EU, 5 ISIMIP, 7 JRC-GL, RCP8.5, SWLs (specific warming levels)	N/A	N/A	N/A	N/A	781	N/A	781	3	N/A	350	Population affected (1000pp/year)	Alfieri et al., 2018	3 JRC-EU(EC-EARTH,HadGEM2-ES,MPI-ESM-LR),5 ISIMIP(GFDL-ESM2M,HadGEM2-ES,IPSL-CM5A-LR,MIROC-ESM-CHEM,NorESM1-M),7 JRC-GL(IPSL-CM5A-LR,GFDL-ESM2M,HadGEM2-ES,EC-EARTH,GISS-E2-H,IPSL-CM5A-MR,HadCM3LC)	4 JRC-EU(RACMO22E,REMO2009,CCLM4-8-17,RCA4),JRC-GL(EC-EARTH3-HR)	N/A	Table 3
River flood risk	38 European countries	Population affected, relative change (%)	1976–2005	N/A	N/A	7 JRC-EU, 5 ISIMIP, 7 JRC-GL, RCP8.5, SWLs (specific warming levels)	N/A	N/A	86	N/A	N/A	N/A	86	1,5	N/A	350	Population affected (1000pp/year)	Alfieri et al., 2018	3 JRC-EU(EC-EARTH,HadGEM2-ES,MPI-ESM-LR),5 ISIMIP(GFDL-ESM2M,HadGEM2-ES,IPSL-CM5A-LR,MIROC-ESM-CHEM,NorESM1-M),7 JRC-GL(IPSL-CM5A-LR,GFDL-ESM2M,HadGEM2-ES,EC-EARTH,GISS-E2-H,IPSL-CM5A-MR,HadCM3LC)	4 JRC-EU(RACMO22E,REMO2009,CCLM4-8-17,RCA4),JRC-GL(EC-EARTH3-HR)	N/A	Table 3
River flood risk	38 European countries	Population affected, relative change (%)	1976–2005	N/A	N/A	7 JRC-EU, 5 ISIMIP, 7 JRC-GL, RCP8.5, SWLs (specific warming levels)	N/A	N/A	N/A	93	N/A	N/A	93	2	N/A	350	Population affected (1000pp/year)	Alfieri et al., 2018	3 JRC-EU(EC-EARTH,HadGEM2-ES,MPI-ESM-LR),5 ISIMIP(GFDL-ESM2M,HadGEM2-ES,IPSL-CM5A-LR,MIROC-ESM-CHEM,NorESM1-M),7 JRC-GL(IPSL-CM5A-LR,GFDL-ESM2M,HadGEM2-ES,EC-EARTH,GISS-E2-H,IPSL-CM5A-MR,HadCM3LC)	4 JRC-EU(RACMO22E,REMO2009,CCLM4-8-17,RCA4),JRC-GL(EC-EARTH3-HR)	N/A	Table 3

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
River flood risk	38 European countries	Population affected, relative change (%)	1976–2005	N/A	N/A	7 JRC-EU, 5 ISIMIP, 7 JRC-GL, RCP8.5, SWLs (specific warming levels)	N/A	N/A	N/A	N/A	123	N/A	123	3	N/A	350	Population affected (1000 pp/year)	Alfieri et al., 2018	3 JRC-EU(EC-EARTH,HadGEM2-ES,MPI-ESM-LR),5 ISIMIP(GFDL-ESM2M,HadGEM2-ES,IPSL-CM5A-LR,MIROC-ESM-CHEM,NorESM1-M),7 JRC-GL(IPSL-CM5A-LR,GFDL-ESM2M,HadGEM2-ES,EC-EARTH,GISS-E2-H,IPSL-CM5A-MR,HadCM3LC)	4 JRC-EU(RACMO22E,REMO2009,CCLM4-8-17,RCA4),JRC-GL(EC-EARTH3-HR)	N/A	Table 3
Increased flooding, increased river flood frequency	Global	Million people (>1000m3cap-1yr-1)	1961–1990	SSP1	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	T	N/A	253	N/A	N/A	N/A	253 (83-473)	Around 1.6	Around 1.3	Population in 2050, total 8411, flood prone 847	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM,MIROC-ESM-CEM,MIROC5,MRI-CGCM3,NorESM1-M,NorESM1-ME,bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Increased flooding, increased river flood frequency	Global	Million people (>1000m3cap-1yr-1)	1961–1990	SSP1	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	279	N/A	N/A	279 (77-478)	Around 2	Around 1.7	Population in 2050, total 8411, flood prone 847	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM,MIROC-ESM-CEM,MIROC5,MRI-CGCM3,NorESM1-M,NorESM1-ME,bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Increased flooding, increased river flood frequency	Global	Million people (>1000m3cap-1yr-1)	1961–1990	SSP2	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	T	N/A	280	N/A	N/A	N/A	280 (93-525)	Around 1.6	Around 1.3	Population in 2050, total 9245, flood prone 931	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM,MIROC-ESM-CEM,MIROC5,MRI-CGCM3,NorESM1-M,NorESM1-ME,bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Increased flooding, increased river flood frequency	Global	Million people (>1000m³cap⁻¹yr⁻¹)	1961–1990	SSP2	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	309	N/A	N/A	309 (84-530)	Around 2	Around 1.7	Population in 2050, total 9245, flood prone 931	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM,MIROC-ESM-CEM,MIROC5,MRI-CGCM3,NorESM1-M,NorESM1-ME,bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Increased flooding, increased river flood frequency	Global	Million people (>1000m3cap-1yr-1	1961–1990	SSP3	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	T	N/A	317	N/A	N/A	N/A	317 (105-596)	Around 1.6	Around 1.3	Population in 2050, total 10233, flood prone 1041	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM,MIROC-ESM-CEM,MIROC5,MRI-CGCM3,NorESM1-M,NorESM1-ME,bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Increased flooding, increased river flood frequency	Global	Million people (>1000m3cap-1yr-1)	1961–1990	SSP3	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	351	N/A	N/A	351 (93-602)	Around 2	Around 1.7	Population in 2050, total 10233, flood prone 1041	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM,GFDL-CM3,GFDL-ESM2G,GFDL-ESM2M,GISS-E2-H,GISS-E2-R,HadGEM2-AO,HadGEM2-ES,IPSL-CM5A-LR,IPSL-CM5A-MR,MIROC-ESM,MIROC-ESM-CEM,MIROC5,MRI-CGCM3,NorESM1-M,NorESM1-ME,bcc-csm1-1,bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Increased flooding, increased river flood frequency	Global	Million people (>1000 m3 cap-1 yr-1)	1961–1990	SSP4	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	T	N/A	268	N/A	N/A	N/A	268 (90-503)	Around 1.6	Around 1.3	Population in 2050, total (9366) flood prone 907	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Increased flooding, increased river flood frequency	Global	Million people (>1000 m3 cap-1 yr-1)	1961–1990	SSP4	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	297	N/A	N/A	297 (81-507)	Around 2	Around 1.7	Population in 2050, total (9366) flood prone 907	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Increased flooding, increased river flood frequency	Global	Million people (>1000 m3 cap-1 yr-1)	1961–1990	SSP5	0,3	Transition of RCP2.6 in 2050s, 19 CMIP5 GCMs	T	N/A	250	N/A	N/A	N/A	250 (83-468)	Around 1.6	Around 1.3	Population in 2050, total (8508) flood prone 846	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Increased flooding, increased river flood frequency	Global	Million people (>1000 m3 cap-1 yr-1)	1961–1990	SSP5	0,3	Transition of RCP4.5 in 2050s, 19 CMIP5 GCMs	T	N/A	N/A	276	N/A	N/A	276 (77-473)	Around 2	Around 1.7	Population in 2050, total (8508) flood prone 846	Million people	Arnell and Lloyd-Hughes, 2014	CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CEM, MIROC5, MRI-CGCM3, NorESM1-M, NorESM1-ME, bcc-csm1-1, bcc-csm1-1-m	N/A	2070–2099	Table 2 Table 3 c) Fig.1
Monthly population exposed to extreme drought	Global	Million people	1955–2005	N/A	N/A	SPEI, 16 CMIP5, RCP8.5, 2021–2040	N/A	Y	114,3	N/A	N/A	N/A	114,3	Around 1.5	N/A	N/A	N/A	Smirnov et al., 2016	ACCESS1-0, BCC-CSM1.1, BNU-ESM, CCSM4, CESM1-CAM5, CMCC-CM, CSIRO-Mk3-6-0, EC-EARTH, FGOALS-g2, GFDL-CM3, IPSL-CM5A-MR, MIROC5, MPI-ESM-MR, MRI-CGCM3, NorESM1-M	N/A	2018–2100	Table 1
Monthly population exposed to extreme drought	Global	Million people	1955–2005	N/A	N/A	SPEI, 16 CMIP5, RCP8.5, 2041–2060	N/A	Y	N/A	190,4	N/A	N/A	190,4	Around 2	N/A	N/A	N/A	Smirnov et al., 2016	ACCESS1-0, BCC-CSM1.1, BNU-ESM, CCSM4, CESM1-CAM5, CMCC-CM, CSIRO-Mk3-6-0, EC-EARTH, FGOALS-g2, GFDL-CM3, IPSL-CM5A-MR, MIROC5, MPI-ESM-MR, MRI-CGCM3, NorESM1-M	N/A	2018–2100	Table 1
Drought	Globally	Affected total population (million)	1986–2005 (GMT), 2000 (population)	SSP1	0,6	11CMIP5, RCP4.5 (2027–2039), RCP8.5 (2029–2047), SSP1	T	Y	+132.5± 216.2	N/A	N/A	N/A	+132.5± 216.2	1.3-1.7	N/A	N/A	N/A	Liu et al., 2018	ACCESS1.0, BCC_CSM1.1, BNU-ESM, CanESM2.3, CNRM-CM5, CSIRO Mk3.6.0, GFDL CM3, INM-CM4.0, IPSL-CM5B-LR, MRI-CGCM3, MIROC-ESM	N/A	2010–2100	p274
Drought	Globally	Affected total population (million)	1986–2005 (GMT), 2000 (population)	SSP1	0,6	11CMIP5, RCP4.5 (2053–2081), RCP8.5 (2042–2053), SSP1	T	Y	N/A	+194.5± 276.5	N/A	N/A	+194.5± 276.5	1.8-2.2	N/A	N/A	N/A	Liu et al., 2018	ACCESS1.0, BCC_CSM1.1, BNU-ESM, CanESM2.3, CNRM-CM5, CSIRO Mk3.6.0, GFDL CM3, INM-CM4.0, IPSL-CM5B-LR, MRI-CGCM3, MIROC-ESM	N/A	2010–2100	p274

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Drought	Globally	Affected urban population (million)	1986–2005 (GMT), 2000 (population)	SSP1	0,6	11CMIP5, RCP4.5 (2027–2039), RCP8.5 (2029–2047), SSP1	T	Y	+350.2±158.8	N/A	N/A	N/A	+350.2± 158.8	1.3-1.7	N/A	N/A	N/A	Liu et al., 2018	ACCESS1.0, BCC_CSM1.1, BNU-ESM, CanESM2.3, CNRM-CM5, CSIRO Mk3.6.0, GFDL CM3, INM-CM4.0, IPSL-CM5B-LR, MRI-CGCM3, MIROC-ESM	N/A	2010–2100	p274
Drought	Globally	Affected total population (million)	1986–2005 (GMT), 2000 (population)	SSP1	0,6	11CMIP5, RCP4.5 (2053–2091), RCP8.5 (2042–2053), SSP1	T	Y	N/A	+410.7±213.5	N/A	N/A	+410.7± 213.5	1.8-2.2	N/A	N/A	N/A	Liu et al., 2018	ACCESS1.0, BCC_CSM1.1, BNU-ESM, CanESM2.3, CNRM-CM5, CSIRO Mk3.6.0, GFDL CM3, INM-CM4.0, IPSL-CM5B-LR, MRI-CGCM3, MIROC-ESM	N/A	2010–2100	p274
Drought	Globally	Affected rural population (million)	1986–2005 (GMT), 2000 (population)	SSP1	0,6	11CMIP5, RCP4.5 (2027–2039), RCP8.5 (2029–2047), SSP1	T	Y	-217.7±79.2	N/A	N/A	N/A	-217.7±79.2	1.3-1.7	N/A	N/A	N/A	Liu et al., 2018	ACCESS1.0, BCC_CSM1.1, BNU-ESM, CanESM2.3, CNRM-CM5, CSIRO Mk3.6.0, GFDL CM3, INM-CM4.0, IPSL-CM5B-LR, MRI-CGCM3, MIROC-ESM	N/A	2100	p274
Drought	Globally	Affected rural population (million)	1986–2005 (GMT), 2000 (population)	SSP1	0,6	11CMIP5, RCP4.5 (2053-2091), RCP8.5 (2042-2053), SSP1	T	Y	N/A	-216.2±82.4	N/A	N/A	-216.2±82.4	1.8-2.2	N/A	N/A	N/A	Liu et al., 2018	ACCESS1.0, BCC_CSM1.1, BNU-ESM, CanESM2.3, CNRM-CM5, CSIRO Mk3.6.0, GFDL CM3, INM-CM4.0, IPSL-CM5B-LR, MRI-CGCM3, MIROC-ESM	N/A	2100	p274
Drought	China, the Haihe River Basin (HRB)	Population exposed to drought (million)	1986–2005 (GMT), 2010 (population)	N/A	0,61	COSMO-CLM (CCLM) model, RCP2.6 (2020–2039)	N/A	N/A	236,4	N/A	N/A	N/A	236,4	1,5	N/A	339,65	Population exposure (million)	Sun et al., 2017	N/A	COSMO-CLM(CCLM) model	N/A	p79
Drought	China, the Haihe River Basin (HRB)	Population exposed to drought (million)	1986–2005 (GMT), 2010 (population)	N/A	0,61	COSMO-CLM (CCLM) model, RCP4.5 (2040–2059)	N/A	N/A	N/A	593,6	N/A	N/A	593,6	2	N/A	339,65	Population exposure (million)	Sun et al., 2017	N/A	COSMO-CLM(CCLM) model	N/A	p79
River flood risk	28 European countries	Expected damage (B€/year)	1976–2005	N/A	N/A	7 JRC-EU, RCP8.5, SWLs (specific warming levels)	N/A	N/A	11	N/A	N/A	N/A	11	1,5	N/A	5	Expected damage (B€/year)	Alfieri et al., 2018	3 JRC-EU (EC-EARTH, HadGEM2-ES, MPI-ESM-LR)	4 JRC-EU(RACMO22E, REMO2009, CCLM4-8-17, RCA4)	N/A	Table 2
River flood risk	28 European countries	Expected damage (B€/year)	1976–2005	N/A	N/A	7 JRC-EU, RCP8.5, SWLs (specific warming levels)	N/A	N/A	N/A	13	N/A	N/A	13	2	N/A	5	Expected damage (B€/year)	Alfieri et al., 2018	3 JRC-EU (EC-EARTH, HadGEM2-ES, MPI-ESM-LR)	4 JRC-EU(RACMO22E, REMO2009, CCLM4-8-17, RCA4)	N/A	Table 2
River flood risk	28 European countries	Expected damage (B€/year)	1976–2005	N/A	N/A	7 JRC-EU, RCP8.5, SWLs (specific warming levels)	N/A	N/A	N/A	N/A	14	N/A	14	3	N/A	5	Expected damage (B€/year)	Alfieri et al., 2018	3 JRC-EU (EC-EARTH, HadGEM2-ES, MPI-ESM-LR)	4 JRC-EU(RACMO22E, REMO2009, CCLM4-8-17, RCA4)	N/A	Table 2
River flood risk	28 European countries	Expected damage, relative change (%)	1976–2005	N/A	N/A	7 JRC-EU, RCP8.5, SWLs (specific warming levels)	N/A	N/A	116	N/A	N/A	N/A	116	1,5	N/A	5	Expected damage (B€/year)	Alfieri et al., 2018	3 JRC-EU (EC-EARTH, HadGEM2-ES, MPI-ESM-LR)	4 JRC-EU(RACMO22E, REMO2009, CCLM4-8-17, RCA4)	N/A	Table 2
River flood risk	28 European countries	Expected damage, relative change (%)	1976–2005	N/A	N/A	7 JRC-EU, RCP8.5, SWLs (specific warming levels)	N/A	N/A	N/A	137	N/A	N/A	137	2	N/A	5	Expected damage (B€/year)	Alfieri et al., 2018	3 JRC-EU (EC-EARTH, HadGEM2-ES, MPI-ESM-LR)	4 JRC-EU(RACMO22E, REMO2009, CCLM4-8-17, RCA4)	N/A	Table 2
River flood risk	28 European countries	Expected damage, relative change (%)	1976–2005	N/A	N/A	7 JRC-EU, RCP8.5, SWLs (specific warming levels)	N/A	N/A	N/A	N/A	173	N/A	173	3	N/A	5	Expected damage (B€/year)	Alfieri et al., 2018	3 JRC-EU (EC-EARTH, HadGEM2-ES, MPI-ESM-LR)	4 JRC-EU(RACMO22E, REMO2009, CCLM4-8-17, RCA4)	N/A	Table 2
Groundwater resources	Global	%	1971–2000	N/A	0,4	5 GCMs, RCP8.5, 2070–2099	T	N/A	N/A	2 (1.1-2.6)	N/A	N/A	2 (1.1-2.6)	2	N/A	N/A	N/A	Portmann et al., 2013	HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M	N/A	2070–2099	Fig.5a, p7
Groundwater resources	Global	%	1971–2000	N/A	0,4	5 GCMs, RCP8.5, 2070–2099	T	N/A	N/A	N/A	3 (1.5-5.3)	N/A	3 (1.5-5.3)	3	N/A	N/A	N/A	Portmann et al., 2013	HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M	N/A	2070–2099	Fig.5a, p7
Groundwater resources	Global	%	1971–2000	N/A	0,4	3 GCMs, RCP8.5, 2070–2099	T	N/A	N/A	N/A	N/A	3.4 (1.9-4.8)	3.4 (1.9-4.8)	4	N/A	N/A	N/A	Portmann et al., 2013	HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM,	N/A	2070–2099	Fig.5a, p7
Groundwater level	Northwest Bangladesh	m	1991–2009	N/A	N/A	MLR	N/A	Y	N/A	N/A	N/A	N/A	-0,15	N/A	1	N/A	N/A	Salem et al., 2017	N/A	N/A	N/A	Fig.5, p89
Groundwater level	Northwest Bangladesh	m	1991–2009	N/A	N/A	MLR	N/A	Y	N/A	N/A	N/A	N/A	-2,01	N/A	5	N/A	N/A	Salem et al., 2017	N/A	N/A	N/A	Fig.5, p89
Chloride concentration	Lake IJsselmeer, the Netherlands	mg/L	1997–2007 (climate change scenarios), 2007–2008 (reference scenarios), 1990 (temperature)	N/A	N/A	KNMI scenario G, 2050	N/A	Y	N/A	N/A	N/A	N/A	105 (79,177)	N/A	+1 (since1990)	105 (81,158)	mg/L	Bonte and Zwolsman, 2010	N/A	N/A	2050	Table 4, p4416
Chloride concentration	Lake IJsselmeer, the Netherlands	mg/L	1997–2007 (climate change scenarios), 2007–2008 (reference scenarios), 1990 (temperature)	N/A	N/A	KNMI scenario W+, 2050	N/A	Y	N/A	N/A	N/A	N/A	121 (77,267)	N/A	+2 (since1990)	105 (81,158)	mg/L	Bonte and Zwolsman, 2010	N/A	N/A	2050	Table 4, p4416
The daily probability of exceeding the chloride standard for drinking water	Lake IJsselmeer, the Netherlands	%	1997–2007 (climate change scenarios), 2007–2008 (reference scenarios), 1990 (temperature)	N/A	N/A	KNMI scenario G, 2050	N/A	Y	N/A	N/A	N/A	N/A	3,1	N/A	+1 (since1990)	2,5	%	Bonte and Zwolsman, 2010	N/A	N/A	2050	Table 5, p4422

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
The daily probability of exceeding the chloride standard for drinking water	Lake IJsselmeer, the Netherlands	%	1997–2007 (climate change scenarios), 2007–2008 (reference scenarios), 1990 (temperature)	N/A	N/A	KNMI scenario W+, 2050	N/A	Y	N/A	N/A	N/A	N/A	14,3	N/A	+2 (since1990)	2,5	%	Bonte and Zwolsman, 2010	N/A	N/A	2050	Table 5, p4422
The maximum duration of the exceedance	Lake IJsselmeer, the Netherlands	Days	1997–2007 (climate change scenarios), 2007–2008 (reference scenarios), 1990 (temperature)	N/A	N/A	KNMI scenario G, 2050	N/A	Y	N/A	N/A	N/A	N/A	124	N/A	+1 (since1990)	103	Days	Bonte and Zwolsman, 2010	N/A	N/A	2050	Table 5, p4422
The maximum duration of the exceedance	Lake IJsselmeer, the Netherlands	Days	1997–2007 (climate change scenarios), 2007–2008 (reference scenarios), 1990 (temperature)	N/A	N/A	KNMI scenario W+, 2050	N/A	Y	N/A	N/A	N/A	N/A	178	N/A	+2 (since1990)	103	Days	Bonte and Zwolsman, 2010	N/A	N/A	2050	Table 5, p4422
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in nitrogen (N) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP4.5, 2015–2039 (2030s), SWAT	N/A	N/A	7,3	N/A	N/A	N/A	7,3	Around 1.5	0,89	1 249 564	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 11
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in nitrogen (N) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP8.5, 2015–2039 (2030s), SWAT	N/A	N/A	N/A	-6,6	N/A	N/A	-6,6	Around 2	1,05	1 249 564	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 11
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in nitrogen (N) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP4.5, 2015–2039 (2030s), SWAT, FG1	N/A	N/A	5,2	N/A	N/A	N/A	5,2	Around 1.5	0,89	1 249 564	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 11
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in nitrogen (N) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP8.5, 2015–2039 (2030s), SWAT, FG1	N/A	N/A	N/A	8,8	N/A	N/A	8,8	Around 2	1,05	1 249 564	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 11
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in nitrogen (N) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP4.5, 2015–2039 (2030s), SWAT, FA1	N/A	N/A	7,5	N/A	N/A	N/A	7,5	Around 1.5	0,89	1 249 564	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 11
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in nitrogen (N) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP8.5, 2015–2039 (2030s), SWAT, FA1	N/A	N/A	N/A	3,7	N/A	N/A	3,7	Around 2	1,05	1 249 564	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 11
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in phosphorus (P) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP4.5, 2015–2039 (2030s), SWAT	N/A	N/A	5,1	N/A	N/A	N/A	5,1	Around 1.5	0,89	459 134	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 12
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in phosphorus (P) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP8.5, 2015–2039 (2030s), SWAT	N/A	N/A	N/A	-3,6	N/A	N/A	-3,6	Around 2	1,05	459 134	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 12
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in phosphorus (P) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP4.5, 2015–2039 (2030s), SWAT, FG1	N/A	N/A	12,6	N/A	N/A	N/A	12,6	Around 1.5	0,89	459 134	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 12

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-economic Scenario and Date	Baseline Global T above Pre-industrial	Climate Scenario Used	Transient (T) or Equilibrium (E)	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	2°C	3°C	4°C	Projected Impact at Delta T(°C)	Delta T Relative to Pre-Industrial	Delta T Relative to Baseline Temperature	Projected Impact (Reference Value)	Projected Impact (Unit)	Reference	GCM (e.g., MIROC5)	RCM	Future Period	Cited Part
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in phosphorus (P) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP8.5, 2015–2039 (2030s), SWAT, FG1	N/A	N/A	N/A	11,7	N/A	N/A	11,7	Around 2	1,05	459 134	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 12
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in phosphorus (P) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP4.5, 2015–2039 (2030s), SWAT, FA1	N/A	N/A	14,9	N/A	N/A	N/A	14,9	Around 1.5	0,89	459 134	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 12
Water quality (nutrient yield)	Southeast Asia (Cambodia, Laos, Vietnam) 3S River Basin (Sekong, Srepok, Sesan)	Change in phosphorus (P) yield (%), annual	1981–2008 (air temperatures), 2004–2008 (water quality)	N/A	N/A	5 GCM, RCP8.5, 2015–2039 (2030s), SWAT, FA1	N/A	N/A	N/A	8,8	N/A	N/A	8,8	Around 2	1,05	459 134	Tons	Trang et al., 2017	HadGEM2-AO, CanESM2, IPSL-CM5A-LR, CNRM-CM5, and MPI ESM-MR	N/A	2030s (2015–2039), 2060s (2045–2069), 2090s (2075–2099)	Table 12

Table 3.SM.2: 3.4.3 Terrestrial and wetland ecosystems

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Overshoot Scenario?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modelled	Reference
Biome shift to north and to higher elevation	Global	%	1980–2010	Present day population	0.7°C	4 RCP	T	No	Y	1°C above baseline: 3 to 8 %	2°C above baseline: 5 to 19%	4°C above baseline: 35%	N/A	N/A	N/A	Warszawski et al. (2013)
Biomass loss (tropical forest to savanna/grassland)	Central America	kg m^{-2}	1961–1990	0.5°C	1°C	HadGEM2-ES, RCP4.5, 2071-2100	T	No	Y	For 2050, biomass decrease to 6.5 kg/m2	N/A	Local warming of 2 to 4°C (NDC): -4 kg m^{-2} (from 7 to 3 kg m^{-2})	N/A	N/A	N/A	Lyra et al. (2017)
Phenological shifts for primary producers (PP), primary consumers (PC), secondary consumers (SC)	UK	Days	1961–1990	N/A	-	UKCP09 projections in 2050	T	-	Y	(Low emission scenario) PP: -2.2 (-1 to -3) / PC: -5 (-2.5 to -7.5) / SC: -2 (-1 to -3)	(Medium emission scenario) PP: -2.3(-1.2 to -4) / PC: -6 (-3.5 to -8.5) / SC: -2.1 (-	-	N/A	N/A	N/A	Thackeray et al. (2016)
Loss of 50% or more of their climate range	Globe	%	2100 (A1B), no mitigation	-	Pre-industrial	SRES all scenarioos are +2°C or more	T	-	Y		-60% losses if emissions peak in 2016, -40% if peak in 2030	-	N/A	N/A	N/A	Warren et al. (2013)
Loss of 50% or more of their climate range for insects	Globe	%	Not provided	N/A	Pre-industrial	21 CMIP5 models	T	No	N	9% (4–24%)	25% (10–44%)	-	6% (1–18%)	18% (6–35%)	Dispersal	Warren et al. 2018a
Loss of 50% or more of their climate range for vertebrates	Globe	%	Not provided	N/A	Pre-industrial	21 CMIP5 models	T	No	N	5% (3–11%)	10% (6–24%)		4% (2–9%)	8% (4–16%)	Dispersal	Warren et al. 2018a
Loss of 50% or more of their climate range for plants	Globe	%	Not provided	N/A	Pre-industrial	21 CMIP5 models	T	No	N	8% (4–15%)	16% (9–28%)	-	8% (4–15%)	16% (9–28%)	Dispersal	Warren et al. 2018a
% of globe identified as climatic refugia for the different taxa (plants/animals)	Global	%	-	-	-	7 CMIP5 models, AVOID2 scenario	T	Y	Y	An additional 4–15% acts as a refugium	-	-	N/A	N/A	N/A	Smith et al. (2018)
Loss of 50% or more of their climate range for plants	Global	%	-	-	-	21 CMIP5 models	-	-	-	Significant reduction	-	-	N/A	N/A	N/A	Smith et al. (2018)
Increase of potental habitat of bamboo	Japan	%	pre-industrial	N/A	Pre-industrial	MRI AGCM CMIP5RCP8.5 at 2027 and 2041	T	No	Y	+11–13%	+16–19%	2°C–1.5°C = 6%	N/A	N/A	N/A	Takano et al. (2017)
Carbon storage in vegetation (GPP) and soil	Europe	%	pre-industrial	-	1881–1910	Euro-Cordex with RCP4.5, 2034-2063	T	No	Y	N/A	+5% in soil and +20% in GPP		N/A	N/A	N/A	Sakalli et al. (2017)
Area of cryogenic land surface processes (nivation, cryoturbation, gelifluction, permafrost)	Northern Europe	%	1981–2010	-	-	CMIP5 ensemble RCP2.6, RCP4.5, RCP8.5	T	-	Y	RCP2.6, 2040–69: -19% (maximum of the 4 processes)	RCP2.6 2070–99: -19% (max)	0%	-	-	-	Aalto et al. (2017)
Spring events in temperate forests (oak)	UK	Days	1961–1990	-	0.5°C	SRES (A1F1) near term (2010–2039) and medium term (2040–2069)	T	-	Y	-14.3 days	-24.6 days	2°C–1.5°C = 10.3 days	-	-	-	Roberts et al. (2015)
Starting date of growing season	Northern China	Days	1961–1990	-	0.5°C	HadGEM3- RA: RCP4.5 and 8.5 (2050)		-	-	-6.5 days (s.d.=4.8 days)	-7.4 days (s.d.=4.8 days)	2°C–1.5°C = 0.9 days	-	-	-	Luo et al. (2014)
Ecosystem NPP and GPP	Europe	%	1971–2000	N/A	0.46°C	Euro-Cordex / IMPACT2C / 3 RCP	T	No	Y	N/A	N/A	2°C–1.5°C: -6 to 10% according to regions	N/A	N/A	N/A	Jacob et al. (2018)
Permafrost area	Globe	km^2	1960–1990	-	0.5°C	CMIP5	T	No	Y	11 millions km^2 (present = 15	9 millions km2 (present = 15	2 millions km^2 (1.55 to 2.5)	N/A	N/A	N/A	Chadburn et al. (2017)
	-	-	-	-	-	CMIP3 SRES A2	-	-	-	-	-	-	-	-	-	Meehl et al. (2007)
Forest biomass	Central America	%	1961–1990	-	-	Eta-HadGEM2	T	-	Y	-20%	-30%	10%	-	-	-	Lyra et al. (2017)
Fynbos biome area	South Africa	%	1961–1990	-	0.5°C above pre-industrial	Regional CCAM os 6 GCM, SRES A2	T	-	Y	-20%	-32% (average between 1°C and 2°C)	12%	-	-	-	Engelbrecht and Engelbrecht (2016)

Table 3.SM.3: 3.4.4 Ocean Systems

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Overshoot Scenario?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Reference
SST/distributions of pelagic fish species	Northeast Pacific shelf seas	km/decade migrated	2000–2050	0.5°C	(SRES) A2	T	N	Y	30.1 ± 2.34 (SRES A2 is around 1.5°C at 2050, average across 28 species)	Likely to increase further	-	-	-	Cheung et al. (2015) (NW Pacific paper)
SST/distributions of pelagic fish species	West coast USA	Local exitinction rate	2000–2050	0.5°C	(SRES) A2	T	N	Y	Increased	Likely to increase further	-	-	-	Cheung et al. (2015) (NW Pacific paper)
SST/distributions of pelagic fish species	Northeast Pacific shelf seas	Species invasion rate	2000–2050	0.5°C	(SRES) A2	T	N	Y	Increased	Likely to increase further	-	-	-	Cheung et al. (2015) (NW Pacific paper)
Increased SST (surface), reduced O2, decreased NPP	Global	Species turnover	1950–1969	Pre-industrial	19 CMIP5 models: RCP8.5 (3.5°C at end of century)	T	N	Y	-	-	21.6 ± 0.33%	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP	Global	Species turnover	1950–1969	Pre-industrial	19 CMIP5 models: RCP2.6	E	N	Y	8.3 ± 0.05%	Likely to increase further	-	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP	Indo-Pacific	Species turnover	1950–2100	1950 and 1969	19 CMIP5 models: RCP8.5	E	N	Y	-	-	36.4 ± 2.1%	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP (species turnover)	Indo-Pacific	Species turnover	1950–2100	1950 and 1969	19 CMIP5 models: RCP2.6	E	N	Y	9.2 ± 0.8%	12.1 ± 0.8%	-	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP (maximum catch potential)	Indo-Pacific	10^6 metric tons	1950–2100	Average of the top 10-year global annual catches since 1950	19 CMIP5 models: RCP8.5	E	N	Y	-	Linear with change in increased SST, O2, NPP decrease, etc.)	−46.8 ± 1.2%	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP (maximum catch potential)	Indo-Pacific	10^6 metric tons	1950–2100	Average of the top 10-year global annual catches since 1950	19 CMIP5 models: RCP8.5	E	N	Y	-	-	−46.8 ± 1.2%	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP (maximum catch potential)	Global	10^6 metric tons	1950–2100	Average of the top 10-year global annual catches since 1950	19 CMIP5 models: RCP2.6	E	N	Y	-11.5 ± 0.6%	-20.2 ± 0.6%	-	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP (maximum catch potential)	Arctic/temperate regions	%	1950–2100	Pre-industrial	19 CMIP5 models: RCP8.5	E	N	Y	50	Likely to increase further	400	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP (maximum catch potential)	Equator	%	1950-2100	Pre-industrial	19 CMIP5 models: RCP8.5	E	N	Y	-70	Likely to increase further	-30	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP (species turnover)	Arctic/temperate regions	%	1950–2100	Prei-ndustrial	19 CMIP5 models: RCP8.5	E	N	Y	3	Likely to increase further	20	-	-	Cheung et al. (2016)
Increased SST (surface), reduced O2, decreased NPP (species turnover)	Equator	%	1950–2100	Pre-industrial	19 CMIP5 models: RCP2.6	E	N	Y	5	Likely to increase further	35	-	-	Cheung et al. (2016)
Increased SST/coral bleaching and mortality	Tropics/subtropics	% loss of today's corals.	2000	0.5°C	"Commit", A1b, A1F1, B1, A2 (B1 is closest to 1.5°C)	T	N	N	80	95	100	Close to zero if corals can increase their tolerance by +1.5°C (no evidence but discussed)	No change	Donner et al. (2009)
Increased SST/coral bleaching and mortality	Tropics/subtropics	% loss of today's corals	1982–2005	-	RCP2.6	E	N	N	95	Even in the pathway with most pronounced emission reductions (RCP2.6), where CO2 equivalent concentrations peak at 455 ppm (Supplementary Fig. S1), 95% of reef locations experience annual bleaching conditions by the end of the century	100	No change	No change	Hooidonk et al. (2013)
Increased SST/coral bleaching and mortality	Tropics/subtropics	Median year at which annual bleaching occurs	1983–2005	Pre-industrial	RCP8.5	T	N	N	2045		2055	No change	No change	Hooidonk et al. (2016)
Increased SST/coral bleaching and mortality	Australia	Likelihood of extreme events like 2015–2016 occurring, that cause coral bleaching	1861–2005 under both natural and anthropogenic forcings (historical), 1861–2005 under natural forcings only, and 2006–2100 under 4 RCP scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) were analysed	1901–2005	16 models CMIP5	T,E	N	-	64% (53–76%)	87% (79–93%)	Even more likely	No change	No change	King et al. (2017)

Table 3.SM.4: 3.4.5 Coastal and low-lying areas

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (50th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2035 to 2150	No	562	N/A	N/A	N/A	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (95th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	575	590	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP1.5 (50th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2035 to 2150	No	128–137	N/A	N/A	N/A	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP1.5 (95th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	134–143	136–144	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (50th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	613	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (95th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	562	590	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (5th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	557	N/A	N/A	N/A	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP2.0 (50th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–132	114–151	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP2.0 (95th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	126–129	134–143	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP2.0 (5th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–134	N/A	N/A	N/A	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (50th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	598	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (95th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	569	591	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (5th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	561	N/A	N/A	N/A	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP2.5 (50th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–132	122–146	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP2.5 (95th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	128–132	134–143	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP2.5 (5th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–134	N/A	N/A	N/A	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (50th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	598	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (95th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	562	591	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (5th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	599	N/A	N/A	N/A	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP3.0 (50th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–132	122–136	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP3.0 (95th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	126–128	134–143	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP3.0 (5th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–134	N/A	N/A	N/A	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (50th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	593	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (95th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	568	591	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (5th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	560	590	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP4.5 (50th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–131	125–137	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP4.5 (95th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	128–133	134–143	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	AMP4.5 (5th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–134	101–144	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	563	576	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (95th percentile)	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	569	585	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots after 2040. Does not return to 1.5°C	No	557	567	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	127–133	130–139	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	RCP8.5 (95th percentile)	N/A	Yes. Overshoots after 2040. Does not return to 1.5°C	No	128–132	133–141	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	125–132	125–136	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (5th percentile). Stabilization at approx. 1.5°C	N/A	N/A	No	N/A	N/A	575	1.26°C in 2100	N/A	N/A	N/A	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (5th percentile). Stabilization at approx. 1.5°C	N/A	N/A	No	N/A	N/A	592	1.15°C in 2200	N/A	N/A	N/A	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (5th percentile). Stabilization at approx. 1.5°C	N/A	N/A	No	N/A	N/A	606	1.12°C in 2300	N/A	N/A	N/A	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (95th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	575	590	669	2.33°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (95th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	575	590	827	2.18°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (95th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	575	590	843	1.82°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (50th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2035 to 2150	No	562	N/A	620	1.58°C in 2100	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (50th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2035 to 2150	No	562	N/A	666	1.41°C in 2200	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP1.5 (50th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2035 to 2150	No	562	N/A	702	1.33°C in 2300	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (5th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	557	N/A	585	1.72°C in 2100	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (5th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	557	N/A	618	1.66°C in 2200	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (5th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	557	N/A	642	1.60°C in 2300	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (95th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	562	590	686	2.64°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (95th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	562	590	827	2.57°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (95th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	562	590	937	2.23°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (50th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	613	637	1.90°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.0 (50th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	613	705	2.03°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km2)	1995	N/A	1850–1900	AMP2.0 (50th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	613	767	1.81°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (5th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	561	N/A	589	1.89°C in 2100	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (5th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	561	N/A	639	2.12°C in 2200	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (5th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	561	N/A	677	2.05°C in 2300	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (95th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	569	591	693	2.95°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (95th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	569	591	875	3.02°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (95th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	569	591	1030	3.71°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (50th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	598	633	2.30°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (50th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	598	737	2.40°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP2.5 (50th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	598	825	2.29°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (5th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	599	N/A	592	1.97°C in 2100	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (5th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	599	N/A	654	2.41°C in 2200	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (5th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	599	N/A	707	2.45°C in 2300	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (95th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	562	591	696	3.21°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (95th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	562	591	911	3.49°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (95th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	562	591	1130	3.15°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (50th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	598	635	2.40°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (50th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	598	759	2.85°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP3.0 (50th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	598	872	2.76°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (5th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	560	590	593	2.05°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (5th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	560	590	672	2.75°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (5th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	560	590	760	3.17°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (95th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	568	591	700	3.28°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (95th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	568	591	961	4.66°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (95th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	568	591	1290	4.75°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (50th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	593	638	2.50°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (50th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	593	786	3.4°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	AMP4.5 (50th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	561	593	960	3.85°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots after 2040. Does not return to 1.5°C	No	557	567	646	4.35°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots after 2040. Does not return to 1.5°C	No	557	567	887	7.02°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots after 2040. Does not return to 1.5°C	No	557	567	1190	7.52°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (95th percentile)	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	569	585	792	5.83°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (95th percentile)	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	569	585	1490	11.23°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (95th percentile)	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	569	585	2220	13.14°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	563	576	708	4.93°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	563	576	1140	8.55°C in 2200	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Area situated below the 1-in-100-year flood plain	Global	(th km^2)	1995	N/A	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	563	576	1630	9.54°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP1.5 (5th percentile). Stabilization at approx. 1.5°C	N/A	N/A	No	N/A	N/A	95–141	1.26°C in 2100	N/A	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP1.5 (5th percentile). Stabilization at approx. 1.5°C	N/A	N/A	No	N/A	N/A	112–170	1.12°C in 2300	N/A	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP1.5 (95th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	134–143	136–144	114–173	2.33°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP1.5 (95th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	134–143	136–144	165–263	1.82°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP1.5 (50th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2035 to 2150	No	128–137	N/A	103–154	1.58°C in 2100	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP1.5 (50th percentile). Stabilization at approx. 1.5°C	N/A	Yes. Overshoots after 2035 to 2150	No	128–137	N/A	133–207	1.33°C in 2300	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.0 (5th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–133	N/A	97–144	1.72°C in 2100	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.0 (5th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–133	N/A	120–183	1.60°C in 2300	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.0 (95th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	126–127	134–143	118–179	2.64°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.0 (95th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	126–127	134–143	192.9–301.8	2.23°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.0 (50th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–132	114–151	106–158	2.03°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.0 (50th percentile). Stabilization at approx. 2.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–132	114–151	147–232	1.81°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.5 (5th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–134	N/A	98–146	1.89°C in 2100	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.5 (5th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–134	N/A	128–197	2.05°C in 2300	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.5 (95th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	128-132	134–143	119–182	2.95°C in 2100	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.5 (95th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	128-132	134–143	208–342	2.71°C in 2300	Increasing (no adaptation assumed)	N/A	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.5 (50th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127-132	122–146	107–160	2.30°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP2.5 (50th percentile). Stabilization at approx. 2.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127-132	122–146	162–257	2.29°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP3.0 (5th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	134-146	N/A	98–146	1.97°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP3.0 (5th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	134-146	N/A	134–207	2.45°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP3.0 (95th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	125–128	134–143	120–183	3.21°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP3.0 (95th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2025. Does not return to 1.5°C	No	125-128	134–143	227–376	3.15°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP3.0 (50th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–132	122–136	107–161	2.40°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP3.0 (50th percentile). Stabilization at approx. 3.0°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127-132	122–136	172–276	2.76°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP4.5 (5th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–134	101–144	99–147	2.05°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP4.5 (5th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	124–134	101–144	146–228	3.17°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP4.5 (95th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	128–133	134–143	120–184	3.28°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP4.5 (95th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2030. Does not return to 1.5°C	No	128–133	134–143	262–441	4.75°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP4.5 (50th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–131	125–137	108–162	2.50°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	AMP4.5 (50th percentile). Stabilization at approx. 4.5°C	N/A	Yes. Overshoots after 2035. Does not return to 1.5°C	No	127–131	125–137	193–313	3.85°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	125–132	125–136	110–166	4.35°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots after 2050. Does not return to 1.5°C	No	125–132	125–136	243–407	7.52°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	RCP8.5 (95th percentile)	N/A	Yes. Overshoots after 2040. Does not return to 1.5°C	No	128–132	133–141	142–221	5.83°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	RCP8.5 (95th percentile)	N/A	Yes. Overshoots after 2040. Does not return to 1.5°C	No	128–132	133–141	504–879	13.14°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	127–133	130–139	123–189	4.93°C in 2100	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
Population situated below the 1-in-100-year flood plain	Global	(millions)	1995	SSP1–5 until 2100, then no change to 2300	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots after 2045. Does not return to 1.5°C	No	127–133	130–139	361–620	9.54°C in 2300	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Brown et al. (2018a)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (50th percentile)	N/A	No	Yes	27,8	N/A	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (95th percentile)	N/A	No	Yes	2,3	N/A	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (50th percentile)	N/A	Yes. Overshoots in 2040. Does not return to 1.5°C	Yes	19,5	52,3	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (95th percentile)	N/A	Yes. Overshoots in 2005. Does not return to 1.5°C	Yes	2,3	14,9	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (5th percentile)	N/A	Yes. Overshoots in 2060. Does not return to 1.5°C	Yes	25,8	N/A	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots in 2035. Does not return to 1.5°C	Yes	30	36,4	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (95th percemtile)	N/A	Yes. Overshoots in 2005. Does not return to 1.5°C	Yes	2,3	14,8	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots in 2045. Does not return to 1.5°C	Yes	21,2	25	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (50th percentile)	N/A	No	Yes	N/A	N/A	62,7	1.48°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (95th percentile)	N/A	No	Yes	N/A	N/A	116,8	1.55°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (5th percentile)	N/A	No	Yes	N/A	N/A	33,4	1.25°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (50th percentile)	N/A	Yes. Overshoots in 2040. Does not return to 1.5°C	Yes	N/A	N/A	75	2.03°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (95th percentile)	N/A	Yes. Overshoots in 2005. Does not return to 1.5°C	Yes	N/A	N/A	131,9	2.32°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (5th percentile)	N/A	Yes. Overshoots in 2060. Does not return to 1.5°C	Yes	N/A	N/A	41,7	1.77°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots in 2035. Does not return to 1.5°C	Yes	N/A	N/A	103	3.81°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (95th percemtile)	N/A	Yes. Overshoots in 2005. Does not return to 1.5°C	Yes	N/A	N/A	166,3	6.29°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots in 2045. Does not return to 1.5°C	Yes	N/A	N/A	69	3.04°C in 2100	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (50th percentile)	N/A	No	Yes	N/A	N/A	103,5	1.46°C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (95th percentile)	N/A	No	Yes	N/A	N/A	180,4	1.55°C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (5th percentile)	N/A	No	Yes	N/A	N/A	60	1.45°C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (50th percentile)	N/A	Yes. Overshoots in 2040. Does not return to 1.5°C	Yes	N/A	N/A	124	1.98°C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (95th percentile)	N/A	Yes. Overshoots in 2005. Does not return to 1.5°C	Yes	N/A	N/A	210,5	2.05C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (5th percentile)	N/A	Yes. Overshoots in 2060. Does not return to 1.5°C	Yes	N/A	N/A	75	1.94°C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots in 2035. Does not return to 1.5°C	Yes	N/A	N/A	238,3	6.87°C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (95th percemtile)	N/A	Yes. Overshoots in 2005. Does not return to 1.5°C	Yes	N/A	N/A	402,4	12.01°C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots in 2045. Does not return to 1.5°C	Yes	N/A	N/A	152,3	4.97°C in 2200	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (50th percentile)	N/A	No	Yes	N/A	N/A	137,6	1.46°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (95th percentile)	N/A	No	Yes	N/A	N/A	233,2	1.54°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	1.5°C scenario (5th percentile)	N/A	No	Yes	N/A	N/A	83,6	1.45°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (50th percentile)	N/A	Yes. Overshoots in 2040. Does not return to 1.5°C	Yes	N/A	N/A	164	1.96°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (95th percentile)	N/A	Yes. Overshoots in 2005. Does not return to 1.5°C	Yes	N/A	N/A	276,5	2.04°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	2.0°C scenario (5th percentile)	N/A	Yes. Overshoots in 2060. Does not return to 1.5°C	Yes	N/A	N/A	100,1	1.95°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (50th percentile)	N/A	Yes. Overshoots in 2035. Does not return to 1.5°C	Yes	N/A	N/A	385,7	7.95°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (95th percemtile)	N/A	Yes. Overshoots in 2005. Does not return to 1.5°C	Yes	N/A	N/A	703,3	14.77°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)
People at risk from flooding	Global	(millions yr^{-1})	1995	Average of SSP1–5	1850–1900	RCP8.5 (5th percentile)	N/A	Yes. Overshoots in 2045. Does not return to 1.5°C	Yes	N/A	N/A	228,4	5.46°C in 2300	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Nicholls et al. (2018)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.3–1.4	0.6–1.0	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.4–1.5	0.6–1.1	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.3–1.4	0.6–1.0	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	0.6–0.7	11.9–13.5	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	0.8–0.8	19.0–21.6	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	0.6–0.7	10.4–11.1	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.4–1.5	0.5–1.0	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.5–1.6	0.5–1.1	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.4–1.5	0.5–1.0	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	0.7–0.7	15.9–18.6	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	0.8–0.8	27.1–31.8	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	6.3–6.6	13.6–15.9	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.4–1.5	0.7–1.2	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.5–1.6	0.7–1.3	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	1.3–1.4	0.7–1.2	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	6.9–7.2	14.4–16.5	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	8.4–8.6	23.7–27.0	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
People at risk from flooding	Global	(millions yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	6.6–6.9	12.6–14.3	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	9.8–10.3	10.4–11.3	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	10.4–11.4	11.5–12.4	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	9.6–10.6	10.1–11.0	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	47.4–53.6	152.7–2678.5	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	57.6–65.0	259.2–452.8	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP2.6. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	543.3–51.1	132.8–23.6	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	10.8–11.9	10.8–11.5	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	11.6–12.7	12.2–12.9	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	10.7–11.7	10.4–11.1	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	52.2–59.3	214.2–410.5	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	64.8–73.6	396.1–752.3	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP4.5. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	49.4–56.0	180.0–345.2	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	10.1–11.1	10.9–11.8	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	10.8–11.9	12.2–13.1	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	9.9–10.8	10.6–11.5	N/A	N/A	Risk increases, but decreases with adaptation	Risk increases, but decreases with adaptation	Dikes are upgraded as sea levels and socio-economic conditions change	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. Medium	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	50.6–57.2	170.0–594.8	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. High	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	62.5–70.6	296.5–512.0	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Annual sea flood costs	Global	(billions USD yr^{-1})	1995	SSP1–5	Not defined	RCP8.5. HadGEM2-ES. Low	N/A	Yes. Overshoots in 2020. Does not return to 1.5°C by 2100	Yes	48.0–54.2	145.7–252.9	N/A	N/A	Increasing (assuming no upgrade to adaptation)	Increasing (assuming no upgrade to adaptation)	Dikes in base year, then no upgrade to adaptation	Hinkel et al. (2014)
Long-term degradation of coral reefs	Global	N/A	1850–1900	N/A	N/A	Emulates the sea-level response of GCMs	N/A	The illustrative 1.5°C scenario used here does not allow for a GMT overshoot, but stays below 1.5°C over the course of the 21st century	N/A	89% [48% and 99% indicating the 66% range] and more of all global reef grid cells will be at risk of long-term degradation for a 1.5°C scenario in 2050	98% [86% and 100% indicating the 66% range] and more of all global reef grid cells will be at risk of long-term degradation for a 2.0°C scenario in 2050	N/A	N/A	N/A	N/A	Constant adaptive capacity	Schleussner et al. (2016)

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Long-term degradation of coral reefs	Global	N/A	1850–1900	N/A	N/A	Emulates the sea-level response of GCMs	N/A	The illustrative 1.5°C scenario used here does not allow for a GMT overshoot, but stays below 1.5°C over the course of the 21st century	N/A	69% [14% and 98% indicating the 66% range] and more of all global reef cells will be at risk of long-term degradation for a 1.5°C scenario in 2100	99% [85% and 100% indicating the 66% range] and more of all global reef grid cells will be at risk of long-term degradation for a 2.0°C scenario in 2050	N/A	N/A	N/A	N/A	Constant adaptive capacity	Schleussner et al. (2016)
Long-term degradation of coral reefs	Global	N/A	1850–1900	N/A	N/A	Emulates the sea-level response of GCMs	N/A	The illustrative 1.5°C scenario used here does not allow for a GMT overshoot, but stays below 1.5°C over the course of the 21st century	N/A	94% [60% and 100% indicating the 66% range] and more of all global reef grid cells will be at risk of long-term degradation for a 1.5°C scenario in 2050	100% [95% and 100% indicating the 66% range] and more of all global reef grid cells will be at risk of long-term degradation for a 2.0°C scenario in 2050	N/A	N/A	N/A	N/A	Saturation adaptive capacity	Schleussner et al. (2016)
Long-term degradation of coral reefs	Global	N/A	1850–1900	N/A	N/A	Emulates the sea-level response of GCMs	N/A	The illustrative 1.5°C scenario used here does not allow for a GMT overshoot, but stays below 1.5°C over the course of the 21st century	N/A	69% [14% and 98% indicating the 66% range] and more of all global reef cells will be at risk of long-term degradation for a 1.5°C scenario in 2100	6% [1% and 50% indicating the 66% range] and more of all global reef cells will be at risk of long-term degradation for a 2.0°C scenario in 2100	N/A	N/A	N/A	N/A	Saturation adaptive capacity	Schleussner et al. (2016)
Long-term degradation of coral reefs	Global	N/A	1850–1900	N/A	N/A	Emulates the sea-level response of GCMs	N/A	The illustrative 1.5°C scenario used here does not allow for a GMT overshoot, but stays below 1.5°C over the course of the 21st century	N/A	9% [2% and 49% indicating the 66% range] and more of all global reef grid cells will be at risk of long-term degradation for a 1.5°C scenario in 2050	39% [8% and 81% indicating the 66% range] and more of all global reef grid cells will be at risk of long-term degradation for a 2.0°C scenario in 2050	N/A	N/A	N/A	N/A	Adaptation adaptive capacity	Schleussner et al. (2016)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Long-term degradation of coral reefs	Global	N/A	1850–1900	N/A	N/A	Emulates the sea-level response of GCMs	N/A	The illustrative 1.5°C scenario used here does not allow for a GMT overshoot, but stays below 1.5°C over the course of the 21st century	N/A	1% [0% and 2% indicating the 66% range] and more of all global reef cells will be at risk of long-term degradation for a 1.5°C scenario in 2100	1% [0% and 2% indicating the 66% range] and more of all global reef cells will be at risk of long-term degradation for a 2.0°C scenario in 2100	N/A	N/A	N/A	N/A	Adaptation adaptive capacity	Schleussner et al. (2016)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	1.5°C ± 0.25°C in 2100 (50th)	N/A	46.12 in 2100	N/A	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	1.5°C ± 0.25°C in 2100 (95th)	N/A	69.23 in 2100	N/A	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	1.5°C ± 0.25°C in 2100 (5th)	N/A	31.92 in 2100	N/A	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.0°C ± 0.25°C in 2100 (50th)	N/A	N/A	48.76 in 2100	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.0°C ± 0.25°C in 2100 (95th)	N/A	N/A	79.65 in 2100	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.0°C ± 0.25°C in 2100 (5th)	N/A	N/A	32.01 in 2100	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.5°C ± 0.25°C in 2100 (50th)	N/A	N/A	N/A	50.35 in 2100	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.5°C ± 0.25°C in 2100 (95th)	N/A	N/A	N/A	77.38 in 2100	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.5°C ± 0.25°C in 2100 (5th)	N/A	N/A	N/A	33.33 in 2100	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	1.5°C ± 0.25°C in 2150 (50th)	N/A	56.05 in 2150	N/A	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	1.5°C ± 0.25°C in 2150 (95th)	N/A	112.97 in 2150	N/A	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	1.5°C ± 0.25°C in 2150 (5th)	N/A	32.54 in 2150	N/A	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.0°C ± 0.25°C in 2150 (50th)	N/A	N/A	61.84 in 2150	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.0°C ± 0.25°C in 2150 (95th)	N/A	N/A	138.63 in 2150	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.0°C ± 0.25°C in 2150 (5th)	N/A	N/A	32.89 in 2150	N/A	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.5°C ± 0.25°C in 2150 (50th)	N/A	N/A	N/A	62.27 in 2150	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.5°C ± 0.25°C in 2150 (95th)	N/A	N/A	N/A	126.9 in 2150	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Human population exposure	Global	millions people	1875–1900	2010 population levels	N/A	Not available	T - 19-yr running average relative to 2000	2.5°C ± 0.25°C in 2150 (5th)	N/A	N/A	N/A	34.08 in 2150	N/A	N/A	N/A	None	Rasmussen et al. (2018)
Potentially inundated areas from SLR (exposure)	Global	th km^2	2006	N/A	1850–1990	MIROC-ESM RCP2.6	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	67.7–74.2	80.4–83.4	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Potentially inundated areas from SLR (exposure)	Global	th km^2	2006	N/A	1850–1990	MIROC-ESM RCP4.5	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	69.9–74.0	81.4–84.7	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Potentially inundated areas from SLR (exposure)	Global	th km^2	2006	N/A	1850–1990	MIROC-ESM RCP8.5	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	69.3–73.9	73.9–81.9	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Potentially inundated areas from SLR and astronomical high tides (exposure)	Global	th km^2	2006	N/A	1850–1990	MIROC-ESM RCP2.6	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	283.0–291.9	308.2–313.3	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Potentially inundated areas from SLR and astronomical high tides (exposure)	Global	th km^2	2006	N/A	1850–1990	MIROC-ESM RCP4.5	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	283.9–291.1	303.2–314.5	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Potentially inundated areas from SLR and astronomical high tides (exposure)	Global	th km^2	2006	N/A	1850–1990	MIROC-ESM RCP8.5	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	285.0–291.1	303.2–322.2	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Exposed population from SLR and astronomical high tides	Global	millions people	2006	SSP1,2,3	1850–1990	MIROC-ESM RCP2.6	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	48.6–65.9	72.8–77.9	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Exposed population from SLR and astronomical high tides	Global	millions people	2006	SSP1,2,3	1850–1990	MIROC-ESM RCP4.5	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	48.9–65.4	72.7–77.7	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Exposed population from SLR and astronomical high tides	Global	millions people	2006	SSP1,2,3	1850–1990	MIROC-ESM RCP8.5	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	58.9–65.8	65.3–73.6	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Economic damage due to SLR and astronomical high tides (Three damage function)	Global	billions USD (2005)	2006	SSP1,2,3	1850–1990	MIROC-ESM RCP2.6	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	32–54	75–133	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)

Risk	Region	Metric (Unit)	Baseline Time Period against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Is it an Overshoot Scenario? How Long is it above 1.5°C and What is the Maximum Temperature and When?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T for Defined Year (°C)	Delta T Relative to Pre-Industrial in Defined Year; Delta T(°C)	Level of Risk after Adaptation at 1.5°C	Level of Risk after Adaptation at 2°C	Type of Adaptation Modeled	Reference
Economic damage due to SLR and astronomical high tides (Three damage function)	Global	billions USD (2005)	2006	SSP1,2,3	1850–1990	MIROC-ESM RCP4.5	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	32–53	75–134	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)
Economic damage due to SLR and astronomical high tides (Three damage function)	Global	billions USD (2005)	2006	SSP1,2,3	1850–1990	MIROC-ESM RCP8.5	T	1.5°C occurs between 2010 and 2020 and temperature continues to increase	N/A	33–54	53–91	N/A	N/A	Increasing (no adaptation assumed)	Increasing (no adaptation assumed)	None	Yotsukuri et al. (2017) (in Japanese)

Table 3.SM.5: 3.4.6 Food security and food production systems

Risk	Region	Metric (Unit)	Baseline Time Period Against Which Change Measured	Socio-Economic Scenario and Date	Baseline Global T	Climate Scenario	Transient (T) or Equilibrium (E)	Overshoot Scenario?	Dynamic Model?	Projected Impact at 1.5°C above Pre-Industrial	Projected Impact at 2°C above Pre-Industrial	Projected Impact at Delta T (°C)	Delta T Relative to Pre-Industrial	Level of Risk After Adaptation at 1.5°C	Level of Risk After Adaptation at 2°C	Type of Adaptation Modelled	Reference
Water scarcity	Mediterranean	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	-9	-17	Not available	Not available	N/A	N/A	Not available	Schleussner et al. (2017)
Crop yield – wheat	Tropical regions	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	-9	-16	Not available	Not available	N/A	N/A	Not available	
Crop yield – maize	Tropical regions	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	-3	-6	Not available	Not available	N/A	N/A	Not available	
Crop yield – soy	Tropical regions	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	6	7	Not available	Not available	N/A	N/A	Not available	
Crop yield – rice	Tropical regions	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	6	6	Not available	Not available	N/A	N/A	Not available	
Crop yield – wheat	Global	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	2	0	Not available	Not available	N/A	N/A	Not available	
Crop yield – maize	Global	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	-1,5	-6	Not available	Not available	N/A	N/A	Not available	
Crop yield – soy	Global	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	7	1	Not available	Not available	N/A	N/A	Not available	
Crop yield – rice	Global	%	1986–2005	Not available	0,6	RCP8.5, CMIP5	N/A	N/A	Y	7	7	Not available	Not available	N/A	N/A	Not available	
Crop yield	France	%	1980–2009	Not available	Mean seasonal T (°C) 1980–2009 (17°C)	Temperature (-3, 0, 3, 6, 9°C) and CO_2 concentration (360, 450, 540, 630, 720 ppm) factor levels	N/A	N/A	N	-6,75	-9	Not available	Not available	N/A	N/A	Not available	Bassu et al. (2015)
Crop yield	USA	%	1980–2009	Not available	Mean seasonal T (°C) 1980–2009 (21°C)	Temperature (-3, 0, 3, 6, 9°C) and CO_2 concentration (360, 450, 540, 630, 720 ppm) factor levels	N/A	N/A	N	-9	-12	Not available	Not available	N/A	N/A	Not available	
Crop yield	Brazil	%	1980–2009	Not available	Mean seasonal T (°C) 1980–2009 (25°C)	Temperature (-3, 0, 3, 6, 9°C) and CO_2 concentration (360, 450, 540, 630, 720 ppm) factor levels	N/A	N/A	N	-11,7	-15,6	Not available	Not available	N/A	N/A	Not available	
Crop yield	Tanzania	%	1980–2009	Not available	Mean seasonal T (°C) 1980–2009 (27°C)	Temperature (-3, 0, 3, 6, 9°C) and CO_2 concentration (360, 450, 540, 630, 720 ppm) factor levels	N/A	N/A	N	-10,6	-14,2	Not available	Not available	N/A	N/A	Not available	
Crop yield – maize	Drylands	%	1971–1981	SSP2	Not available	RCP8.5, 2006–2100	N/A	N/A	Not available	-0,9	~ -1.1	Not available	Not available	N/A	N/A	Not available	Huang et al. (2017)
Crop yield – maize	Humid lands	%	1971–1981	SSP2	Not available	RCP8.5, 2006–2100	N/A	N/A	Not available	3,2	~ 3.5	Not available	Not available	N/A	N/A	Not available	
Crop yield – maize	Global	%	1971–1981	SSP2	Not available	RCP8.5, 2006–2100	N/A	N/A	Not available	2,6	~ 2.8	Not available	Not available	N/A	N/A	Not available	
Crop yield – wheat	Global	%	1981–2010	Not available	Not available	Temperature (12, 14°C) factor levels	N/A	N/A	N	-9	-12	Not available	Not available	N/A	N/A	Not available	Asseng et al. (2015)
Crop yield – maize	Brazil	%	1982–2012	Not available	Precipitation: -30 to -20%	Temperature (10.5, 11, 11.5, 12, 12.5, 13°C) and precipitation (-30, -20, -10, 0, 110, 120, 150%) factor levels	N/A	N/A	N	-10/ -15	~ -15/ -20	Not available	Not available	N/A	N/A	Not available	Lana et al. (2017)
Crop yield – maize	Brazil	%	1982–2012	Not available	Precipitation: -20 to -10%	Temperature (10.5, 11, 11.5, 12, 12.5, 13°C) and precipitation (-30, -20, -10, 0, 110, 120, 150%) factor levels	N/A	N/A	N	-5/ -10	~ -10/ -15	Not available	Not available	N/A	N/A	Not available	
Crop yield – maize	Brazil	%	1982–2012	Not available	Precipitation: -10 to 0%	Temperature (10.5, 11, 11.5, 12, 12.5, 13°C) and precipitation (-30, -20, -10, 0, 110, 120, 150%) factor levels	N/A	N/A	N	0/ -5	~ -5/ -10	Not available	Not available	N/A	N/A	Not available	
Crop yield – maize	Brazil	%	1982–2012	Not available	Precipitation: 0 to 130%	Temperature (10.5, 11, 11.5, 12, 12.5, 13°C) and precipitation (-30, -20, -10, 0, 110, 120, 150%) factor levels	N/A	N/A	N	0/ 15	0/ -5	Not available	Not available	N/A	N/A	Not available	
Crop yield – wheat	Global	%	1960–2012	SSP1, 2, 3	Not available	RCP2.6 (1.8°C), 4.5 (2.7°C), 6.0 (3.2°C), 8.5 (4.9°C), 2000–2100	N/A	N/A	Not available	38	39	Not available	Not available	N/A	N/A	Not available	Iizumi et al. (2017)
Crop yield – maize	Global	%	1960–2012	SSP1, 2, 3	Not available	RCP2.6 (1.8°C), 4.5 (2.7°C), 6.0 (3.2°C), 8.5 (4.9°C), 2000–2100	N/A	N/A	Not available	29	25	Not available	Not available	N/A	N/A	Not available	
Crop yield – soy	Global	%	1960–2012	SSP1, 2, 3	Not available	RCP2.6 (1.8°C), 4.5 (2.7°C), 6.0 (3.2°C), 8.5 (4.9°C), 2000–2100	N/A	N/A	Not available	35	47	Not available	Not available	N/A	N/A	Not available	
Crop yield – rice	Global	%	1960–2012	SSP1, 2, 3	Not available	RCP2.6 (1.8°C), 4.5 (2.7°C), 6.0 (3.2°C), 8.5 (4.9°C), 2000–2100	N/A	N/A	Not available	36	41	Not available	Not available	N/A	N/A	Not available	
Crop yield – onions	Netherlands	Fraction	1992–2008	Not available	Not available	Temperature (1 and 2) factor levels, 2042–2058	N/A	N/A	Not available	-0,235	~ -0.37	Not available	Not available	N/A	N/A	Chemical protection, UV-light protection	Mandryk et al. (2017)
Crop yield – potatoes	Netherlands	Fraction	1992–2008	Not available	Not available	Temperature (1 and 2) factor levels, 2042–2058	N/A	N/A	Not available	-0,09	~ -0.82	Not available	Not available	N/A	N/A	Plant in wider range, drip irrigation, plant cover, air conditioning, chemical protection, UV-light protection	
Crop yield – maize	Southeast United States	%	1950–1999	Not available	0,5	RCP4.5 (2006–2035), RCP8.5 (2006–2035)	N/A	N/A	Not available	-6,9	-9,2	-4.6 (1.1°C)	1.5°C	N/A	N/A	Not available	Cammarano and Tian (2018)
Crop yield – wheat	Southeast United States	%	1950–1999	Not available	0,5	RCP4.5 (2006–2035), RCP8.5 (2006–2035)	N/A	N/A	Not available	-5,7	-7,6	-5.8 (1.1°C)	1.5°C	N/A	N/A	Not available	
Crop yield – maize	Southeast United States	%	1979–2008	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	Not available	Not available	15/ 18.5	-5,-15 (12.5°C)	Not available	N/A	-5,6	Rainfed	Lychuk et al. (2017)
Crop yield – maize	Southeast United States	%	1979–2008	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	Not available	Not available	15/ 18.5	-5,-15 (12.5°C)	Not available	N/A	10	Irrigated	
Crop yield – soy	Southeast United States	%	1979–2008	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	Not available	Not available	-1/ -1.5	Not available	Not available	N/A	N/A	Rainfed	
Crop yield – soy	Southeast United States	%	1979–2008	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	Not available	Not available	-1/ -1.5	Not available	Not available	N/A	N/A	Irrigated	
Crop – C3 aggregated (soybean, alfalfa, winter wheat)	Southeast United States	%	1979–2008	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	Not available	Not available	-10/ -22	Not available	Not available	N/A	-5,-7	Rainfed	
Crop – C3 aggregated (soybean, alfalfa, winter wheat)	Southeast United States	%	1979–2008	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	Not available	Not available	-10/ -22	Not available	Not available	N/A	0	Irrigated	
Crop – C4 aggregated (corn, sorghum, pearl millet)	Southeast United States	%	1979–2008	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	Not available	Not available	-6/ -10	Not available	Not available	N/A	-2,-3	Rainfed	
Crop – C4 aggregated (corn, sorghum, pearl millet)	Southeast United States	%	1979–2008	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	Not available	Not available	-6/ -10	Not available	Not available	N/A	N/A	Irrigated	
Crop NPP – olive tree	Mediterranean	%	1950–1999	Not available	Not available	SRES A1B (2031–2060)	N/A	N/A	Not available	Not available	14	Not available	Not available	N/A	N/A	Not available	Moriondo et al. (2013)
Crop NPP – olive tree	Mediterranean	%	1950–1999	Not available	Not available	SRES A1B (2061–2090)	N/A	N/A	Not available	Not available	18	Not available	Not available	N/A	N/A	Not available	
Loss of area in global biodiversity	Global	%	1500–2005	Not available	Not available	RCP4.5 (median warmth)	N/A	N/A	Not available	Not available	~ -25	Not available	Not available	N/A	N/A	Not available	Jantz et al. (2015)
Wildfire – dead fuel moisture	Western USA	%	1950–2005	Not available	Not available	RCP8.5 (CMIP5 ensemble)	N/A	N/A	Not available	0/ -5	-10/ -15	Not available	Not available	N/A	N/A	Not available	Gergel et al. (2017)
Wildfire – increase in number of days of fire season with conditions conducive to fire growth	Canada (East)	N°	1971–2000	Not available	Not available	RCP8.5 (median warmth)	N/A	N/A	Not available	112/ 145	Not available	Not available	Not available	N/A	N/A	Not available	Wotton et al. (2017)
Wildfire – increase in number of days of fire season with conditions conducive to fire growth	Canada (West)	N°	1971–2000	Not available	Not available	RCP8.5 (median warmth)	N/A	N/A	Not available	12/ 115	Not available	Not available	Not available	N/A	N/A	Not available	
Wildfire – future probability of fire	USA (Alaska)	Ratio	1950–2009	Not available	Not available	RCP6.0 (median warmth)	N/A	N/A	N	~ 1.125	~ 1.144	Not available	Not available	N/A	N/A	Not available	Young et al. (2016)
Wildfire – fire weather index	Mediterranean	%	1961–1990	Not available	Not available	SRES B2	N/A	N/A	N	Not available	19,0	Not available	Not available	N/A	N/A	Not available	Moriondo et al. (2006)
Wildfire – fire weather index	France	%	1961–1990	Not available	Not available	SRES B2	N/A	N/A	N	Not available	21	Not available	Not available	N/A	N/A	Not available	
Wildfire – fire weather index	Portugal	%	1961–1990	Not available	Not available	SRES B2	N/A	N/A	N	Not available	11	Not available	Not available	N/A	N/A	Not available	
Wildfire – fire weather index	Spain	%	1961–1990	Not available	Not available	SRES B2	N/A	N/A	N	Not available	18	Not available	Not available	N/A	N/A	Not available	
Wildfire – increased annual area burned	Canada	%	1961–1990	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	N	Not available	~ 1157	Not available	Not available	N/A	N/A	Not available	Boulanger et al. (2014)
Wildfire – fire occurrence	Canada	%	1961–1990	Not available	Not available	SRES A2 (2041–2070)	N/A	N/A	N	Not available	~ 1182	Not available	Not available	N/A	N/A	Not available	
Wildfire – fire occurrence density	Northeast China	%	1965–2000	Not available	Not available	SRES B1 (2081–2100 – CGCM)	N/A	N/A	N	Not available	~ 130	Not available	Not available	N/A	N/A	Not available	Liu et al. (2012)

3.SM.3.1 Supplementary information to Section 3.4.2

3.SM.3.1.1 Freshwater Resources (Quantity and Quality)

In this section, Arnell and Lloyd-Hughes (2014) assess water scarcity based on the simple indicator of average annual runoff per capita called “water resources stress”, and define that watershed as exposed to such stress if watershed average annual runoff is less than 1000 m^3 cap^{-1} yr^{-1}. The same condition is applied to identify chronic supply-side water scarcity within a given spatial unit in the study by Gerten et al. (2013) that refers to Falkenmark and Widstrand (1992), whose index is called Withdrawal to Water Resouces (WWR) ratio. With WWR, Hanasaki et al. (2013) indicate a chronic water shortage if water withdrawal exceeds 40% of the water resources in a region. A quantitative metric of freshwater stress is defined in terms of future projections of population and aridity, where freshwater stress index is calculated as a population change index multiplied by an aridity change index (Karnauskas et al. 2018). Schewe et al. (2014) apply two water scarcity classes: annual blue water availability below 500 m^3 per capita, namely absolute water scarcity, and below 1000 m^3 per capita that is referred to as chronic water scarcity.

3.SM.3.1.1.2 Extreme hydrological events (floods and droughts)

Alfieri et al. (2017) assume and estimate potential population affected for any positive flood depth by overlaying population density and flood hazard maps. Arnell et al. (2018) define exposure to river flooding by the average annual number of people living in major floodplains affected by floods greater than the baseline 30-year flood. Arnell and Lloyd-Hughes (2014) use an indicator in which the number of flood-prone people living in areas where the frequency of the baseline (1960–1990) 20-year flood either doubles (occurs more frequently than one in 10 years) or halves (occurs more rarely than one in 40 years), although these thresholds are arbitrary. Kinoshita et al. (2018) estimate fatalities due to flooding by multiplying exposure (population prone to flooding, defined in the study as gridded population) by vulnerability, and numerically calculate flood hazard as the extent and depth of flood, while estimating potential affected exposure by superimposing the modelled hazard on the population data. In the study, Kinoshita et al. (2018) consider exposure as gridded population whereas historical vulnerability is defined as a ratio of the observed flood consequences and potentially affected exposure at a national level in equations.

In the study by Arnell et al. (2018), drought is presented by the standardized runoff index called SRI, which is calculated from monthly runoff simulated with the MacPDM.09 global hydrological model described in Gosling and Arnell (2011) . The occurrence of a drought is defined as when the SRI is less than –1.5; and as for drought frequency for a given time series of monthly runoff, it is determined by counting the number of months with SRI less than –1.5. Liu et al. (2018) quantify the changes in drought characteristics, adopting Palmer Drought Severity Index (PDSI) that describes the balance between water supply (precipitation) and atmospheric evaporative demand required by the precipitation estimated under climatically appropriate for existing conditions, which is described by Zhang et al. (2016), Wells et al. (2004) and Zhang et al. (2016). Liu et al.’s (2018) study suggests that PDSI is commonly applicable as an indication of meteorological drought and a hydrological drought for a multi-year time series. Liu et al. (2018) assume a severe drought event when the monthly PDSI is < -3, and identify a severe drought year if a severe drought occurs for at least a month in a year, while multiplying population by annual frequency of severe drought to quantify the population affected by severe drought per grid-cell.

3.SM.3.1.1.3 Groundwater

Portmann et al. (2013) assess groundwater with groundwater recharge (GWR), which is assumed to be curbed by a maximum groundwater recharge rate per day. GWR occurs if daily precipitation exceeds 12.5 mm d^{-1} in case of medium to coarse grained soils (Portmann et al., 2013). In some regions, groundwater is often intensively used to supplement the excess demand, often leading to groundwater depletion; besides climate change, this adds further pressure on water resources and exaggerates human water demands due to increasing temperatures over agricultural lands (Wada et al. 2017).

3.SM.3.1.1.4 Water quality

Water temperature directly affects water quality, and most chemical and bacteriological processes are accelerated according to the temperature rise (Watts et al. 2015). Hosseini et al. (2017) summarize that the main impact on water quality due to climate change is attributed to changing air temperature and hydrology; and particularly ambient air temperature directly affects water temperature, that is projected to increase due to global warming. Watts et al. (2015) describe water quality as affected by many factors, including water temperature, hydrological regime, nutrient status and mobilization of toxic substances, as well as point source, diffuse discharge and acidification potential, referring to Whitehead et al. (2009). Patiño et al. (2014) reveal that changes in water quality can influence the spread of harmful aquatic species, referring to the fact that toxic algae are lethal to some aquatic animals and has posed considerable ecological and economic impacts on freshwater and marine ecosystems. Bonte and Zwolsman (2010) state that salinization due to rising sea levels as well as poor land management and excessive groundwater extractions is putting a strain on freshwater resources availability around the world. Attributing changes in river water quality to specific factors is difficult since multiple factors act at different temporal and spatial scales, and it often requires examining a long-term series of continuous data (Aguilera et al. 2015).

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3.SM.3.2 Supplementary Information to Section 3.4.4

Update of Expert Assessment by Gattuso et al. (2015)

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Risk assessment update: November 18, 2017 (by lead authors and contributing authors of Chapter 3, other chapters of the Special Report on Global Warming of 1.5˚C, and relevant external experts).

This Section 3.SM.3.2 includes:

Supplementary Text

Table 3.SM.6

Full Reference List

Background Information and Rationale of Expert Judgement on the Risk of Impact Due to CO_2 Levels by 2100

This supplementary material provides the background information and rationale for the construction of the burning embers diagrams used in Figure 3.18 to represent the increase in risk as well as the limits to adaptation from rising CO_2 levels for keystone marine and coastal organisms and ecosystem services.

This is the expert judgement by the group on the overall risk – balancing negative, neutral and positive impacts across species and regions using current literature.

Table 3.SM.6: The temperature at which transitions in the level of risk occur in response to climate change, from expert judgement by Gattuso et al. (2015) and updated in March 2018 for the following three years of scientific literature. [White: No detectable risks from climate change; Yellow: Moderate levels of risk; Red: High level of risk; and Purple: Very high level of risk]
Note: These data were used to build the burning embers for representative marine organisms, ecosystems and sectors. Note: Red numbers are where the update has resulted in slightly different conclusions to those of Gattuso et al. (2015).

		Average Global Sea Surface Temperature (SST, ˚C)		
Component	**Colour transition**		**2015**	**2018**
Seagrasses (mid-latitude)	White to Yellow	Begin	0.5	0.5
		End	0.8	0.8
	Yellow to Red	Begin	1.5	1.5
		End	1.8	1.8

		Average Global Sea Surface Temperature (SST, ˚C)		
Component	**Colour transition**		**2015**	**2018**
	Red to Purple	Begin	2.2	2.2
		End	3	3
Mangroves	White to Yellow	Begin	1.8	1.3
		End	3	1.5 (2.5)*
	Yellow to Red	Begin	3	2.5
		End	3.2	2.7
	Red to Purple	Begin	N/A	NA
		End	N/A	NA
Warm-water corals	White to Yellow	Begin	0.3	0.2
		End	0.4	0.4
	Yellow to Red	Begin	0.5	0.4
		End	0.8	0.6
	Red to Purple	Begin	0.8	0.6
		End	1.5	1.2
Pteropods (high latitude)	White to Yellow	Begin	0.7	0.7
		End	0.8	0.8
	Yellow to Red	Begin	0.8	0.8
		End	1.5	1.5
	Red to Purple	Begin	1.5	1.5
		End	2	2
Bivalves (mid-latitude)	White to Yellow	Begin	0.4	0.4
		End	0.6	0.6
	Yellow to Red	Begin	0.9	0.9
		End	1.1	1.1
	Red to Purple	Begin	1.3	1.3
		End	1.5	1.5
Krill (high latitude)	White to Yellow	Begin	0.7	0.7
		End	0.9	0.9
	Yellow to Red	Begin	1	1
		End	1.6	1.6
	Red to Purple	Begin	1.8	1.8
		End	3.2	3.2
Fin fish	White to Yellow	Begin	0.5	0.5

		Average Global Sea Surface Temperature (SST, ˚C)		
Component	**Colour transition**		**2015**	**2018**
		End	0.7	0.7
	Yellow to Red	Begin	1.1	1.1
		End	1.3	1.3
	Red to Purple	Begin	1.4	1.4
		End	1.6	1.6
Open-ocean carbon uptake	White to Yellow	Begin	1	1
		End	1.5	1.5
	Yellow to Red	Begin	2	2
		End	3.2	3.2
	Red to Purple	Begin	N/A	N/A
		End	N/A	N/A
Coastal protection	White to Yellow	Begin	0.5	0.5
		End	0.8	0.8
	Yellow to Red	Begin	1.5	1.5
		End	1.8	1.8
	Red to Purple	Begin	2.2	2.2
		End	3.2	3.2
Recreational services from coral reefs	White to Yellow	Begin	0.6	0.6
		End	0.8	0.8
	Yellow to Red	Begin	1	1
		End	1.5	1.5
	Red to Purple	Begin	2	2
		End	3.2	3.2
Bivalve fisheries and aquaculture (mid-latitude)	White to Yellow	Begin	1.1	1.1
		End	1.3	1.3
	Yellow to Red	Begin	1.7	1.7
		End	1.9	1.9
	Red to Purple	Begin	2.8	2.8
		End	3.2	3.2
Fin-fish (small scale) fisheries (low latitude)	White to Yellow	Begin	0.7	0.5
		End	0.9	0.7
	Yellow to Red	Begin	1	0.9
		End	1.2	1.1

		Average Global Sea Surface Temperature (SST, ˚C)		
Component	**Colour transition**		**2015**	**2018**
	Red to Purple	Begin	2	2
		End	2.5	2.5
Fin-fish fisheries (mid- and high latitude)	White to Yellow	Begin	0.7	0.7
		End	0.9	0.9
	Yellow to Red	Begin	2.2	2.2
		End	3.2	3.2
	Red to Purple	Begin	N/A	N/A
		End	N/A	N/A

Note: *Mangrove value differs from table value but is consistent with main text and general expert consensus.

Expert assessment: Original assessment by Gattuso et al. (2015) using the IPCC Fifth Assessment Report (AR5) and literature published up to 2014. This current assessment updated the original assessment using literature from 2015 to early 2018. References for the current and past assessments are listed at the end of this document. This is online supplementary material for the special report on the implications of 1.5ºC warming.

3.SM.3.2.1 Seagrasses (Mid-Latitude)

Update: Recent literature supports the consensus reached by Gattuso et al. (2015), with increasing ocean temperatures being a major threat and projections of the potential loss of key species such as *Posidonia oceanica* in the Mediterranean by mid-century (Jordà et al., 2012). Recent work has shown that increasing temperatures is a major threat to the shoot density (Guerrero-Meseguer et al., 2017) and quality of the seagrass *Zostera marina* (Repolho et al., 2017). Other studies on related systems reveal subchronic changes to the quality of seagrass shoots and leaves (Unsworth et al., 2014) and have speculated on the impact that these changes might have on coastal food webs (York et al. 2016). Several studies have speculated on the impact of rising seas, storms and flooding on seagrass productivity (Ondiviela et al., 2014; Rasheed et al., 2014; Pergent et al., 2015; Telesca et al., 2015). The consensus of the literature for the last two years, examined since AR5, suggests that the current risk levels for seagrasses proposed by Gattuso et al. (2015) are appropriate.

Therefore, seagrasses are already showing responses to climate change; hence the expert consensus that the transition from undetectable to moderate risk occurs between 0.5°C and 0.8°C. Given the clear sensitivity of seagrass communities to rising sea temperatures, and other aspects of climate change such as sea level rise, storms and flooding, these risks transition from moderate to high from 1.5°C to 1.8°C, and from high to very high risk over the interval from 2.2°C to 3°C.

Expert assessment by Gattuso et al. (2015; SOM):

Seagrasses, important habitats in coastal waters around the world, will be affected by climate change through a number of routes, including: direct effects of temperature on growth rates (Nejrup and Pedersen, 2008; Höffle et al., 2011), occurrence of disease (Burge et al., 2013), mortality and physiology, changes in light levels arising from sea level changes, changes in exposure to wave action (Short and Neckles, 1999), sometimes mediated through effects on adjacent ecosystems (Saunders et al., 2014), and also by changes in the frequency and magnitude of extreme weather events. There will be changes in the distribution of seagrass communities locally and regionally. Here we take the example of temperate seagrasses, including *Posidonia oceanica* from the Mediterranean and *Zostera* spp from the USA, Europe and Australia, because the information on the effects of ocean warming and acidification for these species from several field studies is robust. Results indicate that temperate seagrass meadows have already been negatively impacted by rising sea surface temperatures (SSTs) (Marbà and Duarte, 2010). Models based on observations of natural populations indicate that at temperature increases of 1.5°C – 3°C mortality of shoots of seagrasses will be such that populations will be unsustainable and meadows will decline to the point where their ecological functions as a habitat will cease (reduction to 10% of present density of a healthy meadow; Marbà and Duarte 2010; Jordà et al. 2012; Carr et al. 2012; York et al. 2013).

The confidence level is *very high* under Representative Concentration Pathway (RCP)2.6 because of strong agreement in the literature. Confidence declines to *high* under RCP8.5 due to some uncertainty surrounding regional differences. For example, it has been suggested that the balance of effects on seagrass populations in the northeast Atlantic could tip to positive due to the hypothetical opening of ecological niches with the decline of more sensitive species, and potential reduction of carbon limitation by elevated CO_2 which may help to ameliorate negative effects of other environmental drivers, such as warming, known to impact seagrass growth and survival (Brodie et al., 2014).

3.SM.3.2.2 Mangroves

Update: Recent literature is consistent with previous conclusions regarding the complex changes facing mangroves, together with increasing concern regarding the interaction between climate change (e.g., elevated air and water temperatures, drought and sea level rise) and local factors (deforestation, damming of catchments and reduced sediment and freshwater) as outlined below (Alongi, 2015; Feller et al., 2017). Decreases in the supply of sediments to deltas and coastal areas is impeding the ability of most mangroves (69% of sites) to keep pace with sea level rise through shoreward migration (Lovelock et al., 2015). At the same time, recent extremes associated with El Niño have also had large-scale impacts (e.g., extreme low sea level events; Duke et al., 2017; Lovelock et al., 2017). Shoreward migration is also challenged by the increasing amounts of coastal infrastructure preventing the relocation of mangroves (Di Nitto et al., 2014; Saunders et al., 2014). In some areas, mangroves are increasing in distribution (Godoy and De Lacerda, 2015). The total losses projected for mangrove loss (10–15%) under a 0.6 m sea level rise continue to be dwarfed by the loss of mangroves to deforestation (1–2% per annum).

However, given the scale of the dieback of mangroves in Australia's Gulf of Carpentaria (in 2015–2016), as well as evidence that similar conditions to those of 2015–2016 (extreme heat and low tides) and the projection of greater El Niño-Southern Oscillation (ENSO) variability, (Widlansky et al., 2015; Risser and Wehner, 2017), the risks from climate change for mangroves were judged to be higher than assessed by AR5, and subsequently by Gattuso et al. (2015), leading to the transitions having greater risk of occurring (Figure 3.18). Formal attribution of recent extreme events on mangroves to climate change, however, is at an early stage (*medium agreement*, *limited data*, *hence low-medium confidence*).

Expert assessment by Gattuso et al. (2015; SOM):

Mangroves are critically important coastal habitats for numerous species. Mangrove responses to increasing atmospheric CO_2 are complex, with some species thriving while others decline or exhibit little or no change (Alongi, 2015). Temperature increase alone is likely to result in faster growth, reproduction, photosynthesis and respiration, and changes in community composition, diversity and an expansion of latitudinal limits up to a certain point (Tittensor et al., 2010). Mangroves have already been observed to retreat with sea level rise (McKee et al., 2012). In many areas, mangroves can adapt to sea level rise by landward migration, but these shifts threaten other coastal habitats, such as salt marshes, which have other important biogeochemical and ecological roles. It is in areas with steep coastal inclines or coastal human infrastructure limiting landward migration that mangroves are most at risk. Climate change may lead to a maximum global loss of 10–15% of mangrove forest for a sea level rise of 0.6 m (high end of IPCC projections in AR4), but must be considered of secondary importance compared with current annual rates of deforestation of 1–2% (Alongi, 2008). A large reservoir of below-ground nutrients, rapid rates of nutrient flux microbial decomposition, complex and highly efficient biotic controls, self-design and redundancy of keystone species, and numerous feedbacks, all contribute to mangrove resilience to various types of disturbance.

Mangrove response is species-specific and interacts with temperature, salinity, nutrient availability and patterns of precipitation. Many of these parameters are also subject to regional and local variation, as well as to human-induced pressures, with changes over the coming decades being difficult to assess. Thus, the confidence level decreases from *high* under RCP2.6 to *low* under RCP8.5.

3.SM.3.2.3 Warm-Water Corals

Update: The exceptionally warm conditions of 2015–2017 drove an unprecedented global mass coral bleaching and mortality event which affected coral reefs in a large number of countries (information still being gathered at time of writing; Normile, 2016). In the case of Australia, 50% of shallow-water reef-building corals across the Great Barrier Reef died in unprecedented back-to-back bleaching events (Hughes et al., 2017). Elevated sea temperatures and record mortalities were recorded from the central to the far northern sectors of the Great Barrier Reef. Similar effects occurred in a range of regions, including the Indian Ocean, the western Pacific, Hawaii and the Caribbean Sea (Normile, 2016). The set of events has increased risk with current conditions being of high risk, and even low levels of future climate change having series implications for coral reefs. There continues to be a *high* to *very high* level of confidence as to where the transitions between risk levels due to climate change are located.

The unprecedented thermal stress along many tropical coastlines over the past three years (2015–2017) has led to extraordinary changes to coral reefs across the planet (as described above). The advent of back-to-back bleaching events, which were projected to occur around mid-century, appear to have already begun to occur as demonstrated by impacts on warm-water corals and hence coral reefs. While corals were already stressed from climate change, and are in decline in many parts of the world, the scale and impact of recent events suggests that risk levels for the transitions between risk categories need to be adjusted to represent the current status of corals and coral reefs. For this reason, expert consultation since 2015 concluded that the transition from undetectable to moderate risk has already occurred (0.2°C to 0.4°C). Similarly, the transition from moderate to high levels of risks for warm-water corals occurred approximately from 0.4°C to 0.6°C. In line with these changes, the transition from high to very high levels of risk are associated with increases in GMST from 0.6°C to 1.2°C above the pre-industrial period.

Expert assessment by Gattuso et al. (2015; SOM):

Warm-water corals form reefs that harbour great biodiversity and protect the coasts of low-lying land masses. There are *very high* levels of confidence that impacts were undetectable up until the early 1980s, when coral reefs in the Caribbean and eastern Pacific exhibited mass coral bleaching, as well as temperature-related disease outbreaks in the Caribbean Sea (Glynn, 1984). Given a conservative lag time of 10 years between the atmospheric concentration of CO_2 and changes in SST, the atmospheric CO_2 level of 325 ppm reached in the early 1970s was sufficient to initiate widespread coral bleaching and decline of coral health worldwide (Veron et al., 2009). During the 1980s, visible impacts of increasing were seen in a widening number of areas, with the first global event in 1997–1998 and the loss of 16% of coral reefs (*high confidence*; C. R. Wilkinson 2000). Further increases in atmospheric carbon dioxide and SST have increased the risk to corals (*high confidence*), with multiple widespread bleaching events, including loss of a large fraction of living corals in the Caribbean in 2005 (Eakin et al., 2010) and a subsequent global bleaching in 2010 (e.g., Moore et al. 2012), and current conditions suggesting the development of a third global event in 2015–2016 (C.M. Eakin, unpublished observation). If CO_2 levels continue to increase, there is a very high risk that coral reefs would be negatively affected by doubled pre-industrial CO_2 through impacts of both warming-induced bleaching and ocean acidification (high confidence), supported by a wide array of modelling (e.g., Hoegh-Guldberg et al. 2014, Logan et al. 2014, Hoegh-Guldberg 1999, Donner et al. 2005, van Hooidonk et al. 2014), experimental (e.g., Dove et al. 2013) and field studies (Silverman et al. 2014, De'ath et al. 2012). This leads to a *very high* level of confidence under RCP2.6 and a *high* level of confidence under RCP8.5.

3.SM.3.2.4 Pteropods (High Latitude)

Update: Literature from the last two years is largely consistent with the expert assessment by Gattuso et al. (2015). There is increasing evidence of declining aragonite saturation in the open ocean with the detection of impacts that are most pronounced closest to the surface, and with the severe biological impacts occurring within inshore regions. In this regard, pteropod shell dissolution has increased by 19–26% in both nearshore and offshore waters since the pre-industrial period (Feely et al., 2016). Impacts of ocean acidification are also cumulative with other stresses, such as elevated sea temperature and hypoxia (Bednaršek et al., 2016). These changes are consistent with observations of large portions of the shelf waters associated with the Washington–Oregon–California coast being strongly corrosive, with 53% of onshore and 24% of offshore pteropod individuals showing severe damage from dissolution (Bednaršek et al., 2014). Several researchers propose that the pteropod condition be used as a biological indicator, which they argue will become increasingly important as society attempts to understand the characteristics and rate of change in ocean acidification impacts on marine organisms and ecosystems (Bednaršek et al., 2017; Manno et al., 2017). The last two years of research has increased confidence in our understanding of the impact of ocean acidification on pteropods under field conditions. The question of the genetic adaptation of pteropods to increasing ocean acidification remains unresolved, although the observation of increasing damage to pteropods from field measurements argues against this being a significant factor in the future.

As described here and by Gattuso et al. (2015), multiple lines of evidence conclude that pteropods are being impacted by climate change and ocean acidification, especially in polar regions. Therefore, the transition from undetectable to moderate levels of stress has been judged to occur between 0.7°C and 0.8°C. The transition from moderate to high levels of risk of impact on these important organisms was judged to occur from 0.8°C to 1.5°C, with the transition from high to very high occurring from 1.5°C to 2°C.

Expert assessment by Gattuso et al. (2015; SOM):

Pteropods are key links in ocean food webs between microscopic and larger organisms, including fish, birds and whales. Ocean acidification at levels anticipated under RCP8.5 leads to a decrease in pteropod shell production (Comeau et al., 2009, 2010; Lischka et al., 2011), an increase in shell degradation (Comeau et al., 2012; Lischka and Riebesell, 2012), a decrease in swimming activity when ocean acidification is combined with freshening (Mannoa et al., 2012), and an increase in mortality that is enhanced at temperature changes smaller than those projected for RCP8.5 (Lischka et al., 2011; Lischka and Riebesell, 2012). Shell dissolution has already been observed in high latitude populations (Bednaršek et al., 2012). Aragonite saturation (Ωa) levels below 1.4 results in shell dissolution, with severe shell dissolution between 0.8 and 1 (Bednaršek and Ohman, 2015). Despite high agreement amongst published findings, uncertainty remains surrounding the potential to adapt to environmental drivers because long-term laboratory experiments with pteropods are notoriously difficult. Hence the confidence level is *medium* under RCP2.6. However, confidence increases to *very high* under RCP8.5 because it is almost certain that genetic adaptation to such large and rapid changes in pH and temperature will not be possible.

3.SM.3.2.5 Bivalves (Mid-Latitude)

Update: Literature has rapidly expanded since 2015, with a large number of studies showing impacts of ocean warming and acidification on a wide range of life history stages of bivalve molluscs (e.g., Asplund et al., 2014; Castillo et al., 2017; Lemasson et al., 2017; Mackenzie et al., 2014; Ong et al., 2017; Rodrigues et al., 2015; Shi et al., 2016; Velez et al., 2016; Waldbusser et al., 2014; Wang et al., 2016; Zhao et al., 2017; Zittier et al., 2015). Impacts on adult bivalves include decreased growth, increased respiration and reduced calcification, with larval stages tending to have an increase in developmental abnormalities and elevated mortality after exposure (Wang et al., 2016; Lemasson et al., 2017; Ong et al., 2017; Zhao et al., 2017). Many recent studies have also identified interactions between factors such as increased temperature and ocean acidification, with salinity perturbations as well as decreases in oxygen concentrations (Velez et al., 2016; Lemasson et al., 2017; Parker et al., 2017). Changes in metabolism with increasing ocean acidification has been detected in a number of transcriptome studies, suggesting a complex and wide-ranging response by bivalves to increasing CO_2

and temperature (Li et al., 2016a, 2016b). Observations of reduced immunity may have implications for disease management (Castillo et al., 2017). These changes are likely to impact the ecology of oysters, and may be important when it comes to the maintenance of oyster reefs, which provide important ecological structure for other species. Bivalves, for example, are more susceptible to the impacts of temperature and salinity if they have been exposed to high levels of CO_2, leading to the suggestion that there will be a narrowing of the physiological range and hence distribution of oyster species such as *Saccostrea glomerata* (Parker et al., 2017). The confidence level is adjusted to *high* given the convergence of recent literature. These studies continue to report growing impacts as opposed to a reduction under rapid genetic adaptation by bivalve molluscs. The overall levels of risk are retained – reflecting the moderate risk that already exists, and the potential for transformation into high or very high levels of risk with relatively small amounts of further climate change.

Recent literature reinforces the conclusions of Gattuso et al. (2015) and confirms the transition of risk from low to moderate for the bivalves associated with mid-latitude environments is occurring between 0.4°C and 0.6°C. The transition for these organisms from moderate to high levels of risk occurs at 0.9°C and 1.1°C. Subsequent transition from high to very high was judged to occur between 1.3°C and 1.5°C.

Expert assessment by Gattuso et al. (2015; SOM):

Both cultured and wild bivalves are an important food source worldwide. Temperate bivalve shellfish, such as oysters, clams, mussels and scallops, have already been negatively impacted by ocean acidification. In the northwest United States, Pacific oyster larval mortality has been associated with upwelling of natural CO_2-rich waters acidified by additional fossil fuel CO_2 (*high confidence*; Barton et al. 2012). Ocean acidification acts synergistically with deoxygenation (Gobler et al., 2014) and warming (Kroeker et al., 2013; Mackenzie et al., 2014a) to heighten physiological stress (Wittmann and Pörtner, 2013) on bivalve shellfish (*high confidence*), suggesting that future ocean conditions that include warming, deoxygenation and acidification will be particularly difficult for members of this taxon. Archaeological/geological and modelling studies show range shifts of bivalves in response to prior and projected warming (Raybaud et al., 2015) and acidification (Lam et al., 2014). Model projections also anticipate decreases in mollusc body size under continued harvesting as conditions change farther from the present (Cooley et al., 2015). Impacts are expected to be high to very high when CO_2 concentrations exceed those expected for 2100 in the RCP2.6 and 4.5 levels (*medium confidence*; Lam et al., 2014; Cooley et al., 2015). The confidence level is medium both under RCP2.6 and RCP8.5 primarily due to the possibility of bivalves adapting over generations (Pespeni et al., 2013), or for specific species to outcompete other wild species in future conditions (e.g., Miller et al., 2009).

3.SM.3.2.6 Krill (High Latitude)

Update: Summer sea ice continues to retreat at high rates in polar oceans with both the Artic and Antarctica being among the fastest warming regions on the planet (Notz and Stroeve, 2016; Turner et al., 2017). In Antarctic waters, a decrease in sea ice represents a loss of critical habitat for krill (David et al., 2017). Projected changes of this habitat through increasing temperature and acidification could have major impacts on food, reproduction and development, and hence the abundance of this key organism for Antarctic food webs. Differences appear to be a consequence of regional dynamics in factors such as regional variation in ice, productivity and predation rates, and an array of other factors (Steinberg et al., 2015). Other factors such as interactions with factors such as ocean acidification and the shoaling of the aragonite saturation horizon are likely to play key roles. (Kawaguchi et al., 2013; Piñones and Fedorov, 2016). While factors such as ocean acidification and the loss of sea ice (due to increasing temperatures) are unambiguous in their effects, there continues to be considerable uncertainty around the details of how krill populations are likely to respond to factors such as changing productivity, storms and food web structure.

While there are considerable gaps in our knowledge about the impacts of climate change on krill, there is consensus that direct climate impacts are beginning to be detected at average global SST of around

0.7°C to 0.9ºC. With a *low* level of confidence and hence much uncertainty, expert consensus concludes that transition from moderate to high levels of risk is expected to occur between 1.0°C and 1.6°C. Subsequent transitions from high to very high levels of risk are projected to lie somewhere between 1.8°C and 3.2°C, although levels of confidence are *low* at this time.

Expert assessment by Gattuso et al. (2015; SOM):

Krill (euphausid crustaceans) is a critical link in the food web at higher latitudes, supporting mammals and birds among many other species. Distributional changes and decreases in krill abundance have already been observed associated with temperature increase (Atkinson et al., 2004). The effect of changes in the extent of sea ice is considered to be an indirect effect of temperature. Temperature effects are predicted to be regional (Hill et al., 2013). If the extent of sea ice is maintained, populations in cooler waters may experience positive effects in response to small increases in temperature. In contrast, populations in warmer areas may experience some negative temperature effects by 2100 under RCP2.6. Since all life stages are associated with sea ice, decreases in krill stocks are projected to occur concurrently with the loss of sea ice habitat, potentially outweighing possible positive impacts (Flores et al., 2012). Increases in SST of 1°C–2°C have significant impacts on krill. From Figure 4 in Flores et al. (2012) severe disruptions of the life cycle are expected at a level of 2°C SST rise and 500 µatm pCO_2. Therefore, high impact on populations would be reached approximately at the CO_2 level projected for 2100 by RCP4.5. Conditions in 2100 under the RCP2.6 scenario would be around the upper limit of the high-risk range. Negative effects of ocean acidification on reproduction, larval and early life stages have been observed above 1250 µatm pCO_2, a value that is likely to be reached in parts of the Southern Ocean by 2100 under RCP8.5 (Kawaguchi et al., 2013). Figure 1 in Flores et al. (2012) shows that the area with strongest sea ice decline partly overlaps with areas of high krill density (from the peninsula to the South Orkneys). There is also a significant warming trend in this area which may force populations southwards into less productive regions. Substantial decline in the viability of major krill populations in the Southern Ocean may occur within the next 100 years (Kawaguchi et al., 2013), which could have catastrophic consequences for dependent marine mammals and birds. The genetic homogeneity of krill suggests that rapid adaptation through natural selection of more tolerant genotypes is unlikely (Bortolotto et al., 2011).

3.SM.3.2.7 Fin Fish

Update: Impacts and responses identified in 2015 regarding the relative risk of climate change to fin fish have strengthened. In this regard, there are a growing number of studies indicating that different stages of development may also be made more complex by fish having different stages of the life-cycle in different habitats, which may each be influenced by climate change in different ways and to different extents, as well as evidence of differing sensitivities to change between different stages (Ong et al., 2015, 2017; Esbaugh, 2017). Increasing numbers of fish species have been identified as relocating to higher latitudes, with tropical species being found increasingly in temperate zones (‘tropicalization’, Horta E Costa et al., 2014; Verges et al., 2014; Vergés et al., 2016) and temperate species being found in some polar regions (‘borealization’, Fossheim et al., 2015). Concern has been raised that greater numbers of extinctions will occur in the tropics as species are pushed out of low-latitude areas as conditions become warmer and increasingly unsuitable (Burrows et al., 2014; García Molinos et al., 2015; Poloczanska et al., 2016). Changing conditions in polar regions are particularly risky due to the rapid rates of warming (Notz and Stroeve, 2016; Turner et al., 2017). One of the consequences of this is that an increasing number of fish species are expanding their distributional ranges into the Arctic, being followed by large, migratory fish predators. The borealization of fish communities in the Arctic is leading to a reorganization of species and ecological processes which is not well understood (Fossheim et al., 2015).There is considerable evidence that changes in the distribution of fin fish are, and have been, occurring over the last few decades. Evidence of the movement of tropical species to higher latitudes is unambiguous, as is the shift in many pelagic species of fin fish. Consequently, the distribution and abundance of fin fish is already occurring, and based on the updated expert consensus of Gattuso et al. (2015), appears to have transitioned from undetectable to moderate levels of risk at average global SSTs of 0.5°C and 0.7°C. There is little evidence that these changes are slowing, and therefore risks are estimated as transitioning from moderate to high levels of risk at 1.1°C to 1.3°C, and from high to very high levels of risk at 1.4°C to 1.6°C.

Expert assessment by Gattuso et al. (2015; SOM):

Marine fishes are important predators and prey in ocean ecosystems, contributing substantially to coastal economies, food security and livelihood. Warming-induced shifts in the abundance, geographic distribution, migration patterns and phenology of marine species, including fishes, were reported and projected with *very high confidence* in the IPCC AR5 (Pörtner et al., 2014).

Empirical and theoretical evidence of range shifts in response to temperature gradients are reported across various taxa and many geographical locations (Couce et al., 2013; Poloczanska et al., 2013; Bates et al., 2014), with observations suggesting that range shifts correspond with the rate and directionality of climate shifts or 'climate velocity' across landscapes (Pinsky et al., 2013). Observed range shifts associated with ocean warming may result in hybridization between native and invasive species through overlapping ranges, leading to reduced fitness and thus potentially increasing the risks of genetic extinction and reducing the adaptability to environmental changes (Muhlfeld et al., 2014; Potts et al., 2014). Some taxa are incapable of keeping pace with climate velocities, as observed with benthic invertebrates in the North Sea (Hiddink et al., 2015). The tropicalization of temperate marine ecosystems through poleward range shifts of tropical fish grazers increases the grazing rate of temperate macroalgae as seen in Japan and the Mediterranean (Verges et al., 2014). Such trophic impacts resulting from climate-induced range shifts are expected to affect ecosystem structure and dynamic in temperate reefs (Verges et al., 2014).

Projected future changes in temperature and other physical and chemical oceanographic factors are expected to affect the distribution and abundance of marine fishes, as elaborated by species distribution models with rate of shift at present day rate under the RCP8.5 scenario (Cheung et al., 2009). Limiting emissions to RCP2.6 is projected to reduce the average rate of range shift by 65% by mid-21st century (Jones and Cheung, 2015). Shifts in distribution of some species may be limited by the bathymetry or geographic boundaries, potentially resulting in a high risk of local extinction, particularly under high CO_2 emissions scenarios (Ben Rais Lasram et al., 2010).

While evidence suggests that adult fishes can survive high levels of CO_2, behavioural studies have found significant changes in species' responses under levels of CO_2 elevated above those of the present day level (Munday et al., 2014). Long-term persistence of these phenomena remains unknown. Based on the above, fishes already experience moderate risk of impacts at present day (*high confidence*). Risk increases from moderate to high by the end of the 21st century, when emissions change from RCP2.6 to RCP4.5 and become very high under RCP8.5, highlighting the potential non-reversibility of the potential impacts. Some evidence for direct and indirect impacts of ocean acidification on fin fish is available but varies substantially between species. Also, understanding about the scope of evolutionary adaptation for marine fishes to climate change and ocean acidification is limited, although it is unlikely that the majority of the species can fully adapt to expected changes in ocean properties without any impacts on their biology and ecology. Overall, we have robust evidence and high agreement (thus *high confidence*) from experimental data, field observations and mathematical modelling in detecting and attributing impacts for fin fish in the present day and under RCP2.6. The uncertainty about the sensitivity to ocean acidification and scope for evolutionary adaptation leads to *medium* confidence levels for their risk under high emissions scenarios.

3.SM.3.2.8 Open-Ocean Carbon Uptake

Update: Several recent studies have shown a decreasing CO_2 flux into the Pacific and Atlantic Oceans, Southern Ocean, and oceans in general (Iida et al., 2015). Concern over changes to the circulation of the ocean (e.g., Atlantic Meridional Overturning Circulation; AMOC) has grown since 2015, with the observation of cooling surface areas of the Atlantic (Rahmstorf et al., 2015).

Recent literature is consistent with the expert assessment of Gattuso et al. (2015) with risks of impact from changing ocean carbon uptake being barely detectable today but transitioning to moderate risk between 1°C and 1.5°C. Risks transition from moderate to high levels of risk between 2°C and 3.2°C. Higher levels of risk such as a rapid change in the circulation of the MOC are speculative at this point.

Expert assessment by Gattuso et al. (2015; SOM):

The uptake of anthropogenic carbon by the ocean in the industrial period and in the future is a service that is predominantly provided by physico-chemical processes (Prentice and J. T. Houghton et al., 2001). The sensitivity of ocean carbon uptake to increasing cumulative CO_2 emissions, including effects of changing ocean chemistry, temperature, circulation and biology, is assessed along the following lines of quantitative evidence: (i) the fraction of total cumulative anthropogenic emissions taken up by the ocean over the industrial period and the 21st century in CMIP5 Earth System Model projections for the four RCPs (Jones et al., 2013) (ii) the fraction of additional (marginal) emissions remaining airborne or taken up by the ocean for background atmospheric CO_2 following the four RCPs (Joos et al., 2013). In addition, the risk of large-scale reorganization of ocean circulation, such as a collapse of the North Atlantic overturning circulation and associated reductions in allowable carbon emissions towards CO_2 stabilization, is increasing with the magnitude and rate of CO_2 emissions, in particular beyond the year 2100. Confidence level is *high* for both RCP2.6 and RCP8.5 because the underlying physical and chemical processes are well known.

3.SM.3.2.9 Coastal Protection

Update: Sea level rise and intensifying storms are placing increasing stress on coastal environments and communities. Coastal protection by ecosystems as well as man-made infrastructure are important in terms of mitigating risks ranging from the physical destruction of ecosystems and human infrastructure to the salinization of coastal water supplies and direct impacts on human safety (Bosello and De Cian, 2014). Risks are particularly high for low-lying areas, such as carbonate atoll islands in the tropical Pacific where land for food, dwelling and water are limited, and effects of a rising sea plus intensifying storms create circumstances that may make many of these island systems uninhabitable within decades (Storlazzi et al., 2015). Even in advantaged countries such as the United States, these factors place millions at serious risk from even modest changes in inundation, with over four million US-based people at serious risk in response to a 90 cm sea level rise by 2100 (Hauer et al., 2016).

Both natural and human coastal protection have the potential to reduce the impacts (Fu and Song, 2017). Coral reefs, for example, provide effective protection by dissipating around 97% of wave energy, with 86% of the energy being dissipated by reef crests alone (Ferrario et al., 2014). Natural ecosystems, when healthy, also have the ability to repair themselves after being damaged, which sets them apart from coastal hardening and other human responses that require constant maintenance (Barbier, 2015; Elliff and Silva, 2017). Recognising and restoring coastal ecosystems such as coral reefs, mangroves and coastal vegetation in general may be more cost-effective than human remedies in terms of seawalls and coastal hardening, where costs of creating and maintaining structures may not always be cost-effective (Temmerman et al., 2013).

The last two years have seen an increase in the number of studies identifying the importance of coastal ecosystems as important to the protection of people and property along coastlines against sea level rise and storms. Analysis of the role of natural habitats for the protection people and infrastructure in Florida, New York and California, for example, has delivered a key insight into the significance of the problems and opportunities for the United States (Arkema et al., 2013). Some ecosystems which are important to coastal protection can keep pace with sea level rise, but only if other factors such as harvesting (e.g., of oysters; Rodriguez et al., 2014) or sediment supply (i.e., to mangroves, Lovelock et al., 2015) are managed. Several studies have pointed to the opportunity to reduce risks by promoting more holistic approaches to mitigating damage from sea level rise and storms by developing integrated coastal plans that ensure that human infrastructure enables the shoreward relocation of coastal vegetation, such as mangroves and salt marsh; the latter enhances coastal protection as well as having other important ecological functions, such as habitat for fish and the sources of a range of other resources (Di Nitto et al., 2014; Lovelock et al., 2015; Mills et al., 2016).

Recent studies have increasingly stressed that coastal protection needs to be considered in the context of new ways of managing coastal land, including protecting and managing coastal ecosystems as they also undergo shifts in their distribution and abundance (Saunders et al., 2014; André et al., 2016). These shifts in thinking require new tools in terms of legal and financial instruments, as well as integrated planning that involves not only human communities and infrastructure but also ecosystem responses. In this regard, the interactions between climate change, sea level rise and coastal disasters are being increasingly informed by models (Bosello and De Cian, 2014), with a widening appreciation of the role of natural ecosystems as an alternative to hardened coastal structures (Cooper et al., 2016).

Increased evidence of a rapid decay in ecosystems such as coral reefs and mangroves has increased the confidence around the conclusion that risks in coastal areas are increasing. Escalation of coastal impacts arising from Super Storm Sandy and Typhoon Haiyan (Long et al., 2016; Villamayor et al., 2016) have improved understanding of the future of coastal areas in terms of impacts, response and mitigation (Rosenzweig and Solecki, 2014; Shults and Galea, 2017).

Recent assessments of the last couple of years of literature confirm the expert judgement of Gattuso et al. (2015), although are emphasised by growing evidence that heat stress, ocean acidification and intensifying storms are increasing the breakdown of natural coastal barriers that otherwise provide important protection for coastal communities, ecosystems and infrastructure. While there is growing evidence of changes in the frequency and intensity of climate change, levels of risk remain similar to Gattuso et al. (2015) . Risk of impacts with respect to coastal protection transition from undetectable to moderate at 0.5°C and 0.8°C, with the transition from moderate to high levels of risk occurring from 1.5°C to 1.8°C. Further transition of impact risks from the loss of coastal protection has been judged to occur between 2.2°C and 3.2°C.

Expert assessment by Gattuso et al. (2015; SOM):

Estimating the sensitivity of natural coastal protection to climate change requires combining sensitivity across different ecosystems, especially coral reefs, mangrove forests and seagrass beds. Other ecosystems provide coastal protection, including salt marshes, macroalgae, oyster and mussel beds, and also beaches, dunes and barrier islands (stabilized by organisms; Spalding et al. 2014; Defeo et al. 2009), but there is less understanding of the level of protection conferred by these other organisms and habitats (Spalding et al., 2014). Although studies indicate some of these systems are already impacted by the effects of rising CO_2, or suggest they will be in the near future, levels of sensitivity are not well established, are highly variable, and in some cases their overall influence on coastal protection may be uncertain (i.e., species are replaced by functional equivalents in this context; K. B. Gedan 2009).

We reason that some coastal protection has already been lost – a result of impacts on coral reefs, seagrasses and other ecosystems from sea temperature rise. In the case of corals, this began in the late 1970s. Recent papers demonstrate collapse in the three-dimensional structure of reefs in the Caribbean (Alvarez-Filip et al., 2009) and the Seychelles (Sheppard et al., 2005), the second phase of which appears to be climate-related. Other studies show that some areas have not recovered from the 1997–1998 and 2010 bleaching events and that some reefs have collapsed there (e.g., parts of the Seychelles). There is thus little doubt that the coastal protection function of some reefs has already been reduced. A decreasing protection may also be the case for seagrasses, although such effects have not been measured. It should also be noted that other human impacts have already largely destroyed, or are progressively destroying, some of these ecosystems through direct action (e.g., 85% oyster reefs lost globally and 1–2% of mangrove forests cut down per annum; Beck et al. 2011). It therefore appears that some impact on coastal protection has already occurred, but there is a lack of data to extrapolate globally, hence the confidence level in the present day is *low*.

Confidence in the loss of coastal protection decreases with increasing CO_2 emissions because coastal protection is conferred by a range of habitats and the co-dependency or interactions between them make projections difficult. For example, protection to seagrass beds conferred by coral reefs or the replacement of salt marsh with mangrove forest (Saunders et al., 2014; Alongi, 2015). Additionally, human-driven pressure on these ecosystems is inherently difficult to forecast decades from now due to the possible implementation of new policies. Interacting effects of different symptoms of climate change such as increased temperature, decreasing pH, salinity, nutrient availability, patterns of precipitation and occurrence of pathogens will all influence the physiological response of individual species and ecosystems, and thus further reduce the predictability of responses at higher emissions.

3.SM.3.2.10 Recreational Services from Coral Reefs

Update: Tourism is one of the largest industries globally. A significant part of the global tourist industry is associated with tropical coastal regions and islands (Spalding et al., 2017). Coastal tourism can be a dominant money earner in terms of foreign exchange for many countries, particularly small island developing states (SIDS; Weatherdon et al., 2016). The direct relationship between increased global temperatures, elevated thermal stress and the loss of coral reefs (Section 3.4.4.10; Box 3.4) has raised concern about the risk that climate change poses for local economies and industries based on coral reefs and related ecosystems (e.g., mangroves seagrass beds).

Risks to the recreational services of coral reefs from climate change are considered here. The recent heavy loss of coral reefs from tourist locations worldwide has prompted interest in the relationship between increasing sea temperatures, declining coral reef ecosystems and tourist revenue (Normile, 2016). About 30% of the world's corals support tourism, which generates close to 36 billion USD on an annual basis (Spalding et al., 2017). Tourist expenditure, in this case, represents economic activity which supports jobs, revenue for business and taxes. Climate change in turn can influence the quality of the tourist experience through such aspects, because of changing weather patterns, physical impacts such as storms, and coastal erosion, as well as the effects of extremes on biodiversity within a region. Recent impacts in the Caribbean in 2017 highlight the impacts of climate change related risks associated with coastal tourism, with the prospect that many businesses will take years to recover from impacts such as hurricanes Harvey, Irma and Maria (Gewin, 2017; Shults and Galea, 2017).

A number of projects have attempted to estimate the impact (via economic valuation) of losing key coral reef ecosystems such as the Great Barrier Reef (Oxford Economics, 2009; Spalding et al., 2017). A recent study by O'Mahony et al.(2017) revealed that the Great Barrier Reef contributed 6.4 billion AUD and 64,000 jobs annually to the Australian economy in 2015–16. In terms of its social, economic and iconic value to Australia, the Great Barrier Reef is worth 56 billion AUD. The extreme temperatures of 2015–2017 removed 50% of the reef-building corals on the Great Barrier Reef (Hughes et al., 2017); there is considerable concern about the growing risk of climate change to the Great Barrier Reef, not only for its value biologically but also as part of a series of economic risks at local, state and national levels.

Our understanding of the potential impacts of climate change on tourism within small island and low-lying coastal areas in tropical and subtropical is made less certain by the flexibility and creativity of people. For example, the downturn of coral reefs in countries that are dependent on coral reef tourism does not necessarily mean a decline in gross domestic product (GDP), given that many countries may have other options for attracting international revenue. In addition, our understanding of future tourist expectations and desires are uncertain at this point.

Additional literature over the past couple of years confirms the risk from climate change to the recreational services that are derived from coral reefs, and which are important for a large number of coastal communities throughout the tropics. A transition in the risk of impacts to recreational services from coral reefs occurs between 0.6°C and 0.8°C, with a further transition from moderate to high levels of risk between 1.0°C and 1.5°C. Very high levels of risk occur between 2.0°C and higher as the frequency and intensity of extreme events (i.e. storm events, coastal inundation, and/or droughts, depending on the region) become increasingly difficult to manage for coastal tourism such as that associated with coral reefs. Note, the risks to corals are higher than those to the recreational services that corals provide to coastal communities. This highlights the fact that many communities today have lost coral but still are able to operate using recreational services from other sources. This difference disappears as one goes to higher levels of climate change and hence risk – particularly as the options for supporting recreational activities from the remnants of coral reefs are seriously reduced.

Expert assessment by Gattuso et al. (2015; SOM):

The impacts of CO_2 and SST on the condition of coral reefs ultimately affect the flow of ecosystem goods and services to human communities and businesses. There is an interesting lag between the degradation of corals and coral reefs and a detectable effect on human users. For this reason, the risk of impacts on human recreation and tourism begins significantly later than ecosystem changes are detected by marine scientists. As of 2015, atmospheric CO_2 concentration is 400 ppm and average SST is 0.8°C above that of the pre-industrial period. Mass bleaching and mortality events have degraded coral populations, and this has negatively impacted the recreational choices of a few, but not most, clients (*high confidence*; Hoegh-Guldberg et al. 2007). This impact on tourists' choice is expected to reach moderate to high levels as CO_2 approaches 450 ppm, at which point reefs begin net erosion and sea level, coral cover, storms and other environmental risks become significant considerations in destination attractiveness (*medium confidence*). By 600 ppm, the breakdown of the structure of most reefs becomes obvious, other changes such as reduced coral cover and increased sea level and storm damage mean that significant coastal recreation and tourism becomes difficult in most circumstances and many operations may be discarded (Hoegh-Guldberg et al., 2007). This will have a very high impact on recreational services (*medium confidence*). Confidence levels under RCP2.6 and RCP8.5 are *medium* because predicting tourists' expectations several decades from now remains relatively uncertain.

3.SM.3.2.11 Bivalve Fisheries and Aquaculture (Mid Latitude)

Update: Aquaculture is one of the fastest growing food sectors and is becoming increasingly essential for meeting the demand for protein for the global population (FAO, 2016). Studies published over the period 2015–2017 showed a steady increase in the risks associated with bivalve fisheries and aquaculture at mid-latitude locations coincident with increases in temperature, ocean acidification, introduced species, disease and other associated risks (Lacoue-Labarthe et al., 2016; Clements and Chopin, 2017; Clements et al., 2017; Parker et al., 2017). These have been met with a range of adaptation responses by bivalve fishing and aquaculture industries (Callaway et al., 2012; Weatherdon et al., 2016).

Risks are also likely to increase as a result of sea level rise and intensifying storms which pose a risk to hatcheries and other infrastructure (Callaway et al., 2012; Weatherdon et al., 2016). Some of the least predictable yet potentially most important risks are associated with the invasion of diseases, parasites and pathogens, which may be mitigated to a certain extent by active intervention by humans. Many of these have reduced the risks from these factors although costs have increased in at least some industries.

The risk of impact from ocean warming and acidification to bivalve aquaculture and fisheries is increasing – although not enough to warrant redefinition of the size and transition of risks from climate change. Therefore, literature since 2015 is consistent with the conclusion of how the risk of impact changes with greater levels of climate change. Risk to these important industries increases from nondetectable to moderate at 1.1°C and 1.3°C, with the transition from moderate to high levels of risk occurring from 1.7°C to 1.9°C. The transition from high to very high levels of risk is projected to between 2.8°C and 3.2°C.

Expert assessment by Gattuso et al. (2015; SOM):

Ecosystem services provided by temperate bivalves include marine harvests (both from capture fisheries and aquaculture), water quality maintenance and coastal stabilization. Of these, marine harvests are easiest to quantify and have been the subject of several assessments. Confidence is high that ocean acidification has already jeopardized marine harvest revenues in the northwest United States (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). Although the affected hatcheries have taken steps to enhance monitoring, alter hatchery water intake and treatment, and diversify hatchery locations (Barton et al., 2015), these adaptations will only delay the onset of ocean acidification-related problems (high confidence). Wild harvest populations are fully exposed to ocean acidification and warming, and societal adaptations such as these are not applicable. Services provided by bivalves will continue even if populations migrate, decrease in size, or individuals become smaller, so effects are somewhat more delayed than those on shellfish themselves. In 2100, impacts are expected to be moderate under RCP2.6 and very high under RCP8.5. The level of confidence declines as a function of increasing CO_2 emissions due to the uncertainty about the extent of local adaptation, medium under RCP2.6 and low under RCP8.5.

3.SM.3.2.12 Small-Scale Fin-Fish Fisheries at Low Latitude

Update: Small-scale fin-fish fisheries (low latitude) provide food for millions of people along tropical coastlines and hence play an important role in the food security of a large number of countries (McClanahan et al., 2015; Pauly and Charles, 2015). In many cases, populations are heavily dependent on these sources of protein given the lack of alternatives (Cinner et al., 2012, 2016; Pendleton et al., 2016). The climate-related stresses affecting fin fish (see Section 'Fin fish' above), however, are producing a number of challenges for small-scale fisheries based on these species (e.g., (Kittinger, 2013; Pauly and Charles, 2015; Bell et al., 2017). Recent literature (2015–2017) has continued to outline growing threats from the rapid shifts in the biogeography of key species (Poloczanska et al., 2013, 2016; Burrows et al., 2014; García Molinos et al., 2015) and the ongoing rapid degradation of key habitats such as coral reefs, seagrass and mangroves (see Sections above on 'Seagrasses (mid-latitude)', 'Mangroves' and 'Pteropods', as well as Chapter 3, Box 3.4). As these changes have accelerated, so have the risks to the food and livelihoods associated with small-scale fisheries (Cheung et al., 2010). These risks have compounded with non-climate-related stresses (e.g., pollution, overfishing, unsustainable coastal development) to drive many small-scale fisheries well below the sustainable harvesting levels required to keep these resources functioning as a source of food (McClanahan et al., 2009, 2015; Pendleton et al., 2016). As a result, projections of climate change and the growth in human populations increasingly predict shortages of fish protein for many regions (e.g., Pacific, e.g., Bell et al., 2013, 2017; Indian Ocean, e.g., McClanahan et al., 2015). Mitigation of these risks involved marine spatial planning, fisheries repair, sustainable aquaculture and the development of alternative livelihoods (Kittinger, 2013; McClanahan et al., 2015; Song and Chuenpagdee, 2015; Weatherdon et al., 2016). Threats to small-scale fisheries have also come from the increasing incidence of alien (nuisance) species as well as an increasing incidence of disease, although the literature on these threats is at a low level of development and understanding (Kittinger et al., 2013; Weatherdon et al., 2016).

As assessed by Gattuso et al. (2015), risks of impacts on small-scale fisheries are moderate today, but are expected to reach very high levels under scenarios extending beyond RCP2.6. The research literature plus the growing evidence that many countries will have trouble adapting to these changes place confidence at a high level as to the risks of climate change on low latitude in fisheries. These effects are more sensitive, hence the higher risks at lower levels of temperature change.

Small-scale fisheries are highly dependent on healthy coastal ecosystems. With the growing evidence of impacts described above, the loss of habitat for small-scale fisheries is intensifying the risks of impact from climate change. For this reason, expert consensus has judged that risks have become greater since the assessment of Gattuso et al. (2015). Therefore, the transition from undetectable to moderate levels of risk is projected to occur between 0.5°C and 0.7°C, with the transition from moderate to high levels of risk occurring between 0.9°C and 1.1°C. The transition from high to very high levels of risk of impact is being judged to occur between 2.0°C and 2.5°C.

Expert assessment by Gattuso et al. (2015; SOM):

Evidence of climate change altering species composition of tropical marine fisheries is already apparent globally (Cheung et al., 2013). Simulations suggest that, as a result of range shifts and decrease in abundance of fish stocks, fisheries catch is likely to decline in tropical regions (Barange et al. 2014, Cheung et al. 2010). Projections also suggest that marine taxa in tropical regions are likely to lose critical habitat (e.g., coral reefs), leading to a decrease in fisheries productivity (Bell et al., 2013). Because of the magnitude of impacts, capacity for the fisheries to reduce such risks by protection, repair or adaptation is expected to be low (Pörtner et al., 2014). Thus, these impacts increase with increasing CO_2 emissions. Risk of impacts is close to moderate level in present day, and increases to high and very high when CO_2 concentration reaches the levels expected in 2100 under RCP4.5 and RCP8.5, respectively.

The scope of adaptation for low latitude fin-fish fisheries is narrow because of the high level of impacts on ecosystems and fisheries resources, lack of new fishing opportunities from species range shifts to compensate for the impacts, and relatively lower social-economic capacity of many countries to adapt to changes. Thus, the confidence level is *high* on projected impacts on low latitude fin-fish fisheries.

3.SM.3.2.13 Fin-Fish Fisheries (Mid- and High Latitude)

Update: While risks and reality of decline are high for low latitude fin fisheries, projections for mid- to high latitude fisheries include increases in fishery productivity in many cases (Cheung et al., 2013; Hollowed et al., 2013; Lam et al., 2014; FAO, 2016). These changes are associated with the biogeographical shift of species towards higher latitudes ('borealization', Fossheim et al., 2015) which brings benefits as well as challenges (e.g., increased risk of disease and invasive species). Factors underpinning the expansion of fisheries production to high latitude locations include warming and increase light and mixing due to retreating sea ice (Cheung et al., 2009). As a result of this, fisheries in the cold temperate regions of the north Pacific and north Atlantic are undergoing a major increase of primary productivity, and consequently in the increased harvest of fish from cod and pollock fisheries (Hollowed and Sundby, 2014). At more temperate locations, intensification of some upwelling systems is also boosting primary production and fisheries catch (Sydeman et al., 2014; Shepherd et al., 2017), although there are increasing threats from deoxygenation as excess biomass falls into the deep ocean, fueling higher metabolic rates and oxygen drawdown (Sydeman et al., 2014; Bakun et al., 2015).

Similar to the assessment by Gattuso et al. (2015), our confidence in understanding risks at higher levels of climate change and longer periods diminishes over time. The ability of fishing industries to adapt to changes is considerable, although the economic costs of adapting can be high. Complex changes in fin fisheries at high latitudes has a number of climate-related risks associated with it (as described above and by Gattuso et al. (2015). In this case, risks of climate impacts on fin fisheries at high latitudes is projected to transition from undetectable to moderate levels of risk at 0.7°C to 0.9°C. The shift from moderate to high levels of risk is projected by the expert consensus to occur between 2.2°C and 3.2°C.

Expert assessment by Gattuso et al. (2015; SOM):

Evidence that climate change effects altering species composition in mid- and high latitude fisheries can already be observed globally, with increasing dominance of warmer-water species since the 1970s (Cheung et al., 2013). Global-scale projections suggest substantial increases in potential fisheries catch in high latitude regions (Cheung et al., 2010; Barange et al., 2014) under RCP8.5 by mid- to end-21st century. However, ocean acidification increases uncertainty surrounding the potential fisheries gain, because the Arctic is a hotspot of ocean acidification (Lam et al., 2014). Risks of impacts of warming, ocean acidification and deoxygenation on mid-latitude regions are variable (Cheung et al., 2013; Barange et al., 2014). Overall, existing fish stocks are expected to decrease in catch, while new opportunities for fisheries may emerge from range expansion of warmer-water. Declines in catch have been projected for fisheries in the northeast Pacific (Ainsworth et al., 2011), northwest Atlantic (Guénette et al., 2014) and waters around the UK (Jones et al., 2014) by mid-21st century under SRES A1B and A2 scenarios (equivalent to RCP6.0 to 8.5). While it is uncertain whether small-scale fisheries will have the mobility to follow shifts in ranges of target species, those with access to multiple gears types may be able to adapt more easily to climate-related changes in stock composition. Societal adaptation to reduce the risk of impacts is expected to be relatively higher than tropical fisheries. Thus, moderate risk is assigned from the present day, and the risk increases to high when CO_2 concentration is beyond levels expected from RCP4.5.

Risk to fisheries at mid- and high latitudes depends on how the fishers, fishing industries and fisheries management bodies respond and adapt to changes in species composition and distribution. Prediction of the scope of such adaptive response is uncertain, particularly under greater changes in fisheries resources. Thus, the confidence level is *high* under RCP2.6 and *low* under RCP8.5.

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3.SM.3.3 Supplementary Information to Section 3.4.13

3.SM.3.3.1 Temperature-Related Morbidity and Mortality

Detection and attribution studies show heat-related mortality in some locations has increased because of climate change (Ebi et al. 2017), alongside evidence of acclimatization and adaptation reducing mortality, particularly in high-income countries (Arbuthnott et al. 2016; Chung et al. 2017; de' Donato et al. 2015; Bobb et al. 2014; Lee et al. 2014) with future adaptation trends uncertain.

The projected risks of heat-related morbidity and mortality are generally higher under warming of 2°C than 1.5°C, with projections of greater exposure to high ambient temperatures and increased morbidity and mortality (Section 3.4.7). This indicates a transition in risk between 1.5°C and 2°C (*medium confidence*). The extent of the increase will depend on adaptation (until mid-century) and on adaptation and mitigation later in the century (Smith et al. 2014). Under 1.5°C, most risks associated with exposure to heat could be reduced through adaptation. Risks under warming of 2°C will depend on the timing of when temperature targets are met and on development choices, such as modifying urban infrastructure to reduce heat islands. The longer the delay in reaching 2°C, and the more resilient and sustainable the development pathway, the lower the expected health risks (Sellers and Ebi 2017). Confidence in these assessments of risk range from medium to high (Figure 3.20).

Heat-related mortality	White to Yellow	Begin	0
		End	1
	Yellow to Red	Begin	1
		End	3
	Red to Purple	Begin	no transition to purple
		End	no transition to purple

3.SM.3.3.2 Tourism

Changing weather patterns, extreme weather and climate events, and sea level rise are affecting global tourism investments, environment and cultural destination assets, operational and transportation costs, and tourist demand patterns (Section 3.4.9.1). Assets being affected include biodiversity, beaches, coral reefs, glaciers, and other environmental and cultural assets. 'Last chance' tourism markets are developing based on observed impacts on environmental and cultural heritage. Available evidence suggests that the transistion in risks for tourism have occurred between 0°C and 1ºC (*high confidence*), with *medium confidence* that risks transition to high risks of impacts somewhere between 1°C to 3°C.

Based on limited analyses, risks to the tourism sector are higher at 2°C than at 1.5°C, with greater impacts on climate-sensitive sun, beach and snow sports tourism markets. The degradation or loss of coral reef systems will increase the risks for coastal tourism, particularly in sub-tropical and tropical regions.

Tourism	White to Yellow	Begin	0
		End	1.5
	Yellow to Red	Begin	1.5
		End	3
	Red to Purple	Begin	no transition to purple
		End	no transition to purple

3.SM.3.3.3 Coastal Flooding

Sea level rise and coastal flooding have been observed or projected to be defined by all but two (iv, viii) of the overarching key risks identified by O'Neill et al. (2017). Even without climate change, flooding occurs. Hence it is important to determine the contribution climate change has made to this. Furthermore, the severity and extent of coastal flooding is highly dependent on the rate and timing of sea level rise based on emissions (and therefore commitment to sea level rise) (Section 3.3.9; Section 13.4 in Church et al. 2013; AR5;), plus the ability to adapt (Section 3.4.5.7 and 5.4; Wong et al. 2014; AR5).

Sea level rise has been occurring naturally for hundreds of years Church et al. 2013;Section 13.2; Kopp et al. 2016). It has and will be enhanced by man-made climate change, whilst acknowledging rates of decadal change due to natural conditions (e.g., White et al. 2005). Early signs of sea level rise departing from Holocene rates were reported since approximately 1900 (Jevrejeva et al. 2014; Dangendorf et al. 2015; Kopp et al. 2016), analogous to temperatures approximately 0.1°C above pre-industrial levels. It is very likely that global mean sea level rise was 1.7 [1.5–1.9] mm yr^{-1} between 1901 and 2010, but from 1993 to 2010 the rate was very likely higher at 3.2 [2.8 to 3.6] mm yr^{-1} (Church et al. 2013; Sections 13.2.2.1 and Section 13.2.2.2). Climate-change induced sea level rise has been detectable and attributable for a few decades (Slangen et al. 2016; Kjeldsen et al. 2015; Rignot et al. 2011; Nerem et al. 2018), occurring around 0.3°C rise above pre-industrial levels.

The ability to adapt to changing sea levels is variable between natural and human systems (Nicholls et al. 2007; Sections 6.4 and 6.6; Wong et al. 2014; AR5; Section 5.4). Adaptation may happen more effectively or be more advanced in some nations or communities over others (Section 3.4.5.7; Araos et al. 2016; Ford et al. 2015). Whilst acknowledging that sensitive environments experience the adverse effects of climate-change-induced sea level rise today, analysis suggests that impacts could be more widespread in sensitive systems and ongoing at 1.7°C of temperature rise with respect to pre-industrial levels, even when considering adaptation measures.

Risks of impacts transitioned from non-detectible to moderate between 0.1°C-0.3°C (*medium confidence*), and from moderate to high levels of risk between 0.3ºC and 0.7ºC (*high confidence*). The transition from high to very high risks is projected to occur between 1.7°C and 2.5°C (*high confidence*).

Coastal flooding	White to Yellow	Begin	0.1
		End	0.3
	Yellow to Red	Begin	0.3
		End	1.7
	Red to Purple	Begin	1.7
		End	2.5

3.SM.3.3.4 Fluvial Flooding

Research shows that flood frequency has increased, although there is limited evidence of a decrease in flood magnitude in some regions (Section 3.3.5.1). Tanoue et al. (2016) detected the increase of frequency and magnitude of flood that is attributed to climate change, and found that growing exposure of people and assets to flood according to the increase of population and economy exacerbated flood damage. Therefore, it is concluded that the current status, compared to the pre-industrial level, should be moderate.

In general, fluvial flooding at 1.5°C is projected to be lower than at 2°C, and at both levels of warming projected changes in the magnitude and frequency of flood create regionally differentiated risks (Section 3.4.2). Alfieri et al.'s (2017) study clearly points out a positive correlation between global warming and global flood risk. The projected number of the global population exposed to flood risk increases quadratically as the temperature rises from 1.5°C to 4°C, in which the population affected by river floods is increased by 100% at 1.5°C, 170% at 2°C and 580% at 4.0°C relative to the baseline period (1976–2005) (Alfieri et al. 2017). Relative changes in population affected and economic damage at 2°C warming are projected to exceed 200% in 20 and in 19 countries, respectively (Alfieri et al. 2017). Therefore, it is concluded that the transition to high risk should be at 2°C warming. Warming of 4°C from the pre-industrial level is projected to be a threefold increase of the proportion of the global population who are exposed to a 20th century 100-year fluvial flood compared to the warming of 1.6°C, while the 4.0°C warming is 14 times as high as present-day exposure (Hirabayashi et al. 2013).

The above-mentioned assessments assume the population is constant, although the variation between socio-economic differences is greater than the variation between the extent of the global warming, resulting in a change in the magnitude of the flood risks; however, these changes are not considered in this context.

Meanwhile, Kinoshita et al. (2018) indicate that potential economic loss can be halved by autonomous adaptation. However, few studies assess quantitative mitigation by adaptation, therefore transition to very high risk (red to purple) is not applicable.

Fluvial flooding	White to Yellow	Begin	0
		End	1.5
	Yellow to Red	Begin	1.5
		End	2
	Red to Purple	Begin	N/A
		End	N/A

3.SM.3.3.5 Crop Yields

Scientific literature shows that climate change resulted in changes in the production levels of the main agricultural crops. Crop yields showed contrasting patterns depending on cultivar, geographical area and response to CO_2 fertilization effect, resulting in a transition from no risk (white) to moderate risk (yellow) below recent temperatures (*high confidence*).

The projected risks for several cropping systems are generally higher under warming of 2°C than of 1.5°C (Section 3.4.6), with different impacts depending on geographical area. The most significant crop yield declines are found in West Africa, Southeast Asia, and Central and South America (Section 3.4.6), whilst less-pronounced yield reductions are expected for northern latitudes. Globally, this indicates a different adaptation capacity among the several cropping systems, thus suggesting a transition in risk from moderate (yellow) to high risk (red) between 1.5ºC and 2.5°C (*medium confidence*).

Crop yields	White to Yellow	Begin	0.5
		End	0.8
	Yellow to Red	Begin	1.5
		End	2.5

	Red to Purple	Begin	N/A
		End	N/A

3.SM.3.3.6 Arctic

High-latitude tundra and boreal forest are particularly at risk, and woody shrubs are already encroaching into the tundra (*high confidence*, Section 3.4.3). These impacts had already been detected at recent temperatures (0.7ºC) hence locating transition from undetected to moderate risk between 0ºC and 0.7ºC, but further impacts have been detected more recently and risks increase further with warming (Section 3.4.2).

Model simulations project that there will be least one sea ice-free Arctic summer per decade at 2°C, while this is one per century at 1.5°C. (*high confidence*) (Sections 3.3.8, 3.4.4.7). Further warming is projected to cause greater effects in a 2°C world than a 1.5°C world; for example, limiting warming to 1.5°C would prevent the loss of an estimated permafrost area of 2 million km^2 over future centuries compared to 2°C (*high confidence*) (Sections 3.3.2, 3.4.3, 3.5.5). A transition from high (red) to very high (purple) risk is therefore located between 1.5ºC and 2ºC (*high confidence*).

Arctic	White to Yellow	Begin	0
		End	0.7
	Yellow to Red	Begin	0.7
		End	1.5
	Red to Purple	Begin	1.5
		End	2

3.SM.3.3.7 Terrestrial Ecosystems

Detection and attribution studies show that impacts of climate change on terrestrial ecosystems have been taking place in the last few decades, indicating a transition from no risk (white) to moderate risk (yellow) below recent temperatures.

The projected risks to unique and threatened terrestrial ecosystems are generally higher under warming of 2°C than 1.5°C (Section 3.4.3; *high confidence*). Globally, effects on terrestrial biodiversity escalate significantly between these two levels of warming. Key examples of this include much more extensive shifts of biomes (major ecosystem types) and a doubling or tripling of the number of plants, animals or insects losing over half of their climatically determined geographic ranges (Section 3.4.3). This indicates a transition in risk from moderate (yellow) to high risk (red) between 1.5°C and 2°C (*high confidence*); however, since some systems and species are unable to adapt to levels of warming below 2°C, the transition to high risk is located below 2°C. By 3°C, biome shifts and species range losses escalate to very high levels and the systems have very little capacity to adapt (Section 3.4.3).

Terrestrial ecosystems	White to Yellow	Begin	0.3
		End	0.5
	Yellow to Red	Begin	0.5
		End	1.8
	Red to Purple	Begin	2.0
		End	3.0

3.SM.3.3.8 Mangroves

Recent literature is consistent with previous conclusions regarding the complex changes facing mangroves, together with increasing concern regarding the interaction between climate change (e.g., elevated air and water temperatures, drought and sea level rise) and local factors (deforestation, damming of catchments and reduced sediment and freshwater) as outlined below (Alongi, 2015; Feller et al., 2017). Decreases in the supply of sediments to deltas and coastal areas is impeding the ability of most mangroves (69% of sites) to keep pace with sea level rise through shoreward migration (Lovelock et al., 2015). At the same time, recent extremes associated with El Niño have also had large-scale impacts (e.g., extreme low sea level events; Duke et al., 2017; Lovelock et al., 2017). Shoreward migration is also challenged by the increasing amounts of coastal infrastructure preventing the relocation of mangroves (Di Nitto et al., 2014; Saunders et al., 2014). In some areas, mangroves are increasing in distribution (Godoy and De Lacerda, 2015). The total losses projected for mangrove loss (10–15%) under a 0.6 m sea level rise continue to be dwarfed by the loss of mangroves to deforestation (1–2% per annum).

However, given the scale of the dieback of mangroves in Australia's Gulf of Carpentaria (in 2015–2016), as well as evidence that similar conditions to those of 2015–2016 (extreme heat and low tides) and the projection of greater El Niño-Southern Oscillation (ENSO) variability, (Widlansky et al., 2015; Risser and Wehner, 2017), the risks from climate change for mangroves were judged to be higher than assessed by AR5, and subsequently by Gattuso et al. (2015), leading to the transitions having greater risk of occurring (Figure 3.18). Formal attribution of recent extreme events on mangroves to climate change, however, is at an early stage (*medium agreement, limited data, hence low-medium confidence*).
See accompanying assessment by Gattuso et al. (2015) in Suplementary Material 3.SM.3.2, Supplementary information to Section 3.4.4.

Mangroves	White to Yellow	Begin	1.3
		End	1.5 (2.5)*
	Yellow to Red	Begin	2.5
		End	2.7
	Red to Purple	Begin	NA
		End	NA

3.SM.3.3.9 Warm-Water Corals

The exceptionally warm conditions of 2015–2017 drove an unprecedented global mass coral bleaching and mortality event which affected coral reefs in a large number of countries (information still being gathered at time of writing; Normile, 2016). In the case of Australia, 50% of shallow-water reef-building corals across the Great Barrier Reef died in unprecedented back-to-back bleaching events (Hughes et al., 2017). Elevated sea temperatures and record mortalities were recorded from the central to the far northern sectors of the Great Barrier Reef. Similar effects occurred in a range of regions, including the Indian Ocean, the western Pacific, Hawaii and the Caribbean Sea (Normile, 2016). The set of events has increased risk with current conditions being of high risk, and even low levels of future climate change having series implications for coral reefs. There continues to be a *high* to *very high* level of confidence as to where the transitions between risk levels due to climate change are located.

The unprecedented thermal stress along many tropical coastlines over the past three years (2015–2017) has led to extraordinary changes to coral reefs across the planet (as described above). The advent of back-to-back bleaching events, which were projected to occur around mid-century, appear to have already begun to occur as demonstrated by impacts on warm-water corals and hence coral reefs. While corals were already stressed from climate change, and are in decline in many parts of the world, the scale and impact of recent events suggests that risk levels for the transitions between risk categories need to be adjusted to represent the current status of corals and coral reefs. For this reason, expert consultation since 2015 concluded that the transition from undetectable to moderate risk has already occurred (0.2°C to 0.4°C; *high confidence*). Similarly, the transition from moderate to high levels of risks for warm-water corals occurred approximately from 0.4°C to 0.6°C (*high confidence*). In line with these changes, the transition from high to very high levels of risk are associated with increases in GMST from 0.6°C to 1.2°C (*high confidence*) above the pre-industrial period.See accompanying assessment by Gattuso et al. (2015) in Suplementary Material 3.SM.3.2.

Warm-water corals	White to Yellow	Begin	0.2
		End	0.4
	Yellow to Red	Begin	0.4
		End	0.6
	Red to Purple	Begin	0.6
		End	1.2

3.SM.3.3.10 Small-Scale Fin-Fish Fisheries (Low Latitude)

Small-scale fin-fish fisheries (low latitude) provide food for millions of people along tropical coastlines and hence play an important role in the food security of a large number of countries (McClanahan et al., 2015; Pauly and Charles, 2015). In many cases, populations are heavily dependent on these sources of protein given the lack of alternatives (Cinner et al., 2012, 2016; Pendleton et al., 2016). The climate-related stresses affecting fin fish (see Section 'Fin fish' above), however, are producing a number of challenges for small-scale fisheries based on these species (e.g., (Kittinger, 2013; Pauly and Charles, 2015; Bell et al., 2017). Recent literature (2015–2017) has continued to outline growing threats from the rapid shifts in the biogeography of key species (Poloczanska et al., 2013, 2016; Burrows et al., 2014; García Molinos et al., 2015) and the ongoing rapid degradation of key habitats such as coral reefs, seagrass and mangroves (see Sections above on 'Seagrasses (mid-latitude)', 'Mangroves' and 'Pteropods', as well as Chapter 3, Box 3.4). As these changes have accelerated, so have the risks to the food and livelihoods associated with small-scale fisheries (Cheung et al., 2010). These risks have compounded with non-climate-related stresses (e.g., pollution, overfishing, unsustainable coastal development) to drive many small-scale fisheries well below the sustainable harvesting levels required to keep these resources functioning as a source of food (McClanahan et al., 2009, 2015; Pendleton et al., 2016). As a result, projections of climate change and the growth in human populations increasingly predict shortages of fish protein for many regions (e.g., Pacific, e.g., Bell et al., 2013, 2017; Indian Ocean, e.g., McClanahan et al., 2015). Mitigation of these risks involved marine spatial planning, fisheries repair, sustainable aquaculture and the development of alternative livelihoods (Kittinger, 2013; McClanahan et al., 2015; Song and Chuenpagdee, 2015; Weatherdon et al., 2016). Threats to small-scale fisheries have also come from the increasing incidence of alien (nuisance) species as well as an increasing incidence of disease, although the literature on these threats is at a low level of development and understanding (Kittinger et al., 2013; Weatherdon et al., 2016).

As assessed by Gattuso et al. (2015), risks of impacts on small-scale fisheries are moderate today, but are expected to reach very high levels under scenarios extending beyond RCP2.6. The research literature plus the growing evidence that many countries will have trouble adapting to these changes place confidence at a high level as to the risks of climate change on low latitude in fisheries. These effects are more sensitive, hence the higher risks at lower levels of temperature change.

Small-scale fisheries are highly dependent on healthy coastal ecosystems. With the growing evidence of impacts described above, the loss of habitat for small-scale fisheries is intensifying the risks of impact from climate change. For this reason, expert consensus has judged that risks have become greater since the assessment of Gattuso et al. (2015). Therefore, the transition from undetectable to moderate levels of risk is projected to occur between 0.5°C and 0.7°C (*high confidence*), with the transition from moderate to high levels of risk occurring between 0.9°C and 1.1°C (*medium confidence*). The transition from high to very high levels of risk of impact is being judged to occur between 2.0°C and 2.5°C (*high confidence*).

See accompanying assessment by Gattuso et al. (2015) Suplementary Material 3.SM.3.2.

Small-scale fin-fish fisheries (low latitude)	White to Yellow	Begin	0.5
		End	0.7
	Yellow to Red	Begin	0.9
		End	1.1
	Red to Purple	Begin	2
		End	2.5

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3.SM.3.4 Supplementary Information to Section 3.4.7 Human health

Table 3.SM.7: Decades when 1.5°C, 2°C and higher degrees of warming are reached for multi-climate model means

Generation	Scenario	Decade 1.5°C reached	Decade 2°C reached	dT 2080–2099	dT 2090–2099
SRES	B1	2039–2048	2065–2074	2.18	2.27
SRES	A1b	2029–2038	2045–2054	3.00	3.21
SRES	A2	2032–2041	2048–2057	3.39	3.83
RCP	2.6	2047–2056	a	1.48	1.49
RCP	4.5	2031–2040	2055–2064	2.32	2.37
RCP	6.0	2036–2045	2058–2067	2.63	2.86
RCP	8.5	2026–2035	2040–2049	3.90	4.39

[a]2°C not reached

Table 3.SM.8: Projected temperature-related risks at 1.5°C and 2°C. Abbreviations: DALY: Disability adjusted life year; RCP: Representative Concentration Pathway; SSP: Shared Socio-Economic Pathway; GMST: global mean surface temperature

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
Global and 21 regions	Heat-related mortality in adults over 65 years of age	1961–1990	BCM2.0, EGMAM1, EGMAM2, EGMAM3, CM4vl	A1B	2030, 2050		In 2030 92,207 additional heat-related deaths without adaptation (ensemble mean) and 28,055 with adaptation under BCM2 scenario; the	In 2050 255,486 additional heat-related deaths without adaptation and 73,936 with adaptation under BCM2 scenario; the same regions	Population growth and aging; improved health in elderly due to economic development; three levels of adaptation (none, partial, and full)	(Hales et al. 2014)

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S)***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
							Asia Pacific, Asia, North Africa / Middle East, Sub-Saharan Africa, Europe and north America at higher risk.	are at higher risk.		
Global	Extremely hot summers over land areas (>3 standard deviations anomalies)	1861–1880	26 models from CMIP5	RCP2.6, RCP4.5, RCP8.5	To 2100	Probability of an extremely hot summer (>3 standard deviations) in 1996–2005 (compared with 1951–1980) is 4.3%	Probability of an extremely hot summer is approximatel y 25.5% and probability of an exceedingly hot summer (>5 standard deviations) is approximatel y 7.1% above pre-industrial.	Extremely hot summers are projected to occur over nearly 40% of the land area.		(Wang et al. 2015)
Global	Population exposure to hot days and	1961–1990	21 CMIP5 GCMs	Temperature change based on	Up to 2100	Increasing exposure to heatwaves	The frequency of heatwave	Overall, exposure to heatwaves is		(Arnell et al. 2018)

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S)***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
	heatwaves			pattern scaling		already evident	days increases dramatically as global mean temperature increases, although the extent of increase varies by region. Increases are greatest in tropical and sub-tropical regions where the standard deviation of warm season daily maximum temperature is least, and therefore, a smaller increase in temperature leads to a larger	reduced by more than 75% in all models in each region if GMSTs do not increase to 2°C; the avoided impacts vary by region.		

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
							increase in heat wave frequency.			
Japan, Korea, Taiwan, USA, Spain, France, Italy	Heat-related mortality for 65+ age group	1961–1990	BCM2	A1B	2030, 2050		In 2030 heat-related excess deaths increased over baselines in all countries, with the increase dependent on the level of adaptation.	In 2050 heat-related excess deaths are higher than for 2030, with the increase dependent on the level of adaptation.	Three adaptation assumptions: 0, 50, and 100%	(Honda et al. 2014)
Australia (five largest cities) and UK	Temperature -related mortality	1993–2006	UKCP09 from HadCM3, OzClim 2011	A1B, B1, A1FI	2020s, 2050s, 2080s	For England and Wales, the estimated % change in mortality associated with heat exposure is 2.5% (95% CI: 1.9–3.1) per 1°C rise in temperature above the	In the 2020s heat-related deaths increase from 1503 at baseline to 1511 with a constant population and 1785 with the projected population. In Australia,	In the 2050s heat-related deaths further increase to 2866 with a constant population and to 4012 with the projected population. In Australia, the numbers	Projected population change	(Vardoulakis et al. 2014)

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
						heat threshold (93rd percentile of daily mean temperature). In Australian cities, the estimated overall % change in mortality is 2.1% (95% CI: 1.3, 2.9).	the numbers of projected deaths are 362 and 475, respectively, with a baseline of 214 deaths.	of projected deaths are 615 and 970, respectively.		
Australia	Temperature-related morbidity and mortality; days per year above 35°C	1971–2000	CSIRO	2030 A1B low and high; 2070 A1FI low and high	2030, 2070	4–6 dangerously hot days per year for un-acclimatized individuals	Sydney – from 3.5 days at baseline to 4.1–5.1 days in 2030; Melbourne – from 9 days at baseline to 11–13 days in 2030.	Sydney – 6–12 days and Melbourne – 15–26 days in 2070.		(Hanna et al. 2011)
Brisbane, Sydney and Melbourne, Australia	Temperature-related mortality	1988–2009	62 GCMs, with spatial downscaling and bias	A2, A1B, B1	2050s, 2090s		In 2030 net temperature-related mortality	In 2050 there are further net temperature		(Guo et al. 2016)

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
			correction				(heat/cold) increases in Brisbane under all scenarios, increases in Sydney under A2, and declines in Melbourne under all scenarios.	-related mortality (heat/cold) increases in Brisbane under all scenarios, increases in Sydney under A2 and A1B, and further declines in Melbourne under all scenarios.		
Brisbane, Australia	Years of life lost due to temperature extremes (hot and cold)	1996–2003		Added 1–4°C to observed daily temperature to project for 2050	2000, 2050	In 2000, 3077 temperature-related years of life lost for men, with 616 years of life lost due to hot temperatures and 2461 years of life lost due to	For 1°C above baseline, years of life lost increase by 1014 (840 to 1178) for hot temperatures and decrease by 1112 (–1,337 to –	For 2°C above baseline, years of life lost increase by 2450 (2049 to 2845,) for hot temperatures and decrease by 2069 (–2484		(Huang et al. 2012)

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S)***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
						cold. The numbers for women are 3495 (total), 903 (hot), and 2592 (cold).	871) for cold temperatures.	to −1624) for cold temperatures.		
Quebec, Canada	Heat-related mortality	1981–1999	Ouranos Consortium; SDSM downscaled HADCM3	A2 and B2 (projected impacts the same)	2020 (2010–2039), 2050 (2040–2069), 2080 (2070–2099)		2% increase in summer mortality in 2020.	4–6% increase in summer mortality in 2050.		(Doyon et al. 2008)
USA, 209 cities	Heat- and cold-related mortality	1990 (1976–2005)	Bias corrected (BCCA) GFDL-CM3, MIROC5	RCP6.0	2030 (2016–2045), 2050 (2036–2065), 2100 (2086–2100)		In 2030 a net increase in premature deaths, with decreases in temperature-related winter mortality and increases in summer mortality; the magnitude varied by region and city with an overall	In 2050 a further increase in premature deaths, with decreases in temperature-related winter mortality and increases in summer mortality; the magnitude varied by region and city with an	Held population constant at 2010 levels; mortality associated with high temperatures decreased between 1973–1977 and 2003–2006	(Schwartz et al. 2015)

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
							increase of 11,646 heat-related deaths.	overall increase of 15,229 heat-related deaths.		
Washington State, USA	Heat-related mortality	1970–1999	PCM1, HadCM	Average of PCM1-B1 and HadCM-A1B; humidex baseline; number and duration of heatwaves calculated	2025, 2045, 2085		Under moderate warming in 2025, 96 excess deaths in Seattle area.	Under moderate warming in 2045, 156 excess deaths in Seattle area.	Holding population constant at 2025 projections	(Jackson et al. 2010)
Boston, New York and Philadelphia, USA	Heat-related mortality	1971–2000	CMIP5 bias corrected (BCSD)	RCP4.5, RCP8.5	2010–2039, 2040–2069, 2070–2099	Baseline heat-related mortality is 2.9–4.5/100,000 across the three cities	In the 2020s under both RCPs, heat-related mortality increased to 5.9–10/ 100,000.	In the 2050s heat-related mortality increased to 8.8–14.3/100,000 under RCP4.5 and to 11.7 to 18.9/100,000 under RCP8.5.	Population constant at 2000	(Petkova et al. 2017)
Europe	Heat-related mortality	1971–2000	SMHI RCA4/HadGE	RCP4.5, RCP8.5	2035–2064, 2071–209		2035–2064 excess heat	2071–2099 excess heat		(Kendrovski et al. 2017)

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S)***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
			M2 ES r1 (MOHC)				mortality to be 30,867 and 45,930.	mortality to be 46,690 and 117,333 attributable deaths/year.		
Europe: London, UK and Paris, France	Heat-related mortality	Present climate	(HAPPI)	Climate stabilization at 1.5°C and 2°C		Model of 2003 heat event resulted in about 735 excess deaths for Paris and about 315 for London	Compared with 2°C stabilization, mortality event is 2.4 times less likely in London and 1.6 times less likely in Paris.	22% increase in mortality in Paris and 15% increase in mortality in London, compared with 1.5°C stabilization.		(Mitchell 2018)
UK	Temperature -related mortality	1993–2006	9 regional model variants of HadRm3-PPE-UK, dynamically downscaled	A1B	2000–2009, 2020–2029, 2050–2059, 2080–2089	At baseline, 1974 annual heat-related deaths and 41,408 cold-related deaths	In the 2020s in the absence of adaptation, heat-related deaths projected to increase to 3281 and cold-related deaths to increase to 42,842.	In the 2050s in the absence of adaptation, heat-related deaths projected to increase 257% by the 2050s to 7040 and cold-related mortality to decline	Population projections to 2081	(Hajat et al. 2014)

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S)***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
								about 2%.		
Netherlands	Temperature-related mortality	1981–2010	KNMI' 14; G-scenario is a global temperature increase of 1°C and W-scenario an increase of 2°C		2050 (2035–2065)	At baseline, the attributable fraction for heat is 1.15% and for cold is 8.9%; or 1511 deaths from heat and 11,727 deaths from cold	Without adaptation, under the G scenario, the attributable fraction for heat is 1.7–1.9% (3329–3752 deaths) and for cold is 7.5–7.9% (15,020–15,733 deaths). Adaptation decreases the numbers of deaths, depending on the scenario.	Without adaptation, under the W scenario, the attributable fraction for heat is 2.2–2.5% (4380-5061 deaths) and for cold is 6.6–6.8% (13,149–13,699 deaths). Adaptation decreases the numbers of deaths, depending on the scenario.	Three adaptation scenarios, assuming a shift in the optimum temperature, changes in temperature sensitivity, or both; population growth and declining mortality risk per age group	(Huynen and Martens 2015)

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S)***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
Korea	Burden of disease from high ambient temperatures	2011	CMIP5	RCP4.5, RCP8.5	2030, 2050	DALY for all-cause mortality in 2011 was 0.49 (DALY/1000) DALY for cardio-and cerebrovascular disease was 1.24 DALY/1000	In 2030 DALY for all-cause mortality, 0.71 (DALY/1000) DALY for cardio-and cerebrovascular disease is 1.63 (1.82) DALY/1000	In 2050 DALY for all-cause mortality, 0.77 (1.72) (DALY/1000) DALY for cardio-and cerebrovascular disease is 1.76 (3.66) DALY/1000		(Chung et al. 2017)
Beijing, China	Heat-related mortality	1970–1999	Downscaled and bias corrected (BCSD) 31 GCMs in WCRP CMIP5; monthly change factors applied to daily weather data to create a projection	RCP4.5, RCP8.5	2020s (2010–2039), 2050s (2040–2069), 2080s (2070–2099)	Approximately 730 additional annual heat-related deaths in 1980s	In the 2020s under low population growth and RCP4.5 and RCP8.5, heat-related deaths projected to increase to 1012 and 1019, respectively. Numbers of deaths are higher with	In the 2050s under low population growth and RCP4.5 and RCP8.5, heat-related deaths projected to increase to 1411 and 1845, respectively.	Adults 65+ years of age; no change plus low, medium and high variants of population growth; future adaptation based on Petkova et al., (2013) , plus shifted mortality 5%, 15%, 30%,	(Li et al. 2016c)

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
							medium and high population growth.		50%	
Beijing, China	Cardiovascular and respiratory heat-related mortality	1971–2000	Access 1.0, CSIRO Mk3.6.0, GFDL-CM3, GISS E2R, INM-CM4	RCP4.5, RCP8.5	2020s, 2050s, 2080s	Baseline cardiovascular mortality 0.396 per 100,000; baseline respiratory mortality 0.085 per 100,000	Cardiovascular mortality could increase by an average percentage of 18.4% in the 2020s under RCP4.5, and by 16.6% under RCP8.5. Statistically significant increases are projected for respiratory mortality.	Cardiovascular mortality could increase by an average percentage of 47.8% and 69.0% in the 2050s and 2080s under RCP4.5, and by 73.8% and 134% under RCP8.5. Similar increases are projected for respiratory mortality.		(Li et al. 2015)
Africa	Five thresholds for number of hot days per year	1961–2000	CCAM (CSIRO) forced by coupled GCMs:	A2	2011–2040, 2041–2070, 2071–2100	In 1961–1990, average number of hot days	In 2011–2040, annual average number of hot days	In 2041–2070, annual average number of hot days	Projected population in 2020 and 2025	(Garland et al. 2015)

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
	when health could be affected, as measured by maximum apparent temperature		CSIRO, GFDL20, GFDL 21, MIROC, MPI, UKMO. CCAM was then downscaled. Bias corrected using CRU TS3.1 dataset			(maximum apparent temperature > 27°C) ranged from 0 to 365, with high variability across regions	(maximum apparent temperature > 27°C) projected to increase by 0–30 in most parts of Africa, with a few regions projected to increase by 31–50.	(maximum apparent temperature > 27°C) projected to increase by up to 296, with large changes projected in southern Africa and parts of northern Africa.		

Table 3.SM.9: Projected air quality-related health risks at 1.5°C and 2°C. Abbreviations: DALY: disability adjusted life year; RCP: Representative Concentration Pathway; SSP: Shared Socio-Economic Pathway; CV: cardiovascular

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S) and Air Pollution Models*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
Global	PM 2.5 and O3-related mortality	2000	14 global models participating in ACCMIP CESM	RCP2.6, RCP4.5, RCP6.0 RCP8.5	2000, 2030, 2050, 2100	Global O3 mortality 382,000 (121,000–728,000) deaths year -1; global mortality burden of PM2.5 1.70 (1.30–2.10) million deaths year-1	PM2.5-related mortality peaks in 2030 (2.4–2.6 million deaths/year – except for RCP6.0)	O3-related mortality peaks in 2050 (1.84–2.6 million deaths per year)	Population projected from 2010–2100	(Silva et al. 2016)
Global and Europe and France	PM2.5-related CV- and O3-related respiratory mortality	2010	IPSL-cm5-MR, LDMz-INCA, CHIMERE	RCP4.5 (for Europe and France)	2010, 2030–2050	Global CV mortality 17,243,000	In 2030 in Europe PM2.5-related CV mortality decreases by 3.9% under CLE and 7.9% under MFR. In 2030 O3-related respiratory mortality decreases by 0.3% under	In 2050 4.5% decrease in PM2.5-related CV mortality under CLE and 8.2% MFR.	Population 2030–sensitivity analysis	(Likhvar et al. 2015)

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S) and Air Pollution Models*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
							MFR.			
UK	O3-related morbidity and mortality	2003	EMEP-WRF	A2, B2	2003, 2030	O3-attributable mortality and morbidity in 2003: 11,500 deaths and 30,700 hospitalizations	With no threshold for O3, increase of premature mortality and hospitalization of 28% (under B2 + CLE scenario) – greatest health effects; A2 premature morbidity and mortality projections: 22%. With 35 ppbv, 52% increase in mortality and morbidity (under B2+CLE).	Increases in temperatures by 5°C, projected O3 mortality will increase from 4% (no O3 threshold) to 30% (35 ppbv O3 threshold).	Population projections increase, +5°C scenario	(Heal et al. 2013)
Poland	PM2.5 mortality	2000	ECHAM5-RegCM3, CAMx	A1B	1990s 2040s, 2090s	39,800 premature deaths related to PM2.5 air	0.4°C –1°C in 2040; 6% decrease in PM2.5-related	2°C –3°C in the 2090s; 7% decrease in PM25-related		(Tainio et al. 2013)

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S) and Air Pollution Models***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
						pollution	mortality in 2040s.	mortality in 2090s.		
Korea	O3 summer mortality	2001–2010	ICAMS	RCP2.6 RCP4.5, RCP6.0, RCP8.5	1996–2005, 2016–2025, 2046–2055		In the 2020s summer mortality to increase by: 0.5%, 0.0%, 0.4%, and 0.4% due to temperature change. In the 2020s, due to O3 concentration change, mortality to increase by 0.0%, and 0.5%.	In the 2050s summer mortality to increase by: 1.9%, 1.5%, 1.2% and 4.4% due to temperature change. In the 2050s, due to O3 concentration change, mortality to increase by 0.2%, 0.4% and 0.6%.	Current mortality trends expected to increase, temperature effects compared	(Lee et al. 2017)

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S) and Air Pollution Models***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
US (12 metropolitan areas)	O3 inhalation exposures	2000	APEX, CESM, MIP5, WRF, CMAQ	RCP4.5, RCP6, RCP8.5	1995–2005, 2025–2035	At least one exceedance/year	Comparing 2030 to 2000, almost universal trend with at least three exceedances (of DM8H exposure above the 60 ppb and 70 bbp thresholds).	Health implications increase as population exposures to O3 increases based on the degree of radiative forcing in 2100.	Population projections using IPCC SRES and adapted for US	(Dionisio et al. 2017)

1 **Table 3.SM.10: Projected vectorborne disease risks at 1.5°C and 2°C.** Abbreviations: DALY: disability adjusted life year; RCP: Representative Concentration Pathway; SSP:
2 Shared Socio-Economic Pathway

Region	***Health Outcome Metric***	***Study Baseline***	***Climate Model(S)***	***Scenario***	***Time Periods of Interest***	***Impacts at Study Baseline***	***Projected Impacts at 1.5°C***	***Projected Impacts at 2°C***	***Other Factors Considered***	***Reference***
Malaria										
China	Malaria vectors Anopheles dirus, A. minimus, A. lesteri, A. sinensis	2005–2008	BCC-CSM1-1, CCCma_CanESM2, CSIRO-Mk3.6.0 from CMIP5	RCP2.6, RCP4.5, RCP8.5	2020–2049, 2040–2069		In the 2030s environmentally suitable areas for *A. dirus* and *A. minimus* increase by an average of 49% and 16%, respectively.	In the 2050s environmentally suitable areas for *A. dirus* and *A. minimus* de crease by 11% and 16%, respectively. An increase of 36% and 11%, in environmentally suitable area of *A. lesteri* and *A. sinensis*.	Land use, urbanization	(Ren et al. 2016)
Northern China	Spatial distribution of malaria	2004–2010	GCMs from CMIP3	B1, A1B, A2	2020, 2030, 2040, 2050	Average malaria incidence 0.107% per annum in northern China	In 2020 malaria incidence increases 19–29%, and increases	In 2040 malaria incidence increases 33–119% and 69–182% in	Elevation, GDP, water density index held constant	(Song et al. 2016)

							43–73% in 2030, with increased spatial distribution.	2050, with increased spatial distribution.		
Sub-Saharan Africa	Malaria	2006–2016	21 CMIP5 models	RCP4.5, RCP8.5	2030, 2050, 2100		In 2030 under RCP8.5, many parts of western and central Africa will have no malaria, but significant malaria hotspots will be along the Sahel belt, eastern and southern parts of Africa.	Climate change will redistribute the spatial pattern of future malaria hotspots, especially under RCP8.5.	Various environmental variables	(Semakula et al. 2017)
Aedes										
Global	Global niche models for autochthonous Chikungunya virus transmission	Current climate	CESM 1 bcg, FIO ESM, GISS e2-r, INM CM4 and MPI-ESM-lr	RCP4.5, RCP8.5	2021–2040, 2041–2060, 2061–2080	Current distribution of Chikungunya transmission	In 2021–2040 climatically suitable areas projected to increase in multiple regions,	In 2041–2060 greater geographic expansion.		(Tjaden et al. 2017)

							including China, sub-Saharan Africa, the US and continental Europe.			
North America, United States	Climate suitability for Aedes albopictus vector for dengue, Chikungunya and vectorborne zoonoses, such as West Nile virus (WNV), Eastern equine encephalitis virus, Rift Valley fever virus, Cache Valley virus and LaCrosse	1981–2010	8 RCMs: CanRCM4, CRCM5, CRCM 4.2.3, HIRHAM5, RegCM3, ECPC, MM5I, WRF	RCP4.5, RCP8.5, A2	2020s (2011–2040), 2050s (2041–2070)	Index of precipitation and temperature suitability was highly accurate in discriminating suitable and non-suitable climate	In 2011–2040 under RCP4.5, climate suitability increases across US, with the magnitude and pattern dependent on parameter projected and RCM.	In 2041–2070 under RCP4.5, areal extent larger than in earlier period; under RCP8.5, areal extent larger.	Climatic indicators of Ae. albopictus survival; overwintering conditions (OW); OW combined with annual air temperature (OWAT); and an index of suitability	(Ogden et al. 2014a)

	virus									
Mexico	Dengue	1985–2007	National Institute of Ecology; added projected changes to historic observations	A1B, A2, B1	2030, 2050, 2080	National: 1.001/100.000 cases annually Nuevo Leon: 1.683/100.000 cases annually Queretaro: 0.042/100.000 cases annually Veracruz: 2.630/100.000 cases annually	In 2030 dengue incidence increases 12–18%.	In 2050 dengue incidence increases 22–31%.	At baseline, population, GDP, urbanization, access to piped water	(Colón-González et al. 2013)
Europe, Eurasia and the Mediterranean	Climatic suitability for Chikungunya outbreaks	1995–2007	COSMO-CLM, building on ECHAM5	A1B and B1	2011–2040, 2041–2070, 2071–2100	Currently, climatic suitability in southern Europe. The size of these regions will expand during the 21st century	In 2011–2040 increases in risk are projected for Western Europe in the first half of the 21st century.	In 2041–2070 projected increased risks for Central Europe.		(Fischer et al. 2013)

Europe	Potential establishment of Ae. albopictus	Current bioclimatic data derived from monthly temperature and rainfall values	Regional climate model COSMO-CLM	A1B, B1	2011–2040, 2041–2070, 2071–2100		In 2011–2040 higher values of climatic suitability for Ae. albo pictus increases in Western and Central Europe	Between 2011–40 and 2041–2070 for southern Europe, only small changes in climatic suitability are projected. Increasing suitability at higher latitudes is projected for the end of the century.		(Fischer et al. 2011)
Europe	Dengue fever risk in 27 EU countries	1961–1990	COSMO-CLM (CCLM) forced with ECHAM5/MPIOM	A1B	2011–2040, 2041–2070, 2071–2100	Number of dengue cases are between 0 and 0.6 for most European areas, corresponding to an incidence of less than 2	In 2011–2040 increasing risk of dengue in southern parts of Europe.	In 2041–2070 increased dengue risk in many parts of Europe, with higher risks towards the end of the century.	Socio-economic variables, population density, degree of urbanization and log population	(Bouzid et al. 2014)

						per 100,000 inhabitants		Greatest increased risk around the Mediterranean and Adriatic coasts and in northern Italy.		
Tanzania	Distribution of infected Aedes aegypti co-occurrence with dengue epidemics risk	1950–2000	CMIP5		2020, 2050	Currently high habitat suitability for Ae. aegypti in relation to dengue epidemic, particularly near water bodies	Projected risk maps for 2020 show risk intensification in dengue epidemic risks areas, with regional differences.	In 2050 greater risk intensification and regional differences.		(Mweya et al. 2016)
West Nile virus										
Europe, Eurasia, and the Mediterranean	Distribution of human WNV infection	Monthly temperature anomalies relative to 1980–1999, environme	NCAR CCSM3	A1B	2015–2050		In 2025 progressive expansion of areas with an elevated probability for WNV	In 2050 increases in areas with a higher probability of expansion.	Prevalence of WNV infections in the blood donor population	(Semenza et al. 2016)

		ntal variables for 2002–2013					infections, particularly at the edges of the current transmission areas.			
Lyme disease and other tick-borne diseases										
North America (mainly Ontario and Quebec, Canada, and northeast and midwest, United States)	Capacity of Lyme disease vector (*Ixodes scapularis*) to reproduce under different environmental conditions	1971–2010	CRCM4.2.3, WRF, MM5I, CGCM3.1, CCSM3	A2	1971–2000, 2011–2040, 2041–2070	In 1971–2010 reproductive capacity increased in North America; increase consistent with observation	In 2011–2040 mean reproductive capacity increased, with projected increases in the geographic range and number of ticks.	In 2041–2070 further expansion and numbers of ticks projected. R_0 values for *I. scapularis* are projected to increase 1.5–2.3 times in Canada. In the US values are expected to double.		(Ogden et al. 2014b)

Southeastern New York, United States	Emergence of *I. scapularis*, leading to Lyme disease	1994–2012			2050	19 years of tick and small mammal data (mice, chipmunks)	In the 2020s the number of cumulative degree-days enough to advance the average nymphal peak by 4–6 days, and the mean larval peak by 5–8 days, based on 1.11°C – 1.67°C increase in mean annual temperature.	In the 2050s the nymphal peak advances by 8–11 days, and the mean larval peak by 10–14 days, based on 2.22°C – 3.06°C increase in mean annual temperature.		(Levi et al. 2015)
Other										
Venezuela	Chagas disease: number of people exposed to changes in the geographic	1950–2000	CSIRO3.0	A1B, B1	2020, 2060, 2080		In 2020 decreasing population vulnerability.	In 2060 effects more pronounced, with less of a change under B1.	MaxEnt model of climatic niche suitability	(Ceccarelli and Rabinovich 2015)

	range of five species of triatomine species									
Colombia	Visceral leishmaniasis caused by the trypanosomatid parasite *Leishmania infantum*	Present	CSIRO, Hadley	A2A, B2A	2020, 2050, 2080		In 2020 shift in the altitudinal distribution in the Caribbean coast and increase in the geographic area of potential occupancy under optimistic scenarios.	In 2050 even greater geographic area of potential occupancy, with a greater impact under A2.	MaxEnt model; three topographical variables	(González et al. 2014)

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3.SM.3.5 Supplementary information to Key Economic Sectors

Table 3.SM.11: Key Economic Sectors (Energy, Tourism, Transport, Water)

Projected Risks at 1.5°C and 2°C

Sector (Sub-Sector)	*Region*	*Metric*	*Baselines*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
Energy (thermal and hydro plants; cooling demand)	Global	Cooling demand (absolute growth in annual cooling degree days; CDD); hydroclimate risk to power production	1971–2000	5 GCMS GFDL-ESM2M; HadGEM2-ES; IPSL-CM5A-LR; MIROC-ESM-CHEM; NorESM1-M	RCP8.5 SSP1–3	1.5°C (2002–2048), 2.0°C (2014–2065)			Increased CCD, especially in tropical areas. Increased risk to thermal and hydro power plants in Europe, North America, South and Southeast Asia, and southeast Brazil.		(Byers et al. 2018)
Energy (wind)	Europe	Daily wind power output (transformed from daily near	2006–2015	HAPPI		1.5°C (2106–2115		Great potential for wind energy in northern		Limited spatial resolution	(Hosking et al. 2018)

		surface wind speeds)						Europe, especially in the UK.			
Energy (electricity demand)	US	Electric sector models: GCAM-USA ReEDS IPM		MIT IGSM-CAM	REF CS3 REF CS6 POL4.5 CS3 POL3.7 CS3 TEMP 3.7 CS3	2015−2050			Increase in electricity demand by 1.6–6.5% in 2050.		(McFarland et al. 2015)
Energy (demand)	Global	Economic and end-use energy model Energy service demands for space heating and cooling			RCP2.6 (2°C) RCP8.5 (4°C) RCP8.5 constant after 2020 (1.5°) SSP1 SSP2 SSP3	2050−2100		Economic loss of 0.31% in 2050 and 0.89% in 2100 globally	GDP negative impacts in 2100 are highest (median: –0.94%) under 4.0°C (RCP8.5) scenario compared with a GDP change (median: −0.05%) under 1.5°C scenario		(Park et al. 2018)
Energy (heating and cooling	Global and regional	Degree days above or below 18°C	1961−1990	21 CMIP5		2100		Cooling energy demand: 31% impacts			(Arnell et al. 2018)

demand)								avoided; heating energy demand: 27% impacts avoided, relative to 2°C.			
Energy (hydropower)	US (Florida)	Conceptual rainfall-runoff (CRR) model: HYMOD MOPEX	1971–2000	CORDEX (6 RCMs) CMIP5, bias corrected	RCP4.5	2091–2100			Based on a min/max temperature increase of 1.35°C −2°C, overall stream flow to increase by an average of 21% with pronounced seasonal variations, resulting in increases in power generation (72% winter, 15% autumn) and decreasing (–14%) in summer		(Chilkoti et al. 2017)

Energy (hydropower)	Global	Gross hydropower potential; global mean cooling water discharge	1971–2000	5 bias-corrected GCMs	RCP2.6, RCP8.5	2080			Global gross hydropower potential expected to increase (+2.4% RCP2.6; +6.3% RCP8.5). Strongest increases in central Africa, Asia, India and northern high latitudes. 4.5–15% decrease in global mean cooling water discharge with largest reductions in US and Europe.	Socio-economic pathways	(van Vliet et al. 2016)

Energy (hydropower)	Brazil	Hydrological model for natural water inflows (MGB)	1960–1990	HadCM3 Eta-CPTEC-40		2011–2100		A decrease in electricity generation of about 15% and 28% for existing and future generation systems starting in 2040.		Other water use and economic development scenarios	(de Queiroz et al. 2016)
Energy (hydropower)	Ecuador	CRU TS v.3.24 monthly mean temperature, precipitation and potential evapotranspiration (PET) conceptual hydrological model assessing runoff and hydropower electricity model	1971–2000	CMIP5 bias corrected using PET	RCP8.5, RCP4.5, RCP2.6	2071–2100			Annual hydroelectric power production to vary between −55 and +39% of the mean historical output. Inter-GCM range of projections is extremely large (−82%−+277%).	ENSO impacts	(Carvajal et al. 2017)

Energy (wind)	Europe	Near surface wind data: wind energy density means; intra and inter annual variability	1986–2005	21 CMIP5 Euro-CORDEX	RCP8.5, RCP4.5	2016–2035, 2046–2065, 2081–2100		No major differences in large scale wind energetic resources, interannual or intraannual variability in near term future (2016–2035).	Decreases in wind energy density in eastern Europe, increases in Baltic regions (−30% vs. +30%). Increase of intraannual variability in northern Europe, decrease in southern. Interannual variability not expected to change.	Changes in wind turbine technology	(Carvalho et al. 2017)
Energy (wind)	Europe	Near surface wind speed wind power simulated energy mix scenario		Euro-CORDEX	RCP4.5, RCP8.5	2050		Changes in the annual energy yield of the future European wind farms fleet as a whole will remain within ±5%.			(Tobin et al. 2016)

Energy (wind)	Europe	Potential wind power generation		ENSEMBLES 15 RCM 6 GCM	SRES A1B				In Europe changes in wind power potential will remain within ±15% and ±20%.		(Tobin et al. 2015)
Energy (solar)	Europe	Mean photovoltaic (PV) power generation potential (PVPot); surface wind velocity (SWV); radiation (RSDS); surface air temp (TAS)	1970−1999	Euro-CORDEX	RCP4.5, RCP8.5	2070−2099			Solar PV supply by the end of 2100 should range from −14_+2% with largest decreases in northern countries.	Solar spectrum distribution and the air mass effect	(Jerez et al. 2015)
Energy (solar)	Global	Energy yields of PV systems		CMIP5	RCP8.5	2006−2049		Decreases in PV outputs in large parts of the world, but notable exceptions with positive trends in large parts of Europe, southeast of North America and the			(Wild et al. 2015)

								southeast China.			
Energy (electricity: wind, solar PV, hydro, thermal)	Europe	Wind power production; PV power generation potential; gross hydropower potential (VIC model); thermoelectric power generation (VIC-RBM models)	1971–2000	Euro-CORDEX (ensemble of 3 RCMs and 3 GCMs)	RCP4.5, RCP8.5	+1.5°C (2004-2043) +2.0°C (2016–2059) +3.0°C (2037–2084)		Impacts remain limited for most countries. PV and wind power potential may reduce 10%, hydro and thermal may reduce 20%.	At 2.0°C impacts across sub-sectors remain limited, negative impacts double at 3°C. Impacts more severe in southern Europe.	No spatial distribution accounted for in analysis	(Tobin et al. 2018)
Energy (hydropower)	Suriname	VHM hydrological model	1960–1990	CMIP5	RCP2.6, RCP4.5, RCP6.0, RCP8.5	1.5°C (2070–2100)		40% decrease in hydropower potential (RCP2.6).	50% decrease in hydropower potential (RCP4.5); 80% decrease in hydropower potential at 3°C GMST (RCP8.5).		(Donk et al. 2018)
Tourism	Europe	Climate Index for Tourism; Tourism Climatic Index (three variants)		Euro-CORDEX	RCP4.5, RCP8.5	+2°C			Varying magnitude of change across different indices;		(Grillakis et al. 2016)

									improved climate comfort for majority of areas for May to October period; June to August period climate favourability projected to reduce in Iberian peninsula due to high temperatures.		
Tourism	Southern Ontario, Canada	Weather-visitation models (peak, shoulder, off-season)				1°C –5°C warming		Each additional degree of warming experienced annual park visitation could increase by 3.1%, annually.		Social variables, for example, weekends or holidays	(Hewer et al. 2016)
Tourism	Europe	Natural snow	1971–20	Euro-CORDEX	RCP2.6,	+2°C			Under a	Tourism	(Damm et al. 2017)

		conditions (VIC); monthly overnight stay; weather value at risk	00		RCP4.5, RCP8.5	periods: 2071–2100 2036–2065 2026–2055			+2°C global warming, up to 10 million overnight stays are at risk (+7.3 million nights), Austria and Italy are most affected.	trends based on economic conditions	
Tourism	Sardinia (Italy) and the Cap Bon peninsula (Tunisia)	Overnight stays; weather/climate data (E-OBS)	1971–2000	EU-FP6 ENSEMBLES (ECH-REM, ECH-RMO, HCH-RCA and ECH-RCA)		2041–2070			Climate-induced tourism revenue gains, especially in the shoulder seasons during spring and autumn; threat of climate-induced revenue losses in the summer months due to increased heat stress.	GDP, prices, holidays, events	(Köberl et al. 2016)

Tourism	Iran (Zayandehroud River route)	Physiologically equivalent temperature (PET)	1983–2013	HADCM3	B1, A1B	2014–2039		The PET index shows a positive trend with a reduction in number of climate comfort days (18 < PET < 29), particularly in the western area.			(Yazdanpanah et al. 2016)
Tourism	Portugal	Arrivals of inbound tourists; GDP						Increasing temperatures are projected to lead to a decrease of inbound tourism arrivals between 2.5% and 5.2%, which is expected to reduce Portuguese GDP between 0.19% and			(Pintassilgo et al. 2016)

								0.40%.			
Transportation (shipping)	Arctic Sea (North Sea route; NSR)	Climatic losses; gross gains; net gains		PAGE-ICE	RCP4.5, RCP8.5 SSP2	2013–2200		Large-scale commercial shipping is unlikely possible until 2030 (bulk) and 2050 (container) under RCP8.5.	The total climate feedback of NSR could contribute 0.05% to global mean temperature rise by 2100 under RCP8.5, adding $2.15 trillion to the net present value of total impacts of climate change over the period until 2200. The climatic losses offset 33% of the total economic gains from NSR under RCP8.5 with the biggest	Business restrictions	(Yumashev et al. 2017)

									losses set to occur in Africa and India.		
Transpor tation (shipping)	Arctic Sea	Sea ice ship speed (in days); sea ice thickness (SIT)	1995–20 14	CMIP5	RCP2.6, RCP4.5, RCP8.5	2045–20 59, 2075–20 89			Shipping season 4–8 under RCP8.5, double that of RCP2.6. Average transit times decline to 22 days (RCP2.6) and 17 days (RCP8.5).		(Melia et al. 2016)
Transpor tation (shipping)	Arctic Sea (NSR)	Mean time of NSR transit window; sea ice concentration	1980–20 14	CMIP5	RCP4.5, RCP8.5	2020–21 00			Increase in transit window by 4 (RCP4.5) and 6.5 (RCP8.5) months.		(Khon et al. 2017)
Water	Europe	Runoff discharge snowpack based on hydrological models: E-HYPE Lisflood WBM		CMIP5 CORDEX (11) Bias corrected to E-OBS	RCP2.6, RCP4.5, RCP8.5	1.5°C 2°C 3°C		Increases in runoff affect the Scandinavian mountains; decreases in runoff in Portugal.	Increases in runoff in Norway, Sweden and north Poland; decreases in runoff around		(Donnelly et al. 2017)

		LPJmL							Iberian, Balkan and parts of French coasts.		
Water	Global (8 river regions)	River runoff Glob-HM Cat-HM		HadGEM2-ES IPSL-CM5A-LR; MIROCESM-CHEM; GFDL-ESM2; NorESM1-M;	RCP8.5	1°C 2°C 3°C 1971–2099		Projected runoff changes for the Rhine decrease, Tagus decrease and Lena increase with global warming.	Increased risk of decreases in low flows for Rhine (−11% at 2°C to −23% at 3°C); risk of increases in high flows increases for Lena +17% (2°C) to +26% (3°C).		(Gosling et al. 2017)

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3.SM.4 Supplementary information to Cross-Chapter Box 6 Food Security

Table 3.SM.12: Projected health risks of undernutrition and dietary change at 1.5°C and 2°C. Abbreviations: DALY: disability adjusted life year; RCP: Representative Concentration Pathway; SSP: Shared Socio-Economic Pathway

Region	*Health Outcome Metric*	*Study Baseline*	*Climate Model(S)*	*Scenario*	*Time Periods of Interest*	*Impacts at Study Baseline*	*Projected Impacts at 1.5°C*	*Projected Impacts at 2°C*	*Other Factors Considered*	*Reference*
Global and 21 regions	Undernutrition	1961–1990	BCM2.0, EGMAM1, EGMAM2, EGMAM3, CM4vl	A1B	2030, 2050		In 2030 95,175 additional undernutrition deaths without adaptation and (ensemble mean) 131,634 with adaptation under the low growth scenario and 77,205 under the high growth scenario; Asia and sub-Saharan Africa at highest risk.	In 2050 risks are generally lower in most regions because of underlying trends, with 84,695 additional undernutrition deaths without adaptation, 101,484 with adaptation under the low growth scenario and 36,524 under the high growth scenario.	Population growth; improved population health; crop models include adaptation measures	(Hales et al. 2014)

Global and 17 regions	Undernourished population; DALY (disability) caused by underweight of a child under 5 years of age	2005–2100	5 models from ISIMIP (GFDL-ESM2, NorESM1-M, IPSL-CM5A-LR, HadGEM2-ES, MIROC-ESM-CHEM)	RCP2.6 and 8.5 with SSP2 and SSP3	2005–2100	Baseline assumed no climate change (no temperature increase from present)	In 2025 under SSP3, global undernourished population is 530–550 million at 1.5°C. Global mean DALYs of 11.2 per 1000 persons at 1.5°C.	In 2050 under SSP3, global undernourished population is 540–590 million at 2.0°C. Global mean DALYs of 12.4 per 1000 persons at 2°C.	Population growth and aging; equity of food distribution	(Hasegawa et al. 2016)
Global divided into 17 regions	DALYs from stunting associated with undernutrition	1990–2008	12 GCMs from CMIP5	Six scenarios: RCP2.6 + SSP1, RCP4.5 + SSPs 1–3, RCP8.5 + SSP2, SSP3	2005–2050	57.4 million DALYs in 2005	In 2030 DALYs decrease by 36.4 million (63%), for RCP4.5, SSP1, and by 30.4 million (53%) and 16.2 million (28%) for RCP8.5, SSP2 and SSP3, respectively.	By 2050 DALYs decrease further to 17.0 million for RCP4.5, SSP1, and to 11.6 million for RCP8.5, SSP2. DALYs increase to 43.7 million under RCP8.5, SSP3.	Future population and per capita GDP from the SSP database	(Ishida et al. 2014)

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4.SM Strengthening and Implementing the Global Response
Supplementary Material

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4.SM.1 Benchmark Indicators for Sectoral Changes in Emissions as Presented in Table 4.1 (Section 4.2.1)

Integrated assessment models (IAMs) and other sector scenarios provide sectoral detail underpinning the declines in greenhouse gas (GHG) emissions by the middle of the century (Section 2.3 and Section 2.4). Table 4.SM.1 indicates the pace of the transitions that are deemed necessary in 2020, 2030 and 2050 at the sector level for 1.5°C-consistent pathways, and complements this with bottom-up studies from literature that give actionable policy targets (the lines in white). A summary of this table is presented in Section 4.2.1.

Table 4.SM.1: Benchmark indicators indicating the sectoral changes in emissions, fuels and technologies that would need to take place in 1.5°C-consistent pathways, based on selected IAM 1.5°C pathways assessed in Chapter 2 (with no, low and high overshoot) (dark grey rows), four archetype scenarios (light grey rows) and bottom-up studies including IEA (white rows). The numbers in square brackets in some columns indicate the scenario count for the specific indicator.

		Median (interquartile range)	Scenario count	Share of Renewables in primary energy (%)	Share of Renewables in electricity generation (%)	Share of Fossil Fuels in electricity generation (%)	Change in Energy Demand in Buildings relative to 2010 (%)	Direct Emissions Reductions from Buildings relative to 2010 (%)	Share of Low-Carbon Fuels in transport (%)	Share of Electricity in transport (%)	Share of Biofuels in transport (%)	Industrial Emissions Reductions relative to 2010 (%)
2020	IAM pathways	No or low overshoot 1.5	50	14.90 (16.25, 14.24)	26.32 (29.04, 24.13)	61.32 (63.15, 58.64)	-10.84 (-7.49, -11.96) [42]	-1.47 (6.62, -7.98) [42]	4.42 (4.51, 3.66) [29]	1.24 (1.75, 1.10) [49]	3.03 (3.23, 1.69) [37]	-12.68 (-0.50, -15.79) [42]
2020	IAM pathways	Low overshoot 1.5	43	15.31 (16.23, 14.03)	26.26 (28.83, 23.58)	61.08 (63.17, 58.74)	-10.86 (-7.53, -14.83) [35]	-0.83 (6.62, -9.69) [35]	4.39 (4.51, 3.59) [23]	1.24 (1.79, 1.09) [42]	1.97 (3.17, 1.55) [31]	-11.81 (-1.66, -17.80) [35]
2020	IAM pathways	High overshoot 1.5	35	15.08 (15.84, 14.44)	28.37 (29.24, 24.33)	61.58 (63.83, 59.70)	-12.49 (-10.75, -19.44) [29]	-3.52 (6.62, -15.22) [29]	3.59 (4.45, 3.27) [23]	1.40 (1.53, 1.10)	2.18 (2.98, 1.72) [24]	-15.50 (-12.70, -23.70) [29]
2020	IAM pathways	S1		12.46	23.24	63.72	-9.20	-0.83		0.95	1.69	4.46
2020	IAM pathways	S2		16.61	27.00	60.11	-16.20	-0.25	2.18	0.97	1.22	-20.61
2020	IAM pathways	S5		13.46	17.38	71.03			3.16	0.95	2.20	
2020	IAM pathways	LED		15.63	24.61	54.11	-8.78	15.11		2.51		-32.87
2020	Sectoral studies	Löffler et al. (2017)		13.47	31.41	57.60						
2020	Sectoral studies	IEA (2017a) (ETP)		19.02	29.91	58.63	-1.52	10.25	5.74	1.70	4.03	-9.37
2020	Sectoral studies	IEA (2017b) (WEM)		16.67	29.32	58.75	-7.44	5.78	4.94	1.21	3.73	-6.51
2030	IAM pathways	No or low overshoot 1.5	50	29.08 (37.06, 25.73)	53.68 (64.80, 46.74)	30.04 (37.60, 20.25)	0.30 (7.31, -6.73) [42]	33.53 (51.77, 21.47) [42]	12.07 (17.83, 8.55) [29]	5.20 (7.13, 3.27) [49]	6.54 (10.05, 2.51) [37]	42.29 (54.71, 34.25) [42]
2030	IAM pathways	Low overshoot 1.5	43	28.75 (35.31, 25.45)	52.63 (58.90, 44.48)	31.54 (38.14, 23.14)	-2.61 (5.41, -7.73) [35]	30.11 (43.16, 20.58) [35]	9.71 (15.24, 8.44) [23]	4.99 (6.84, 3.18) [42]	5.06 (9.60, 2.12) [31]	39.81 (49.58, 30.13) [35]
2030	IAM pathways	High overshoot 1.5	35	23.65 (27.45, 20.03)	42.73 (53.78, 36.91)	42.02 (47.27, 32.61)	-16.64 (-12.07, -20.01) [29]	8.15 (23.54, -0.61) [29]	6.65 (8.32, 5.55) [23]	3.46 (4.68, 2.54)	3.54 (3.85, 1.38) [24]	17.67 (27.65, -12.81) [29]

		S1		28.79	57.89	27.84	-7.68	35.32		3.92	5.06	49.09
		S2		28.72	47.89	35.37	-14.12	47.92	5.17	4.46	0.71	19.11
		S5		13.78	25.11	57.38			3.43	1.32	1.93	
		LED		37.42	59.64	17.14	30.42	59.81		20.93		42.10
	Sectoral studies	**Löffler et al. (2017)**		45.59	79.25	13.73						
		IEA (2017a) (ETP)		31.09	46.73	37.92	1.98	46.91	13.80	5.47	8.18	22.39
		IEA (2017b) (WEM)		27.24	49.58	34.74	-6.37	32.03	17.12	5.76	11.20	15.28
2050	**IAM pathways**	**No or low overshoot 1.5**	50	60.24 (67.09, 51.77)	77.12 (86.43, 69.23)	8.61 (13.42, 3.88)	-17.19 (3.31, -36.20) [42]	70.26 (89.56, 54.48) [42]	55.00 (65.66, 34.67) [29]	22.67 (28.73, 17.30) [49]	15.24 (22.95, 10.95) [37]	78.75 (90.79, 67.33) [42]
		Low overshoot 1.5	43	58.37 (66.65, 49.97)	75.98 (85.32, 68.54)	8.69 (13.59, 4.80)	-19.43 (2.17, -37.44) [35]	68.30 (89.48, 54.32) [35]	52.95 (65.14, 34.10) [23]	22.63 (30.20, 16.74) [42]	14.71 (21.73, 10.11) [31]	78.69 (89.17, 70.60) [35]
		High overshoot 1.5	35	62.16 (67.51, 47.48)	82.39 (88.34, 63.65)	6.33 (16.06, 2.26)	-37.41 (-13.37, -51.04) [29]	48.64 (59.49, 40.82) [29]	38.38 (43.62, 27.01) [23]	18.49 (22.88, 13.67)	14.96 (17.78, 5.10) [24]	68.12 (80.61, 53.62) [29]
		S1		58.37	81.26	10.15	-20.54	79.74		33.68	12.95	73.70
		S2		52.90	63.08	11.42	-24.59	89.65	25.65	22.67	2.98	72.81
		S5		67.04	70.27	6.69			53.36	9.54	35.46	
		LED		72.51	77.40	0.19	44.67	95.00		59.21		91.38
	Sectoral studies	**Löffler et al. (2017)**		100.00	99.76	0.00						
		IEA (2017a) (ETP)		57.77	74.33	9.72	5.10	82.71	54.83	29.65	24.43	57.26
		IEA (2017b) (WEM)		47.02	68.72	13.71	-5.38	73.14	58.18	32.07	25.19	54.61

Notes: Values for no or low, low and high overshoot 1.5 indicate the median and the interquartile ranges for indicators for 1.5°C-consistent pathways distinguishing the level of overshoot, collected in the scenario database established for the assessment of this Special Report (see Section 2.1 and Annex 2.3). Four illustrative pathway archetypes were selected for comparison: S1 (AIM 2.0, SSP1–19), S2 (MESSAGE-GLOBIOM 1.0, SSP2–19), S5 (REMIND-MAgPIE 1.5, SSP5–19) and low energy demand (MESSAGEix-GLOBIOM 1.0, LED) (see Section 2.1). The selected studies indicate mitigation transitions in key sectors consistent with limiting warming to 1.5°C (IEA, 2017a, 2017c; Löffler et al., 2017), grounded in published scenarios combined with expert judgement.

4.SM.2 Enabling Conditions and Constraints of Overarching Adaptation Options as Discussed in Section 4.3.5

Table 4.SM.2: Overarching adaptation options: Enabling conditions and constraints. This table underpins Section 4.3.5.

Adaptation Option	Feasibility	Enabling Conditions	Constraints	Examples
Disaster risk management	*Medium evidence (high agreement)*	Pools resources and expertise for risk reduction (Howes et al., 2015; Kelman et al., 2015; Wallace, 2017). Integrates adaptation into existing management (Howes et al., 2015). Supports post-disaster recovery and reconstruction (Kelman et al., 2015; Kull et al., 2016). Engages local and indigenous knowledge to improve preparedness and response (McNamara and Prasad, 2014; Mawere and Mubaya, 2015; Kaya and Koitsiwe, 2016; Chambers et al., 2017; Granderson, 2017).	Uncertainty over projected climate impacts and absence of downscaled climate projections (van der Keur et al., 2016; de Leon and Pittock, 2017; Wallace, 2017). Limited institutional, technical and financial capacity in frontline agencies (de Leon and Pittock, 2017; Kita, 2017; Wallace, 2017). Adaptation and disaster risk management communities operate separately (Kelman et al., 2015; Serrao-Neumann et al., 2015; de Leon and Pittock, 2017).	*Glacial lake outburst floods (GLOFs)* 1.5°C will increase risk of GLOFs (Cogley, 2017; Kraaijenbrink et al., 2017). Infrastructural measures technically and economically unfeasible in many regions (Muñoz et al., 2016; Schwanghart et al., 2016; Watanabe et al., 2016; Haeberli et al., 2017). Early warning systems (Anacona et al., 2015) and monitoring of dangerous lakes and surrounding slopes (including using remote sensing) offer disaster risk management opportunities (Emmer et al., 2016; Milner et al., 2017). Institutional leadership and community engagement essential for effectiveness (Anacona et al., 2015; Watanabe et al., 2016).
Risk sharing and spreading: insurance	*Medium evidence (medium agreement)*	Buffers climate risk (Wolfrom and Yokoi-Arai, 2015; O'Hare et al., 2016; Glaas et al., 2017; Jenkins et al., 2017; Patel et al., 2017). Shifts the mobilization of financial resources towards strategic approaches (Surminski et al., 2016). Incentivizes investments and behaviour that reduce exposure (Linnerooth-Bayer and Hochrainer-Stigler, 2015; Shapiro, 2016; Jenkins et al., 2017).	Can provide disincentives for reducing risk and can distort incentives for adaptation strategies (Annan and Schlenker, 2015; de Nicola, 2015). Underwrites a return to the 'status quo' rather than enabling adaptive behaviour (O'Hare et al., 2016). Financial, social and institutional barriers to implementation and uptake, especially in low-income nations (García Romero and Molina, 2015; Joyette et al., 2015;	*Crop insurance* In Kenya during the 2011 drought, index-based insurance payouts for livestock reduced distress sales by 64% among better-off pastoralist households and reduced the likelihood of rationing food intake by 43% among poorer households (Hansen et al., 2017). In USA Annan and Schlenker (2015) found insured crops were significantly more sensitive to extreme heat because insured farmers were disincentivized from investing in costly adaptation strategies since their insurance compensated for potential losses

			Lashley and Warner, 2015; Jin et al., 2016).	In Bangladesh low institutional trust and financial literacy mean that fewer women enrol in weather-based crop insurance (Akter et al., 2016). *World Bank 'cat bond' issuance in Caribbean* In 2007 the Caribbean Catastrophe Risk Insurance Facility (CCRIF) was formed to pool risk from tropical cyclones, earthquakes and excess rainfalls (Murphy et al., 2012; CCRIF, 2017). 36 payouts have been made to 13 governments, totalling 130.5 million USD and partially funded by CCRIF, within 14 days of the event (CCRIF, 2017). Speed of payment allows countries to finance immediate needs (Murphy et al., 2012). Though widely perceived to be successful, evidence of success remains limited (Teh, 2015).
Risk sharing and spreading: social protection programmes	*Medium evidence (medium agreement)*	Builds generic adaptive capacity and reduces social vulnerability (Weldegebriel and Prowse, 2013; Eakin et al., 2014; Lemos et al., 2016; Schwan and Yu, 2017). Must be complemented with a comprehensive climate risk management approach (Schwan and Yu, 2017) that also takes into account disaster risk management, adaptation and vulnerability reduction goals (Davies et al., 2013).	Inadequate targeting, leakages and lack of institutional architecture, especially in Least Developed Countries (Ravi and Engler, 2015; Schwan and Yu, 2017). Uncertainties about effectiveness of processes of delivering social protection (e.g., cash or 'in kind'). Necessary but insufficient to decrease households' vulnerability if stand-alone (Lemos et al., 2016). When delivered without emphasis on vulnerability reduction, investments may be maladaptive in long run (Nelson et al., 2016).	*Cash transfer programmes* In sub-Saharan Africa cash transfer programmes targeting poor communities have proven successful in smoothing household welfare and food security during droughts, strengthening community ties and reducing debt levels (del Ninno et al., 2016; Asfaw et al., 2017; Asfaw and Davis, 2018). In Brazil higher levels of income due to cash transfer programmes have been linked to food security, as households are able to invest in irrigation, but there have been limited long-term investments in reducing vulnerability among the poorest households (Lemos et al., 2016; Mesquita and Bursztyn, 2016; Nelson et al., 2016).
Education and learning	*Medium evidence (high agreement)*	Co-production of solutions strengthens adaptation implementation (Butler et al., 2016a; Thi Hong Phuong et al., 2017; Ford et al., 2018).	Not appropriate in all circumstances (e.g., highly marginalized locations) (Ford et al., 2016, 2018).	*Participatory scenario planning (PSP)* PSP is a process by which multiple stakeholders work together to envision future scenarios under a range of climatic conditions (Flynn et al., 2018).

		Social learning strengthens adaptation and affects longer-term change (Clemens et al., 2015; Ensor and Harvey, 2015; Henly-Shepard et al., 2015). International learning and cooperation mechanisms, supranational organizations (Vinke-de Kruijf and Pahl-Wostl, 2016) and international, collaborative projects (Cochrane et al., 2017; Harvey et al., 2017) can build adaptive capacity.	Education and learning on their own may not provide 'enough adaptive capacity to respond to climate change' (Thi Hong Phuong et al., 2017). Participation in and of itself does not necessarily build capacity (Ford et al., 2016).	PSP has been observed to facilitate the interaction of multiple knowledge systems, resulting in learning and the co-production of knowledge on adaptation (Tschakert et al., 2014; Oteros-Rozas et al., 2015; Star et al., 2016; Flynn et al., 2018).
Population health and health systems	*Medium evidence (high agreement)*	1.5°C will primarily exacerbate existing health challenges (K.R. Smith et al., 2014), which can be targeted by enhancing health services. Age, pre-existing medical conditions and social deprivation are found to be the key (but not the only) factors that make people vulnerable and lead to more adverse health outcomes related to climate change impacts. Interventions to reduce climate change-driven health impacts can be mainstreamed through existing health programming and service delivery (WHO, 2015; Paavola, 2017). Needs to be combined with iterative management involving regular monitoring of effectiveness in the light of climate impacts (Hess and Ebi, 2016; Ebi and Otmani del Barrio, 2017). Collaboration with local stakeholders, public education campaigns and the tailoring of communication to local needs are essential (Berry and Richardson, 2016; van Loenhout et al., 2016).	Governance challenges: for example, absence of coordination across scales, lack of mandate for action on adaptation (Austin et al., 2016; Ebi and Otmani del Barrio, 2017; Shimamoto and McCormick, 2017). Absence of information and understanding on climate impacts (Nigatu et al., 2014; Xiao et al., 2016; Sheehan et al., 2017). Many health services currently do not consider climate change (Hess and Ebi, 2016). Adaptation strategies based on individual preparedness, action and behaviour change may aggravate health and social inequalities due to their selective uptake, unless they are coupled with broad public information campaigns and financial support for undertaking adaptive measures (Paavola, 2017).	*Heat wave early warning and response systems* Heat wave early warning and response systems coordinate the implementation of multiple measures in response to predicted extreme temperatures (e.g., public announcements, opening public cooling shelters, distributing information on heat stress symptoms) and have been shown to be effective in a wide variety of contexts (Knowlton et al., 2014; Takahashi et al., 2015; Nitschke et al., 2016, 2017).

Indigenous knowledge	*Medium evidence (high agreement)*	Indigenous knowledge underpins the adaptive capacity of indigenous communities through the diversity and flexibility of indigenous agro-ecological systems, collective social memory, repository of accumulated experience and from social networks that are essential for disaster response and recovery (Hiwasaki et al., 2015; Pearce et al., 2015; Mapfumo et al., 2016; Sherman et al., 2016; Ingty, 2017; Ruiz-Mallén et al., 2017). Knowledge of environmental conditions helps communities detect and monitor change (Johnson et al., 2015; Mistry and Berardi, 2016; Williams et al., 2017).	Acculturation, dispossession of land rights and land grabbing, colonization and social change are challenging indigenous knowledge systems (Ford, 2012; Nakashima et al., 2012; McNamara and Prasad, 2014; Pearce et al., 2015). Broader structural challenges, systemic inequality and dominant governance systems prevent indigenous epistemologies and worldviews from meaningfully being integrated into adaptation (Thornton and Manasfi, 2010; Mistry et al., 2016; Russell-Smith et al., 2017). Can promote conservative attitudes, limit uptake of new information and practices and may not be sustainable in all circumstances given socio-cultural changes experienced (Granderson, 2017; Kihila, 2017; Mccubbin et al., 2017).	*Cultural programming* Options such as integration of indigenous knowledge into resource management systems and school curricula, digital storytelling and filmmaking, cultural events, web-based knowledge banks, radio dramas and documentation of knowledge are identified as potential adaptations (Cunsolo Willox et al., 2013; McNamara and Prasad, 2014; MacDonald et al., 2015b; Pearce et al., 2015; Chambers et al., 2017; Inamara and Thomas, 2017), but need to be carefully analysed for their potential to reduce vulnerability, including potential trade-offs (Granderson, 2017).
Human migration	*Low evidence* (but rapidly growing, *low agreement)*	Revising and adopting migration issues in national disaster risk reduction policies, national action plans, and intended nationally determined contributions (INDCs)/NDCs (Kuruppu and Willie, 2015; Yamamoto et al., 2017). Utilizing existing social protection programmes to manage climate-induced migration (Schwan and Yu, 2017). Moving away from ad hoc approaches to migration and displacement (Thomas and Benjamin, 2018).	Research conducted on a 'case by case' approach fails to provide the effective scaling of policy to national or international levels (Gemenne and Blocher, 2017; Grecequet et al., 2017). Few policies on migration exist at the national or sub-national scales (Yamamoto et al., 2017). Financial, social and ecological costs (Grecequet et al., 2017). Stress on urban system resources and services (Bhagat, 2017).	*Autonomous and planned relocation in small island developing states and semi-arid regions* Migration is improving access to financial and social capital and reducing risk exposure in some locations (e.g., in the Solomon Islands; Birk and Rasmussen, 2014). The ad hoc nature of migration and displacement can be overcome by integrating disaster risk reduction and climate change adaptation into national sustainable development plans (Thomas and Benjamin, 2018). In semi-arid India, populations in rural regions already experiencing 1.5°C warming are migrating to cities (Gajjar et al., 2018) but are inadequately covered by existing policies (Bhagat, 2017).

		Migration can serve as an important risk management strategy, leading to increased incomes (Cattaneo and Peri, 2016). Migration might become the only feasible adaptation option in highly vulnerable areas (Betzold, 2015; Wilkinson et al., 2016).	Migrants at risk of insecure tenure, unsafe living conditions and exclusion in their destinations (Gioli et al., 2016; Bettini et al., 2017; Bhagat, 2017; Schwan and Yu, 2017).	
Climate services	*Medium evidence (high agreement)*	Rapid technical development, due to increased financial inputs and growing demand, is enabling improved quality of climate information (Rogers and Tsirkunov, 2010; Clements et al., 2013; Perrels et al., 2013; Gasc et al., 2014; WMO, 2015; Roudier et al., 2016). Multiple stakeholder engagement and participatory processes to interpret climate information are effective to improve uptake and use (Mantilla et al., 2014; Sivakumar et al., 2014; Coulibaly et al., 2015; Gebru et al., 2015; Brasseur and Gallardo, 2016; Lourenço et al., 2016; Singh et al., 2016; Vaughan et al., 2016; Kihila, 2017; Lobo et al., 2017). Scaling climate services may occur through: leveraging capacities of project champions, knowledge brokers, and intermediaries (Mantilla et al., 2014; Coulibaly et al., 2015); co-production of knowledge (Kirchhoff et al., 2013) that enables users to actively participate in adaptation decisions (Vaughan and Dessai, 2014); developing clear financial models to ensure sustainability (Webber and Donner, 2017), which includes multi-stakeholder engagement through iterative participatory processes (Girvetz et al., 2014; Dorward et al., 2015); and leveraging appropriate	Issues of timing of information provision and scale of information remain barriers (Dinku et al., 2014; Jancloes et al., 2014; Gebru et al., 2015; Weisse et al., 2015; Brasseur and Gallardo, 2016; Cortekar et al., 2016; Singh et al., 2016; Snow et al., 2016; Vaughan et al., 2016; Kihila, 2017). Lower uptake by women, remote communities and those without technical support (Singh et al., 2017; Carr and Onzere, 2018). Issues of trust and usability of information provided (L. Jones et al., 2016; Singh et al., 2017; C.J. White et al., 2017). Continued focus on supply-driven provision of climate information rather than specific needs of end users (Lourenço et al., 2016).	Semi-arid regions in India and sub-Saharan Africa facing 1.5°C warming are seeing benefits of climate services in agriculture planning, drought management and flood warning (Vincent et al., 2015; Lobo et al., 2017; Singh et al., 2017; C. Vaughan et al., 2018). Climate services are being widely applied in sectors such as agriculture, health, disaster management and insurance (Lourenço et al., 2016; C. Vaughan et al., 2018), with implications for adaptation decision-making. Several programmes aimed at using climate services for better decision-making are showing signs of success: from various actors, at various scales, using different forms of information delivery and uptake. These involve: participatory analysis of seasonal forecasts in East Africa (Dorward et al., 2015); non-governmental organization-driven weather advisories in India (Lobo et al., 2017); innovations in government agriculture extension services in various countries across sub-Saharan Africa and South Asia (Singh et al., 2016); and broadening the scope of climate services to directly inform spatial planning and adaptation interventions in the Netherlands (Goosen et al., 2013).

		communication channels such as mobile technology (Hampson et al., 2014; Gebru et al., 2015).		

4.SM.3 Carbon Dioxide Removal Costs, Deployment and Side Effects: Literature Basis for Figure 4.2 (Section 4.3.7)

Table 4.SM.3: References supporting Figure 4.2 in Section 4.3.7. Evidence on Carbon Dioxide Removal (CDR) abatement costs, 2050 deployment potentials and side effects. Based on systematic review (Fuss et al., 2018).

Technology	**Costs**	**Potentials**
Afforestation and reforestation (AR)	Myers and Goreau, 1991; van Kooten et al., 1992, 1999; Winjum et al., 1992, 1993; Dixon et al., 1993; Swisher, 1994; Brown et al., 1995; Chang, 1999; Plantinga et al., 1999; Sohngen and Alig, 2000; van Kooten, 2000; Plantinga and Mauldin, 2001; Ravindranath et al., 2001; Sohngen and Mendelsohn, 2003; van Vliet et al., 2003; Baral and Guha, 2004; Richards and Stokes, 2004; Koning et al., 2005; Lakyda et al., 2005; Lee et al., 2005; Olschewski and Benítez, 2005; Richards and Stavins, 2005; Yemshanov et al., 2005; Benítez and Obersteiner, 2006; Han et al., 2007; Ahn, 2008; Hedenus and Azar, 2009; Dominy et al., 2010; Rootzén et al., 2010; Ryan et al., 2010; Torres et al., 2010; Winsten et al., 2011; Paterson and Bryan, 2012; Townsend et al., 2012; Nijnik et al., 2013; Paul et al., 2013; Polglase et al., 2013; Carwardine et al., 2015; Evans et al., 2015; Maraseni and Cockfield, 2015; Haim et al., 2016	Dixon et al., 1994; Nilsson and Schopfhauser, 1995; Cannell, 2003; Richards and Stokes, 2004; Houghton et al., 2015; Houghton and Nassikas, 2018
Bioenergy with carbon dioxide capture and storage (BECCS)	Möllersten et al., 2003, 2004, 2006; Keith et al., 2006; Azar et al., 2006; Luckow et al., 2010; Abanades et al., 2011; Gough and Upham, 2011; Laude and Ricci, 2011; Laude et al., 2011; Ranjan and Herzog, 2011; Carbo et al., 2011; De Visser et al., 2011; Fabbri et al., 2011; Koornneef et al., 2012b; Kärki et al., 2013; Fornell et al., 2013; Akgul et al., 2014; N. Johnson et al., 2014; Arasto et al., 2014; Al-Qayim et al., 2015; Onarheim et al., 2015; Creutzig et al., 2015; Moreira et al., 2016; Rochedo et al., 2016; Sanchez and Callaway, 2016	Fischer and Schrattenholzer, 2001; Yamamoto et al., 2001; Hoogwijk et al., 2005, 2009; Moreira, 2006; Obersteiner et al., 2006; Smeets et al., 2007; Smeets and Faaij, 2007; Hakala et al., 2008; van Vuuren et al., 2009; Dornburg et al., 2010; Gregg and Smith, 2010; Thrän et al., 2010; Beringer et al., 2011; Haberl et al., 2011; Cornelissen et al., 2012; Erb et al., 2012; Rogner et al., 2012; W.K. Smith et al., 2012; Lauri et al., 2014; Kraxner and Nordström, 2015; Searle and Malins, 2015; Buchholz et al., 2016; Calvin et al., 2016; Tokimatsu et al., 2017
Biochar	McCarl et al., 2009; Smith, 2016	Lehmann et al., 2006; Laird et al., 2009; Lee et al., 2010; Moore et al., 2010; Pratt and Moran, 2010; Woolf et al., 2010; Powell and Lenton, 2012; Hamilton et al., 2015; Lomax et al., 2015; Smith, 2016
Soil carbon sequestration	Smith et al., 2008; Smith, 2016	Batjes, 1998; Metting et al., 2001; Lal, 2003a, b, 2004a, c, 2010, 2011, 2013; Lal et al., 2007; Smith et al., 2008; Salati et al., 2010; Conant, 2011; Smith, 2012, 2016; Benbi, 2013; Lorenz and Lal, 2014; Powlson et al., 2014; Sommer and Bossio, 2014; Henderson et al., 2015; Lassaletta and Aguilera, 2015; Smith, 2016; Minasny et al., 2017; Zomer et al., 2017

Direct air carbon dioxide capture and storage (DACCS)	Zeman, 2003, 2014; Keith et al., 2006; Nikulshina et al., 2006; Stolaroff et al., 2008; Lackner, 2009; House et al., 2011; Simon et al., 2011; Socolow et al., 2011; Holmes and Keith, 2012; Kulkarni and Sholl, 2012; Mazzotti et al., 2013; W. Zhang et al., 2014; Geng et al., 2016; Sakwa-Novak et al., 2016; SEAB, 2016; Sinha et al., 2017; van der Giesen et al., 2017	
Enhanced weathering (EW)	Schuiling and Krijgsman, 2006; Hartmann and Kempe, 2008; Köhler et al., 2010; Renforth, 2012; Taylor et al., 2016; Strefler et al., 2018a	Hartmann and Kempe, 2008; Köhler et al., 2010, 2013; Renforth et al., 2011; Hauck et al., 2016; Taylor et al., 2016; Strefler et al., 2018a
Ocean alkalinization (OA)	Rau and Caldeira, 1999; Rau et al., 2007; Harvey, 2008; Rau, 2008; Paquay and Zeebe, 2013; Renforth et al., 2013; Renforth and Kruger, 2013; Renforth and Henderson, 2017	Harvey, 2008; Paquay and Zeebe, 2013; González and Ilyina, 2016
Reviews	Lenton, 2010, 2014; McGlashan et al., 2012; McLaren, 2012; Caldecott et al., 2015; NRC, 2015; UNEP, 2017b	

4.SM.4 Guidance and Assessment for Feasibility Assessment

4.SM.4.1 Guidance for Feasibility Assessment in Section 4.5.1

Table 4.SM.4: Guidance for conducting the feasibility assessment of mitigation and adaptation options. See 4.SM.4.2 for the assessment and literature basis of the assessment of mitigation options and 4.SM.4.3 for the assessment and literature basis of adaptation options.

<table>
<tr><th>Entry for Indicator-Option Combination</th><th colspan="2">Guidance for Conducting the Feasibility Assessment of Mitigation and Adaptation Options</th></tr>
<tr><td>NA (not applicable)</td><td colspan="2">The indicator is not relevant to the option</td></tr>
<tr><td>NE (no evidence)</td><td colspan="2">- No peer-reviewed literature could be located supporting an assessment of whether this indicator would limit the option’s feasibility
- The peer-reviewed literature that mentions the issue is not robust enough</td></tr>
<tr><td>LE (limited evidence)</td><td colspan="2">- One or two papers make statements/present research that could be a basis for the assessment, but this evidence is considered too limited
- Two or more papers provide a basis for the assessment as a side issue in the paper, not as a core issue</td></tr>
<tr><td>A</td><td rowspan="3">A feasibility assessment can be made:

- If there are one or two robust papers (or more) that contain references which also support the assessment
- If literature is plentiful
- If one or a number of meta-studies and reviews provide extensive treatment of the indicator-option combination</td><td>A = The indicator could block the feasibility of this option</td></tr>
<tr><td>B</td><td>B = The indicator does not have a positive nor a negative effect on the feasibility of the option</td></tr>
<tr><td>C</td><td>C = The indicator does not pose any barrier to the feasibility of this option</td></tr>
</table>

Table 4.SM.5: Parameters used for the calculation of the overall feasibility of the dimension-option combinations.

$\#indicators$	Number of indicators used to assess the overall feasibility of a dimension, typically two to five
$\#NA$	Number of indicators that are not applicable (NA) to the option
$\#NE\&LE$	Total number of indicators for which there is no evidence (NE) or limited evidence (LE)
$\#A$	Number of indicators assessed as A
$\#B$	Number of indicators assessed as B
$\#C$	Number of indicators assessed as C

$\#effective\ indicators$	$\#effective\ indicators = \#indicators - \#NA$
AVG	*(1*#A +2*#B+3*#C)/(#effective indicators - #NE&LE)*

Table 4.SM.6: Legend criteria for the overall feasibility of the dimension-option combinations as shown in Table 4.11 for mitigation options and Table 4.12 for adaptation options.

Legend of Table 4.11 and Table 4.12	**Legend Criteria for the Overall Feasibility of each of the Dimension-Option Combinations**
NA	$\#indicators = \#NA$
	$\#NE\&LE > 0.5 * \#effective\ indicators$
	$AVG \leq 1.5$ $\#NE\&LE \leq 0.5 * \#effective\ indicators$
	$1.5 < AVG \leq 2.5$ $\#NE\&LE \leq 0.5 * \#effective\ indicators$
	$AVG > 2.5$ $\#NE\&LE \leq 0.5 * \#effective\ indicators$

4.SM.4.2 Feasibility Assessment of Mitigation Options as Presented in Section 4.5.2

4.SM.4.2.1 Feasibility Assessment of Mitigation Options in Energy System Transitions

Table 4.SM.7: Feasibility assessment of energy system transition mitigation options: wind (on-shore and off-shore), solar photovoltaic (PV), and bioenergy. For methodology, see 4.SM.4.1.

		Wind (On-shore and Off-shore)		**Solar PV**		**Bioenergy**	
	Evidence	Robust		Robust		Robust	
	Agreement	Medium		High		Medium	
Economic	Cost-effectiveness		IRENA, 2015, 2016; Shafiee et al., 2016; Silva Herran et al., 2016; Voormolen et al., 2016; WEC, 2016		Cengiz and Mamiş, 2015; IRENA, 2015, 2016; Climate Council, 2017a		Brown, 2015; Creutzig et al., 2015; Patel et al., 2016
	Absence of distributional effects		Corfee-Morlot et al., 2012; Greene and Geisken, 2013		Corfee-Morlot et al., 2012; Toovey and Malin, 2016		Agoramoorthy et al., 2009; Ewing and Msangi, 2009; Arndt et al., 2011a; Schoneveld et al., 2011; German and Schoneveld, 2012; Creutzig et al., 2013; Hunsberger et al., 2014; Popp et al., 2014; Persson, 2015; Buck, 2016; Kline et al., 2017; Robledo-Abad et al., 2017; Stevanović et al., 2017
	Employment and productivity enhancement potential		Clean Energy Council, 2012; Climate Council, 2016; IEA, 2017; IRENA, 2017		Climate Council, 2016, 2017b; IEA, 2017d; IRENA, 2017b		Parcell and Westhoff, 2006; Gohin, 2008; Wicke et al., 2009; Arndt et al., 2011a; Rathmann et al., 2012; Silalertruksa et al., 2012; Augusto Horta Nogueira and Silva Capaz, 2013; Ribeiro, 2013
Technological	Technical scalability		Al-Maghalseh and Maharmeh, 2016; Silva Herran et al., 2016; IRENA, 2017a, b		IRENA, 2017a		Soccol et al., 2009; Fiorese et al., 2014; Vimmerstedt et al., 2015; Humpenöder et al., 2017

	Maturity		IRENA, 2017a; UNEP, 2017a		Despotou, 2012		Soccol et al., 2009; Corsatea, 2014; Fiorese et al., 2014; Creutzig et al., 2015; Strzalka et al., 2017
	Simplicity		IRENA, 2016		IRENA, 2016		Demirbas and Demirbas, 2007; Surendra et al., 2014
	Absence of risk		UNEP, 2017a		Bahill and Chaves, 2013; UNEP 2017a		Carbon neutrality debate (Buchholz et al., 2016; Liu et al., 2018)
Institutional	Political acceptability		Borch et al., 2014; Baker, 2015; Furtado and Perrot, 2015; Kar and Sharma, 2015; WEC, 2016; Bistline, 2017; UNEP, 2017a		Baker, 2015; UNEP, 2017a; Shukla et al., 2018		Longstaff et al., 2015; Favretto et al., 2017; Goetz et al., 2017 (Timilsina et al., 2012; Broch et al., 2013; Montefrio and Sonnenfeld, 2013; Stattman et al., 2013; Aha and Ayitey, 2017)
	Legal and administrative acceptability		Kar and Sharma, 2015; Bistline, 2017; Comello et al., 2017; UNEP, 2017a		Shrimali and Rohra, 2012; Comello et al., 2017; UNEP, 2017a; Shukla et al., 2018		Gamborg et al., 2014; Amos, 2016; Naiki, 2016
	Institutional capacity		Corfee-Morlot et al., 2012; Kar and Sharma, 2015; Goodale and Milman, 2016; Bistline, 2017; Comello et al., 2017; UNEP, 2017a		Corfee-Morlot et al., 2012; Shrimali and Rohra, 2012; Comello et al., 2017; UNEP, 2017a; Shukla et al., 2018	LE	Gamborg et al., 2014; Favretto et al., 2017
	Transparency and accountability potential		Eberhard et al., 2014; Furtado and Perrot, 2015; Swilling et al., 2016; Bistline, 2017; UNEP, 2017a		Eberhard et al., 2014; Swilling et al., 2016; UNEP, 2017a		Plevin et al., 2010; Schulze et al., 2012; Zanchi et al., 2012; Pyörälä et al., 2014; Buchholz et al., 2014; Repo et al., 2015; Röder et al., 2015; Creutzig et al., 2015; Hammar et al., 2015; Harris et al., 2015; Qin et al., 2016; Röder and Thornley, 2016; Torssonen et al., 2016; DeCicco et al., 2016; Baul et al., 2017; Robledo-Abad et al., 2017; Daioglou et al., 2017; Kilpeläinen et al., 2017; Booth, 2018; Sterman et al., 2018

Socio-cultural	Social co-benefits (health, education)		Silva Herran et al., 2016; Geels et al., 2017; IEA, 2017d; UNEP, 2017a, b		Geels et al., 2017; IEA, 2017d; UNEP, 2017a, b		Kar et al., 2012; Anenberg et al., 2013; Knoblauch et al., 2014; Porter et al., 2015; Weldu et al., 2017
	Public acceptance		Kondili and Kaldellis, 2012; Borch et al., 2014; Heidenreich, 2015; Geraint and Gianluca, 2016; Brennan et al., 2017; Geels et al., 2017; IEA, 2017d; Sütterlin and Siegrist, 2017; UNEP, 2017a, b		Brennan et al., 2017; Geels et al., 2017; IEA, 2017d; Sütterlin and Siegrist, 2017; UNEP, 2017a, b		Khanal et al., 2010; Delshad and Raymond, 2013; Dragojlovic and Einsiedel, 2015; Fytili and Zabaniotou, 2017; Goetz et al., 2017; Moula et al., 2017
	Social and regional inclusiveness		Geels et al., 2017; IEA 2017d; UNEP,. 2017a, b		Geels et al., 2017; IEA 2017d; UNEP, 2017a, b		Creutzig et al., 2013, 2015; Favretto et al., 2017; Robledo-Abad et al., 2017
	Intergenerational equity		Geels et al., 2017; IEA, 2017d; UNEP, 2017a, b		Geels et al., 2017; IEA 2017d; UNEP, 2017a, b	NE	
	Human capabilities		Bistline, 2017; Geels et al., 2017; IEA, 2017d; UNEP, 2017a, b		Shrimali and Rohra, 2012; Geels et al., 2017; IEA, 2017d; UNEP, 2017a, b; Shukla et al., 2018	NE	
Environmental/ecological	Reduction of air pollution		Clean Energy Council, 2012; Kondili and Kaldellis, 2012; UNEP, 2017a, b		UNEP, 2017a, b	LE	Kar et al., 2012; Anenberg et al., 2013; Knoblauch et al., 2014; Porter et al., 2015; Weldu et al., 2017
	Reduction of toxic waste		UNEP, 2017a, b		UNEP, 2017a, b	NE	
	Reduction of water use		UNEP, 2017a, b; Kondili & Kaldellis 2012		UNEP, 2017a, b		Gerbens-Leenes et al., 2009; Gheewala et al., 2011; Smith and Torn, 2013; Bonsch et al., 2016; Lampert et al., 2016; Mouratiadou et al., 2016; Smith et al., 2016; Wei et al., 2016; Mathioudakis et al., 2017
	Improved biodiversity		UNEP, 2017a, b		UNEP, 2017a, b		Immerzeel et al., 2014; Dale et al., 2015; Holland et al., 2015; Kline et al., 2015; Santangeli et al., 2016; Tarr et al., 2017

Geophysical	Physical feasibility (physical potentials)		Al-Maghalseh & Maharmeh, 2016; UNEP, 2017a, b		UNEP, 2017a, b		Beringer et al., 2011; Klein et al., 2014; Slade et al., 2014; Creutzig et al., 2015; Kraxner and Nordström, 2015; Searle and Malins, 2015; Smith et al., 2016; Boysen et al., 2017b; Tokimatsu et al., 2017; Heck et al., 2018
	Limited use of land		Silva Herran et al., 2016; Mohan, 2017; UNEP, 2017a, b		Mohan, 2017; UNEP, 2017a, b		Popp et al., 2014; Creutzig et al., 2015; Bonsch et al., 2016; Hammond and Li, 2016; Williamson, 2016; Robledo-Abad et al., 2017
	Limited use of scarce (geo)physical resources		UNEP, 2017a, b		UNEP, 2017a, b	NA	
	Global spread		UNEP, 2017a, b		UNEP, 2017a, b		Deng et al., 2015; Daioglou et al., 2017; Robledo-Abad et al., 2017

Table 4.SM.8: Feasibility assessment of energy system transition mitigation options: electricity storage, power sector carbon capture and storage (CCS) and nuclear energy. For methodology, see 4.SM.4.1.

		Electricity Storage		**Power Sector CCS**		**Nuclear Energy**	
	Evidence	Robust		Robust		Robust	
	Agreement	Medium		High		High	
Economic	Cost-effectiveness		ACOLA, 2017; IRENA, 2015; Schmidt et al., 2017; Quann, 2017		Studies indicate that CCS in the power sector is somewhere in the middle range of mitigation options. It is a significant additional cost but the scale is usually large, so much carbon dioxide is reduced (Rubin et al., 2015; Global CCS Institute, 2017; IEA, 2017a; Castrejón et al., 2018)		Finon and Roques, 2013; Bruckner et al., 2014; Lovering et al., 2016; Koomey et al., 2017
	Absence of distributional effects		Corfee-Morlot et al., 2012; ACOLA, 2017	NE		NE	
	Employment and productivity enhancement potential		ACOLA, 2017; Climate Council, 2017a; IEA, 2017d; IRENA, 2017b		Higher than coal/gas without CCS, on par with wind, geothermal and nuclear (Wei et al., 2010; Koelbl et al., 2016; IEA, 2017a)		Kenley et al., 2009; Wei et al., 2010
Technological	Technical scalability		ACOLA, 2017; IRENA, 2017a		IPCC, 2005; de Coninck and Benson, 2014; Aminu et al., 2017		Bruckner et al., 2014; IAEA, 2018 (for current-generation plants)
	Maturity		ACOLA, 2017; IRENA, 2017a		Zheng and Xu, 2014; Abanades et al., 2015; Bui et al., 2018; Qiu and Yang, 2018		Bruckner et al., 2014
	Simplicity		IRENA, 2016; ACOLA, 2017	LE	Wei et al., 2010; IEA GHG, 2012		Esteban and Portugal-Pereira, 2014
	Absence of risk		ACOLA, 2017; UNEP, 2017a		IPCC, 2005; Boot-Handford et al., 2014; de Coninck and Benson, 2014; Aminu et al., 2017		Hirschberg et al., 2016; Rose and Sweeting, 2016; Wheatley et al., 2016

Institutional	Political acceptability		ACOLA, 2017; Nguyen et al., 2017; UNEP, 2017a		de Coninck and Benson, 2014; Boot-Handford et al., 2014; Aminu et al., 2017		Bruckner et al., 2014; IAEA, 2017
	Legal and administrative acceptability		ACOLA, 2017; Nguyen et al., 2017; UNEP, 2017a		Boot-Handford et al., 2014; de Coninck and Benson, 2014; Dixon et al., 2015	NE	
	Institutional capacity		Corfee-Morlot et al., 2012; ACOLA, 2017; IEA, 2017a; Nguyen et al., 2017; UNEP, 2017a	LE	Ashworth et al., 2015		Tosa, 2015; Vivoda and Graetz, 2015; Figueroa, 2016; Juraku, 2016; Taebi and Mayer, 2017;
	Transparency and accountability potential		ACOLA, 2017; Nguyen et al., 2017; UNEP, 2017a	NE			Figueroa, 2016
Socio-cultural	Social co-benefits (health, education)		ACOLA, 2017; Geels et al., 2017; IEA, 2017c; UNEP, 2017a, b	NE			WHO, 2011; Endo et al., 2012; Nagataki et al., 2013; Bruckner et al., 2014; Ishikawa, 2014; Nakayachi et al., 2015; Beresford et al., 2016; Fridman et al., 2016; Hirschberg et al., 2016; Oe et al., 2016; Suzuki et al., 2016; Kawaguchi and Yukutake, 2017
	Public acceptance		ACOLA, 2017; Climate Council, 2017a; Geels et al., 2017; IEA, 2017c; UNEP, 2017a, b		Seigo et al., 2014; Ashworth et al., 2015; Aminu et al., 2017		Bruckner et al., 2014; Kim et al., 2014; Diaz-Maurin and Kovacic, 2015; Murakami et al., 2015; Nishikawa et al., 2016; Tsujikawa et al., 2016; Huhtala and Remes, 2017; IAEA, 2017; Wu, 2017; Ho et al., 2018
	Social and regional inclusiveness		ACOLA, 2017; Geels et al., 2017; IEA, 2017d; UNEP, 2017a, b	NA		NE	
	Intergenerational equity		ACOLA, 2017; Geels et al., 2017; IEA, 2017c; UNEP, 2017a, b		Alcalde et al., 2018		Bruckner et al., 2014
	Human capabilities		ACOLA, 2017; Geels et al., 2017; IEA, 2017d; Newman et al., 2017; UNEP, 2017a, b		Shackley et al., 2009; IEA GHG, 2012	NE	
Environmental/ec	Reduction of air pollution		ACOLA, 2017; UNEP, 2017a, b		Koornneef et al., 2008; Odeh and Cockerill, 2008; Pehnt and Henkel,		Cheng and Hammond, 2017

					2009; Korre et al., 2010; Nie et al., 2011; Modahl et al., 2012; Corsten et al., 2013; Cuéllar-Franca and Azapagic, 2015; Gibon et al., 2017		
	Reduction of toxic waste		ACOLA, 2017; UNEP, 2017a, b		Koornneef et al., 2008; Odeh and Cockerill, 2008; Pehnt and Henkel, 2009; Korre et al., 2010; Nie et al., 2011; Modahl et al., 2012; Corsten et al., 2013; Cuéllar-Franca and Azapagic, 2015; Gibon et al., 2017		Bruckner et al., 2014
	Reduction of water use		ACOLA, 2017; UNEP, 2017a, b		Koornneef et al., 2008, 2012a; Odeh and Cockerill, 2008; Pehnt and Henkel, 2009; Korre et al., 2010; Nie et al., 2011; Modahl et al., 2012; Corsten et al., 2013; Cooney et al., 2015; Cuéllar-Franca and Azapagic, 2015; Gibon et al., 2017		Bailly du Bois et al., 2012; Kato et al., 2012; Sakaguchi et al., 2012; Tsumune et al., 2012; Ueda et al., 2013; Bruckner et al., 2014
	Improved biodiversity	NA			Koornneef et al., 2008, 2012a; Odeh and Cockerill, 2008; Pehnt and Henkel, 2009; Korre et al., 2010; Nie et al., 2011; Modahl et al., 2012; Corsten et al., 2013; Cuéllar-Franca and Azapagic, 2015; Gibon et al., 2017		Cheng and Hammond, 2017
Geophysical	Physical feasibility (physical potentials)		ACOLA, 2017; UNEP, 2017a, b		IPCC, 2005; de Coninck and Benson, 2014; Scott et al., 2015		Bruckner et al., 2014
	Limited use of land		ACOLA, 2017; UNEP, 2017a, b		Non-controversial so not investigated		Cheng and Hammond, 2017
	Limited use of scarce (geo)physical resources		ACOLA, 2017; Newman et al., 2017; UNEP, 2017a, b		IPCC, 2005; de Coninck and Benson, 2014; Scott et al., 2015 On storage capacity, otherwise no issues		Bruckner et al., 2014; NEA, 2016
	Global spread		ACOLA, 2017; UNEP, 2017a, b		IPCC, 2005; de Coninck and Benson, 2014		IAEA, 2017

4.SM.4.2.2 Feasibility Assessment of Mitigation Options in Land and Ecosystem Transitions

Table 4.SM.9: Feasibility assessment of the land and ecosystem transition mitigation options: reduced food wastage and efficient food production, dietary shifts, sustainable intensification of agriculture and ecosystems restoration. For methodology, see 4.SM.4.1.

		Reduced Food Wastage and Efficient Food Production		**Dietary Shifts**		**Sustainable Intensification of Agriculture**		**Ecosystems Restoration**	
	Evidence	Robust		Medium		Medium		Medium	
	Agreement	High		High		High		High	
Economic	Cost-effectiveness		FAO, 2013a; Thyberg and Tonjes, 2016; Hebrok and Boks, 2017	LE	FAO, 2013b	LE	Havlik et al., 2014		Kindermann et al., 2008; Dang Phan et al., 2014; Overmars et al., 2014; Griscom et al., 2017; Ickowitz et al., 2017; Phan et al., 2017; Rakatama et al., 2017
	Absence of distributional effects		Porpino et al., 2015; Thyberg and Tonjes, 2016; Alexander et al., 2017; Hebrok and Boks, 2017	LE	Żukiewicz-Sobczak et al., 2014	LE	A. Smith et al., 2017		Caplow et al., 2011; German and Schoneveld, 2012; Atela et al., 2014; Sunderlin et al., 2014; Howson and Kindon, 2015; Erb et al., 2016; Poudyal et al., 2016
	Employment and productivity enhancement potential		Shepon et al., 2016; Thyberg and Tonjes, 2016; Alexander et al., 2017; Popp et al., 2017		Haggblade et al., 2015; Tschirley et al., 2015; Berti and Mulligan, 2016; Blay-Palmer et al., 2016; Shepon et al., 2016; Alexander et al., 2017; Clark and Tilman, 2017		Foley et al., 2011; Harvey et al., 2014; Clark and Tilman, 2017; Griscom et al., 2017		Brander et al., 2013; Neimark et al., 2016; Fenger et al., 2017; Jena et al., 2017, but are not uncontested (Blackman and Rivera, 2011; Hidayat et al., 2015; Oya et al., 2017)
Technological	Technical scalability		Högy et al., 2009; DaMatta et al., 2010; Lin et al., 2013; Challinor et al., 2014; Papargyropoulou et al.,		Hallström et al., 2015; Alexander et al., 2017; Clark and Tilman, 2017		Harvey et al., 2014; Pretty and Bharucha, 2014; Petersen and Snapp, 2015; Clark and Tilman, 2017; Griscom		P. Smith et al., 2014, Table 11.22; Houghton et al., 2015; Griscom et al., 2017; Houghton and Nassikas, 2018

			2014; De Souza et al., 2015; Hebrok and Boks, 2017				et al., 2017; Waldron et al., 2017; P. Adhikari et al., 2018; Ramankutty et al., 2018		
	Maturity	NE		NE		LE	Pretty and Bharucha, 2014; Petersen and Snapp, 2015		McLaren, 2012; P. Smith et al., 2012; Goetz et al., 2015
	Simplicity	NE		NE		NE			(P. Smith et al., 2014; Erb et al., 2017; Griscom et al., 2017)
	Absence of risk		Lin et al., 2013; Papargyropoulou et al., 2014; Hebrok and Boks, 2017		Hallström et al., 2015; Alexander et al., 2017; Clark and Tilman, 2017; Röös et al., 2017		Harvey et al., 2014; Clark and Tilman, 2017; Griscom et al., 2017; Waldron et al., 2017; P. Adhikari et al., 2018; Ramankutty et al., 2018; Sparovek et al., 2018		P. Smith et al., 2014 Table 11.9 *No major breakthroughs since AR5
Institutional	Political acceptability		Refsgaard and Magnussen, 2009; Lin et al., 2013; Thornton and Herrero, 2014; L. Jones et al., 2016; Thyberg and Tonjes, 2016; Singh et al., 2017; C.J. White et al., 2017	NE			Smith and Gregory, 2013; Godfray and Garnett, 2014; Harvey et al., 2014; Sparovek et al., 2018		Cronin et al., 2016; Di Gregorio et al., 2017; Nantongo, 2017
	Legal and administrative acceptability	NE		NE			Smith and Gregory, 2013; Harvey et al., 2014		Sunderlin et al., 2014
	Institutional capacity		Refsgaard and Magnussen, 2009; Thornton and Herrero, 2014; Briley et al., 2015; L. Jones et al., 2016; Thyberg and Tonjes, 2016; Singh et al., 2017; C.J. White et al., 2017	NE			Smith and Gregory, 2013; Harvey et al., 2014; Lu et al., 2015; Petersen and Snapp, 2015; Mungai et al., 2016; P. Adhikari et al., 2018; Sparovek et al., 2018		Unruh, 2011; Marion Suiseeya and Caplow, 2013; Wylie et al., 2016

	Transparency and accountability potential		Briley et al., 2015; L. Jones et al., 2016; Thyberg and Tonjes, 2016; Singh et al., 2017; C.J. White et al., 2017	NE		NE			Strassburg et al., 2014; Neimark et al., 2016
Socio-cultural	Social co-benefits (health, education)		Lin et al., 2013; Tilman and Clark, 2014; Wellesley et al., 2015; Thyberg and Tonjes, 2016; Hebrok and Boks, 2017; Popp et al., 2017		Alexander et al., 2016, 2017; Stoll-Kleemann and Schmidt, 2017; Ritchie et al., 2018		Pretty et al., 2011; Jones et al., 2012; Smith and Gregory, 2013; Harvey et al., 2014; Falconnier et al., 2018; Ramankutty et al., 2018; Sparovek et al., 2018		Caplow et al., 2011; Spencer et al., 2017
	Public acceptance		Lin et al., 2013; Popp et al., 2017		Alexander et al., 2016, 2017; Stoll-Kleemann and Schmidt, 2017		Smith and Gregory, 2013; Godfray and Garnett, 2014; Harvey et al., 2014; P. Adhikari et al., 2018; Ramankutty et al., 2018; Sparovek et al., 2018		Lin et al., 2012; Kragt et al., 2016; Scholte et al., 2016; Thompson et al., 2016; Braun et al., 2017
	Social and regional inclusiveness		Lin et al., 2013; Tilman and Clark, 2014; Hebrok and Boks, 2017; Popp et al., 2017		Khoury et al., 2014; Tilman and Clark, 2014; Alexander et al., 2016, 2017; Stoll-Kleemann and Schmidt, 2017; Ritchie et al., 2018		Pretty et al., 2011; Smith and Gregory, 2013; Franke et al., 2014; Harvey et al., 2014; Pretty and Bharucha, 2014; Petersen and Snapp, 2015; Struik and Kuyper, 2017; Ramankutty et al., 2018; Sparovek et al., 2018		Ribot and Larson, 2012; Jagger et al., 2014; Lyons and Westoby, 2014; Brimont et al., 2015; Howson and Kindon, 2015
	Intergenerational equity	NE		LE	Bajželj et al., 2014	NE			Pascuala et al., 2010; Unruh, 2011 *No major breakthroughs since AR5
	Human capabilities		Tilman and Clark, 2014; Thyberg and Tonjes, 2016; Hebrok and Boks, 2017		Tilman and Clark, 2014; Ritchie et al., 2018	LE	Baltenweck et al., 2003; Pretty and Bharucha, 2014; Mungai et al., 2016	LE	P. Smith et al., 2014 Table 11.5 *No major breakthroughs since AR5

Environmental/ ecological	Reduction of air pollution	LE	Thyberg and Tonjes, 2016		Tilman and Clark, 2014; Hallström et al., 2015; Ritchie et al., 2018	NE		NE	
	Reduction of toxic waste	NE		NE			Stevens and Quinton, 2009; Tilman et al., 2011a; Pretty and Bharucha, 2014; Soussana and Lemaire, 2014; Lu et al., 2015; Ramankutty et al., 2018	NE	
	Reduction of water use		Bajželj et al., 2014; West et al., 2014; Westhoek et al., 2014; Thyberg and Tonjes, 2016		Bajželj et al., 2014; West et al., 2014; Westhoek et al., 2014	LE	Pretty and Bharucha, 2014		Brander et al., 2013; Devaraju et al., 2015; van Noordwijk et al., 2016; Ellison et al., 2017
	Improved biodiversity		J.A. Johnson et al., 2014; Ramankutty et al., 2018		Tilman and Clark, 2014; Hallström et al., 2015; Clark and Tilman, 2017; Ramankutty et al., 2018		Pretty and Bharucha, 2014; Waldron et al., 2017		Rey Benayas et al., 2009; Bullock et al., 2011; Jantz et al., 2014; Veldman et al., 2015; Jantke et al., 2016; Kaiser-Bunbury et al., 2017
Geophysical	Physical feasibility (physical potentials)		Cherubin et al., 2015; Ivy et al., 2017	NE		NE			Canadell and Schulze, 2014; Houghton et al., 2015; Erb et al., 2016, 2017; Griscom et al., 2017; Houghton and Nassikas, 2018 REDD+ (Canadell and Raupach, 2008; Strassburg et al., 2014)
	Limited use of land		Thyberg and Tonjes, 2016; Ramankutty et al., 2018; Sparovek et al., 2018	LE	Shepon et al., 2016; Benton et al., 2018; Ramankutty et al., 2018		Harvey et al., 2014; Clark and Tilman, 2017		Strassburg et al., 2014; Humpenöder et al., 2015; Erb et al., 2016; Kreidenweis et al., 2016
	Limited use of scarce (geo)physical resources	NE		NE			Foley et al., 2011	NE	
	Global spread	LE	Thyberg and Tonjes, 2016	NE		LE	Tilman et al., 2011b; Havlik et al., 2014;		(Strassburg et al., 2014; Erb et al., 2017)

							Petersen and Snapp, 2015; Mungai et al., 2016		

4.SM.4.2.3 Feasibility Assessment of Mitigation Options in Urban and Infrastructure System Transitions

Table 4.SM.10: Feasibility assessment of urban and infrastructure system transition mitigation options: land use and urban planning; electric cars and buses; and sharing schemes. For methodology, see 4.SM.4.1.

		Land Use and Urban Planning		**Electric Cars and Buses**		**Sharing Schemes**	
	Evidence	Robust		Medium		Limited	
	Agreement	Medium		High		Medium	
Economic	Cost-effectiveness		Trubka et al., 2010; Nahlika and Chester, 2014; Ahlfeldt and Pietrostefani, 2017; Lee and Erickson, 2017; Sharma, 2018		Peterson and Michalek, 2013; IEA, 2017b		Ambrosino et al., 2016; Cheyne and Imran, 2016; Kent and Dowling, 2016
	Absence of distributional effects		Colenbrander et al., 2015; Lwasa, 2017; Broekhoff et al., 2018; Teferi and Newman, 2018; Wiktorowicz et al., 2018		Glazebrook and Newman, 2018; Sivak and Schoettle, 2018		Gomez et al., 2015; Ambrosino et al., 2016; Kent and Dowling, 2016
	Employment and productivity enhancement potential		Ambrosino et al., 2016; Ahlfeldt and Pietrostefani, 2017; Broto, 2017; Gao and Newman, 2018; Han et al., 2018		Whitelegg, 2016; IEA, 2017b		Sweet, 2014; Cheyne and Imran, 2016
Technological	Technical scalability		Broekhoff et al., 2018; Sharma, 2018; R. Zhang et al., 2018		Brown et al., 2010; IEA, 2017b		Broch et al., 2013; Ambrosino et al., 2016; Kent and Dowling, 2016; Reis et al., 2016
	Maturity		Parnell, 2015; Newman et al., 2017		Whitelegg, 2016; IEA, 2017b		Le Vine et al., 2014; Kent and Dowling, 2016
	Simplicity		Lilford et al., 2017; Newman et al., 2017		IEA, 2017b; Glazebrook and Newman, 2018		Ambrosino et al., 2016; Giuliano and Hanson, 2017
	Absence of risk	LE	Newman et al., 2017		Whitelegg, 2016; IEA, 2017b		Ambrosino et al., 2016; Kent and Dowling, 2016
Institutional	Political acceptability		Broekhoff et al., 2018; Grandin et al., 2018		Bakker and Trip, 2013; IEA, 2017b		Le Vine et al., 2014; Ambrosino et al., 2016
	Legal and administrative acceptability		Broekhoff et al., 2018; Grandin et al., 2018		Wirasingha et al., 2008; IEA, 2017b		Cannon and Summers, 2014; Le Vine et al., 2014

	Institutional capacity		Geneletti et al., 2017; Chau et al., 2018		Wirasingha et al., 2008; IEA, 2017b		Kent and Dowling, 2016; Glazebrook and Newman, 2018
	Transparency and accountability potential		Moglia et al., 2018		Wirasingha et al., 2008; IEA, 2017b		Newman et al., 2017; Glazebrook and Newman, 2018
Socio-cultural	Social co-benefits (health, education)		Nahlika and Chester, 2014; Jillella et al., 2015; Chava and Newman, 2016; Su et al., 2016; Chava et al., 2018a, b		IEA, 2017b; Newman et al., 2017		de Groot and Steg, 2007; Rojas-Rueda et al., 2012; Cheyne and Imran, 2016; Kent and Dowling, 2016
	Public acceptance		Jillella et al., 2015; Chava and Newman, 2016; Chava et al., 2018a, b; Moglia et al., 2018		Zhang et al., 2011; Bockarjova and Steg, 2014; Liao et al., 2017		de Groot and Steg, 2007; Le Vine et al., 2014; Ambrosino et al., 2016; Kent and Dowling, 2016; Reis et al., 2016
	Social and regional inclusiveness		Jillella et al., 2015; Chava and Newman, 2016; Colenbrander et al., 2017; Endo et al., 2017; Lwasa, 2017; Broekhoff et al., 2018; Chava et al., 2018a, b; Teferi and Newman, 2018	LE	Newman et al., 2017		Cheyne and Imran, 2016; Kent and Dowling, 2016
	Intergenerational equity	LE	Newman et al., 2017		Newman et al., 2017; Kenworthy and Schiller, 2018		Le Vine et al., 2014; Cheyne and Imran, 2016; Glazebrook and Newman, 2018
	Human capabilities		Moglia et al., 2018		Wirasingha et al., 2008; Newman et al., 2017		Reis et al., 2016; Newman et al., 2017
Environmental/ecological	Reduction of air pollution		Zubelzu et al., 2015; Glazebrook and Newman, 2018; Sharma, 2018; Thomson and Newman, 2018; R. Zang et al., 2018		Sioshansi and Denholm, 2009; Kenworthy and Schiller, 2018		Le Vine et al., 2014; Newman and Kenworthy, 2015; Nijland and van Meerkerk, 2017; Glazebrook and Newman, 2018
	Reduction of toxic waste	LE	Thomson and Newman, 2018	LE	Hawkins et al., 2013		Newman and Kenworthy, 2015; Newman et al., 2017; Glazebrook and Newman, 2018
	Reduction of water use		Serrao-Neumann et al., 2017	LE	Glazebrook and Newman, 2018		Stephan and Crawford, 2016; Newman et al., 2017
	Improved biodiversity		Huang et al., 2018	LE	Glazebrook and Newman, 2018		Newman and Kenworthy, 2015; Newman et al., 2017; Glazebrook and Newman, 2018

Geophysical	Physical feasibility (physical potentials)		Hsieh et al., 2017; Wiktorowicz et al., 2018		Glazebrook and Newman, 2018; Kenworthy and Schiller, 2018		Kent and Dowling, 2016; Newman et al., 2017
	Limited use of land		Hsieh et al., 2017		Glazebrook and Newman, 2018; Kenworthy and Schiller, 2018		Kent and Dowling, 2016; Newman et al., 2017; Hamilton and Wichman, 2018
	Limited use of scarce (geo)physical resources	LE	Thomson and Newman, 2018		Newman et al., 2017; Kenworthy and Schiller, 2018		Newman and Kenworthy, 2015; Newman et al., 2017; Glazebrook and Newman, 2018
	Global spread		Pacheco-Torres et al., 2017; Glazebrook and Newman, 2018		Dhar et al., 2017, 2018; Newman et al., 2017		Le Vine et al., 2014; Kent and Dowling, 2016

Table 4.SM.11: Feasibility assessment of urban and infrastructure system transition mitigation options: public transport, non-motorised transport, and aviation and shipping. For methodology, see 4.SM.4.1.

		Public Transport		**Non-motorised Transport**		**Aviation and Shipping**	
	Evidence	Robust		Robust		Medium	
	Agreement	Medium		High		Medium	
Economic	Cost-effectiveness		Nahlika and Chester, 2014; Bouf and Faivre D'arcier, 2015; Lee and Erickson, 2017; Lin and Du, 2017; Glazebrook and Newman, 2018; Kenworthy and Schiller, 2018		Deenihan and Caulfield, 2014; Gössling and Choi, 2015; MacDonald Gibson et al., 2015; V. Brown et al., 2016; Matan and Newman, 2016; Rajé and Saffrey, 2016; Litman, 2017, 2018		Corbett et al., 2009; Dessens et al., 2014; Cames et al., 2015a, b
	Absence of distributional effects		Kenworthy and Schiller, 2018; Linovski et al., 2018; Yangka and Newman, 2018		Newman and Kenworthy, 2015; Matan and Newman, 2016; Jensen et al., 2017; Lohmann and Gasparini, 2017; Litman, 2018	LE	Cames et al., 2015a
	Employment and productivity enhancement potential		Hazledine et al., 2017; Gao and Newman, 2018; Kenworthy and Schiller, 2018		Matan and Newman, 2016; Litman, 2017, 2018; Rohani and Lawrence, 2017		Cames et al., 2015a; Gencsü and Hino, 2015
Technological	Technical scalability		Kenworthy and Schiller, 2018; Yangka and Newman, 2018; R. Zhang et al., 2018		Newman and Kenworthy, 2015; Matan and Newman, 2016; Reis et al., 2016; Stevenson et al., 2016		Dessens et al., 2014; Gencsü and Hino, 2015
	Maturity		Newman et al., 2017; Kenworthy and Schiller, 2018		Newman et al., 2015, 2017; Matan and Newman, 2016; Stevenson et al., 2016; Jensen et al., 2017		Corbett et al., 2009; Cames et al., 2015b
	Simplicity		Newman et al., 2017; Kenworthy and Schiller, 2018		Matan and Newman, 2016; Rajé and Saffrey, 2016; Stevenson et al., 2016; Litman, 2017, 2018	LE	Dessens et al., 2014
	Absence of risk		Mohamed et al., 2017; Kenworthy and Schiller, 2018		Matan and Newman, 2016; Stevenson et al., 2016; Lohmann and Gasparini, 2017	LE	Dessens et al., 2014

Institutional	Political acceptability		Mohamed et al., 2017; Wijaya et al., 2017; Gao and Newman, 2018; Glazebrook and Newman, 2018; Kenworthy and Schiller, 2018; Sharma, 2018; Yangka and Newman, 2018		Newman and Kenworthy, 2015; Giles-Corti et al., 2016; Matan and Newman, 2016; Jensen et al., 2017; Litman, 2017, 2018; McCosker et al., 2018		Smale et al., 2012; Bows-Larkin, 2015; Sikorska, 2015; Shi, 2016; Zhang, 2016
	Legal and administrative acceptability		Kenworthy and Schiller, 2018; Yangka and Newman, 2018		Lohmann and Gasparini, 2017; Litman, 2018		Smale et al., 2012; Bows-Larkin, 2015; Sikorska, 2015; Shi, 2016; Zhang, 2016
	Institutional capacity		Newman et al., 2017; Kenworthy and Schiller, 2018; Sharma, 2018		Reis et al., 2016; Litman, 2018		Smale et al., 2012; Bows-Larkin, 2015; Sikorska, 2015; Shi, 2016; Zhang, 2016
	Transparency and accountability potential	LE	Bouf and Faivre D'arcier, 2015; Kenworthy and Schiller, 2018		Newman and Kenworthy, 2015; Matan and Newman, 2016; Lah, 2017		Smale et al., 2012; Bows-Larkin, 2015; Sikorska, 2015; Shi, 2016; Zhang, 2016
Socio-cultural	Social co-benefits (health, education)		Steg, 2003; Gatersleben and Uzzell, 2007; Nahlika and Chester, 2014; Lin and Du, 2017; Yangka and Newman, 2018		Woodcock et al., 2009; Maibach et al., 2009; Deenihan and Caulfield, 2014; Mansfield and Gibson, 2015; Matan et al., 2015; Gilderbloom et al., 2015; MacDonald Gibson et al., 2015; V. Brown et al., 2016; Matan and Newman, 2016; Rajé and Saffrey, 2016; Stevenson et al., 2016; Giles-Corti et al., 2016; Maizlish et al., 2017; Jensen et al., 2017; Lah, 2017; Lohmann and Gasparini, 2017; Litman, 2018	LE	EEA, 2017
	Public acceptance		Steg, 2003; Wijaya et al., 2017		Gatersleben and Uzzell, 2007; Matan and Newman, 2016; Jensen et al., 2017; Lohmann and Gasparini, 2017; Newman et al., 2017		Bows-Larkin, 2015; Sikorska, 2015; EEA, 2017

	Social and regional inclusiveness		Nahlika and Chester, 2014; Yangka and Newman, 2018		Gilderbloom et al., 2015; Stevenson et al., 2016; Jensen et al., 2017	LE	EEA, 2017
	Intergenerational equity		Newman et al., 2017; Kenworthy and Schiller, 2018; Yangka and Newman, 2018		Rajé and Saffrey, 2016; Litman, 2018	LE	Gencsü and Hino, 2015
	Human capabilities		Newman et al., 2017; Kenworthy and Schiller, 2018		Reis et al., 2016; Newman et al., 2017		Bows-Larkin, 2015; Sikorska, 2015; EEA, 2017b
Environmental/ecological	Reduction of air pollution		Glazebrook and Newman, 2018; Kenworthy and Schiller, 2018; Yangka and Newman, 2018; R. Zhang et al., 2018		Woodcock et al., 2009; Stevenson et al., 2016; Maizlish et al., 2017		Dessens et al., 2014; Cames et al., 2015a; Bouman et al., 2017; EEA, 2017
	Reduction of toxic waste	LE	Newman et al., 2017	LE	Newman et al., 2017		Maragkogianni et al., 2016; EEA, 2017
	Reduction of water use	LE	Newman et al., 2017	LE	Newman et al., 2017		Maragkogianni et al., 2016; EEA, 2017
	Improved biodiversity		Newman et al., 2017; Kenworthy and Schiller, 2018	LE	Newman et al., 2017		Maragkogianni et al., 2016; EEA, 2017
Geophysical	Physical feasibility (physical potentials)		Kenworthy and Schiller, 2018; Yangka and Newman, 2018		Panter et al., 2016; Lah, 2017		Bows-Larkin, 2015; Sikorska, 2015; EEA, 2017
	Limited use of land		Ahmad et al., 2016; Kenworthy and Schiller, 2018		McCormack and Shiell, 2011; Stevenson et al., 2016; Litman, 2017; Newman et al., 2017; Ye et al., 2018	LE	EEA, 2017
	Limited use of scarce (geo)physical resources		Lin and Du, 2017; Kenworthy and Schiller, 2018		Newman et al., 2017; Ye et al., 2018		de Jong et al., 2017; EEA, 2017
	Global spread		Bouf and Faivre D'arcier, 2015; Glazebrook and Newman, 2018; Kenworthy and Schiller, 2018		Stevenson et al., 2016; Litman, 2017; Lohmann and Gasparini, 2017		Maragkogianni et al., 2016; EEA, 2017

Table 4.SM.12: Feasibility assessment of urban and infrastructure system transition mitigation options: smart grids, efficient appliances and low/zero-energy buildings. For methodology, see 4.SM.4.1.

		Smart Grids		**Efficient Appliances**		**Low/Zero-energy Buildings**	
	Evidence	Medium		Medium		Medium	
	Agreement	Medium		High		High	
Economic	Cost-effectiveness		Crispim et al., 2014; Hall and Foxon, 2014; Marques et al., 2014; Muench et al., 2014; Foxon et al., 2015; Bigerna et al., 2016; Ramos et al., 2016; Schachter and Mancarella, 2016		McNeil and Bojda, 2012; Garg et al., 2017; Gerke et al., 2017		Neroutsou and Croxford, 2016; Balaban and Puppim de Oliveira, 2017; Ballarini et al., 2017; Stocker and Koch, 2017; Carlson and Pressnail, 2018
	Absence of distributional effects		Green and Newman, 2017; Neureiter, 2017; Wiktorowicz et al., 2018		Rao, 2013; Rao et al., 2016; McInnes, 2017; Rao and Ummel, 2017		Figus et al., 2017; McInnes, 2017
	Employment and productivity enhancement potential		Naus et al., 2014; Foxon et al., 2015; Shomali and Pinkse, 2016		Ryan and Campbell, 2012; Cambridge Econometrics, 2015; Garrett-Peltier, 2017; Hartwig et al., 2017		Scott et al., 2008; Ryan and Campbell, 2012; Urge-Vorsatz et al., 2012; Mirasgedis et al., 2014; Cambridge Econometrics, 2015; Hartwig et al., 2017; Krarti and Dubey, 2018
Technological	Technical scalability		Connor et al., 2014; Crispim et al., 2014; Zheng et al., 2014; Derakhshan et al., 2016; Ramos et al., 2016		Roland and Wood, 2009; Parikh and Parikh, 2016; Rao et al., 2016; Rao and Ummel, 2017; Salleh et al., 2018		Hartwig et al., 2017; Krarti et al., 2017
	Maturity		Abi Ghanem and Mander, 2014; Crispim et al., 2014; Zheng et al., 2014; Clerici et al., 2015; Derakhshan et al., 2016; Ramos et al., 2016; Otuoze et al., 2018		Zogg et al., 2009; Diczfalusy and Taylor, 2011; Rao et al., 2016; Rao and Ummel, 2017		Diczfalusy and Taylor, 2011; González et al., 2017; Jain et al., 2017b
	Simplicity		Abi Ghanem and Mander, 2014; Crispim et al., 2014; Giannantoni, 2014; Zheng et al., 2014; Clerici et al., 2015; Derakhshan et al., 2016;		Reyna and Chester, 2017	LE	Salvalai et al., 2017

			Ramos et al., 2016; Otuoze et al., 2018				
	Absence of risk		Crispim et al., 2014; Naus et al., 2014; Clerici et al., 2015; Bigerna et al., 2016; Ramos et al., 2016; Otuoze et al., 2018	NE		NE	
Institutional	Political acceptability		Crispim et al., 2014; Hall and Foxon, 2014; Marques et al., 2014; Naus et al., 2014; Bulkeley et al., 2016; Shomali and Pinkse, 2016; Vesnic-Alujevic et al., 2016; Meadowcroft et al., 2018		Pereira and da Silva, 2017; Ringel, 2017		Pereira and da Silva, 2017; Ringel, 2017
	Legal and administrative acceptability		Crispim et al., 2014; Marques et al., 2014; Foxon et al., 2015; Bigerna et al., 2016		Pereira and da Silva, 2017		Chandel et al., 2016; Jain et al., 2017a; Pereira and da Silva, 2017
	Institutional capacity		Crispim et al., 2014; Marques et al., 2014; Muench et al., 2014; Clerici et al., 2015; Foxon et al., 2015; Ramos et al., 2016; Meadowcroft et al., 2018; Otuoze et al., 2018		Shah et al., 2015; Pereira and da Silva, 2017		Pereira and da Silva, 2017; Yu et al., 2017
	Transparency and accountability potential		Hall and Foxon, 2014; Naus et al., 2014; Bigerna et al., 2016; Hansen and Hauge, 2017; Otuoze et al., 2018	LE	Gentile et al., 2015	LE	Meyers and Kromer, 2008
Socio-cultural	Social co-benefits (health, education)		Naus et al., 2014; Foxon et al., 2015; Shomali and Pinkse, 2016; Hansen and Hauge, 2017; Meadowcroft et al., 2018; Otuoze et al., 2018		Ryan and Campbell, 2012; Payne et al., 2015		Ryan and Campbell, 2012; Payne et al., 2015; Xiong et al., 2015; Balaban and Puppim de Oliveira, 2017
	Public acceptance		Hall and Foxon, 2014; Naus et al., 2014; Bigerna et al., 2016; Green and Newman, 2017; Hansen and Hauge, 2017		Winward et al., 1998; Boardman, 2004; Swim et al., 2014; Reyna and Chester, 2017; Jain et al., 2018	NE	
	Social and regional inclusiveness		Green and Newman, 2017; Neureiter, 2017; Wiktorowicz et al., 2018		Rao et al., 2016; Rao and Pachauri, 2017; Rao and Ummel, 2017	NE	
	Intergenerational equity		Schlör et al., 2015; Green and Newman, 2017	NA	Energy efficiency saves natural resources and therefore it is fair for future generations	NA	Energy efficiency saves natural resources and therefore it is fair for future generations

	Human capabilities		Naus et al., 2014; Hansen and Hauge, 2017	NA		NE	
Environmental/ecological	Reduction of air pollution		Clerici et al., 2015; Newman et al., 2017		Ryan and Campbell, 2012; Zhou et al., 2018		Ryan and Campbell, 2012; Xiong et al., 2015; Balaban and Puppim de Oliveira, 2017; Zhou et al., 2018
	Reduction of toxic waste		Foxon et al., 2015; Newman et al., 2017		Ryan and Campbell, 2012		Ryan and Campbell, 2012
	Reduction of water use		Newman et al., 2017; Wiktorowicz et al., 2018		Zhou et al., 2018		Loiola et al., 2018
	Improved biodiversity		Newman et al., 2017; Wiktorowicz et al., 2018	NA		NA	
Geophysical	Physical feasibility physical potentials)		Foxon et al., 2015; Green and Newman, 2017; Wiktorowicz et al., 2018		Laitner, 2013; Heidari et al., 2018		Laitner, 2013
	Limited use of land	NA		NA	Energy efficient appliances do not take up more land than inefficient appliances	NA	Existing buildings refurbishment do not use additional land New buildings use more land if not rebuilt over demolished buildings
	Limited use of scarce (geo)physical resources		Newman et al., 2017; Wiktorowicz et al., 2018	LE	Needhidasan et al., 2014 Possible that upgrades lead to landfill contamination	NA	Limited impact and limited use of scarce resources
	Global spread		Crispim et al., 2014; Foxon et al., 2015; Ramos et al., 2016	NA	Efficient appliances available everywhere where access to electricity or energy is available	NA	

4.SM.4.2.4 Feasibility Assessment of Mitigation Options in Industrial System Transitions

Table 4.SM.13: Feasibility assessment of industrial system transition mitigation options: energy efficiency; bio-based and circularity; electrification and hydrogen; and industrial carbon capture, utilization and storage (CCUS). For methodology, see 4.SM.4.1.

		Energy Efficiency		**Bio-based and Circularity**		**Electrification and Hydrogen**		**Industrial CCUS**	
	Evidence	Robust		Medium		Medium		Robust	
	Agreement	High		Medium		High		High	
Economic	Cost-effectiveness		Hasanbeigi et al., 2014; Napp et al., 2014; Forman et al., 2016; Wesseling et al., 2017		Taibi et al., 2012; Ali et al., 2017; Wesseling et al., 2017		Åhman et al., 2016; Philibert, 2017; Wesseling et al., 2017; Bataille et al., 2018		Mikunda et al., 2014; Rubin et al., 2015; Irlam, 2017
	Absence of distributional effects	LE	Zha and Ding, 2015	NE		LE	Nabernegg et al., 2017	NE	
	Employment and productivity enhancement potential		He et al., 2013; Zhang et al., 2015; Henriques and Catarino, 2016; Färe et al., 2018		Fuentes-Saguar et al., 2017; Nabernegg et al., 2017	LE	Nabernegg et al., 2017		Koelbl et al., 2016
Technological	Technical scalability		Fischedick et al., 2014; Bataille et al., 2018		de Besi and McCormick, 2015; Wesseling et al., 2017		Fischedick et al., 2014; J. Wang et al., 2017; Bataille et al., 2018		Boot-Handford et al., 2014; Global CCS Institute, 2017; Bui et al., 2018
	Maturity		Hasanbeigi et al., 2014; Napp et al., 2014; Forman et al., 2016; Wesseling et al., 2017		Quader et al., 2016; Wesseling et al., 2017		Quader et al., 2016; Philibert, 2017		Boot-Handford et al., 2014; Mikunda et al., 2014; Abanades et al., 2015; Global CCS Institute, 2017; Bui et al., 2018
	Simplicity		Fernández-Viñé et al., 2010; Wakabayashi, 2013		Henry et al., 2006; Wesseling et al., 2017	NE			IEA GHG, 2012
	Absence of risk	NA		LE	Ali et al., 2017	NE			IPCC, 2005; Boot-Handford et al., 2014; de Coninck and Benson, 2014; Aminu et al., 2017

Institutional	Political acceptability		Zhang et al., 2015; Åhman et al., 2016; Henriques and Catarino, 2016	LE	Longstaff et al., 2015; Sleenhoff and Osseweijer, 2016; Goetz et al., 2017		Åhman et al., 2016; Philibert, 2017; Wesseling et al., 2017; Bataille et al., 2018		Mikunda et al., 2014; Aminu et al., 2017
	Legal and administrative acceptability		Zhang et al., 2015; Åhman et al., 2016; Henriques and Catarino, 2016		Wesseling et al., 2017	NE			de Coninck and Benson, 2014; Dixon et al., 2015; Bui et al., 2018
	Institutional capacity		Fernández-Viñé et al., 2010; Wakabayashi, 2013; Henriques and Catarino, 2016		Henry et al., 2006; Lewandowski, 2016	NE			Boot-Handford et al., 2014; de Coninck and Benson, 2014; Dixon et al., 2015; Bui et al., 2018
	Transparency and accountability potential	NA		LE	Schulze et al., 2012; Harris et al., 2015; Lewandowski, 2015; Repo et al., 2015; DeCicco et al., 2016; Qin et al., 2016	NA		NE	
Socio-cultural	Social co-benefits (health, education)	NA		NE		NA		NA	
	Public acceptance		Fischedick et al., 2014		Khanal et al., 2010; Delshad and Raymond, 2013; Pfau et al., 2014; Dragojlovic and Einsiedel, 2015; Lewandowski, 2015; Sleenhoff and Osseweijer, 2016; Moula et al., 2017	LE	Åhman et al., 2016; Wesseling et al., 2017		Wallquist et al., 2012; Seigo et al., 2014; Ashworth et al., 2015; Aminu et al., 2017
	Social and regional inclusiveness	NA			Creutzig et al., 2013, 2015; Knoblauch et al., 2014; Porter et al., 2015; Robledo-Abad et al., 2017	NA		NE	
	Intergenerational equity	NA		NE		NA		NE	
	Human capabilities		Cagno et al., 2013; Brunke et al., 2014; Wesseling et al., 2017	LE	Henry et al., 2006	NE		LE	IEA GHG, 2012

Environmental/ecological	Reduction of air pollution		Brunke et al., 2014; Rasmussen, 2017; S. Zhang et al., 2018	NE		NE			IPCC, 2005; Koornneef et al., 2012a
	Reduction of toxic waste	NE		NE		NE		NE	
	Reduction of water use		Walker et al., 2013; Gu et al., 2014; Kubule et al., 2016	NE		NE			Koornneef et al., 2012a; Hylkema and Rand, 2014
	Improved biodiversity	NE		NE		NE		LE	Koornneef et al., 2012a
Geophysical	Physical feasibility (physical potentials)		Napp et al., 2014; Åhman et al., 2016; Wesseling et al., 2017		Beringer et al., 2011; Klein et al., 2014; Slade et al., 2014; Creutzig et al., 2015; Kraxner and Nordström, 2015; Searle and Malins, 2015; Smith et al., 2016; Boysen et al., 2017b; Tokimatsu et al., 2017; Heck et al., 2018		Philibert, 2017		IPCC, 2005; de Coninck and Benson, 2014; Scott et al., 2015
	Limited use of land	NA			Popp et al., 2014; Creutzig et al., 2015; Bonsch et al., 2016; Hammond and Li, 2016; Williamson, 2016; Robledo-Abad et al., 2017; Henry et al., 2018	NE		NE	
	Limited use of scarce (geo)physical resources		S. Zhang et al., 2014; Rasmussen, 2017	NE		NE		NE	
	Global spread		Worrell et al., 2008; Fischedick et al., 2014; Åhman et al., 2016; Bataille et al., 2018		Taibi et al., 2012; Fischedick et al., 2014; Wesseling et al., 2017		Taibi et al., 2012; Fischedick et al., 2014; Wesseling et al., 2017		Kuramochi et al., 2012; Mikunda et al., 2014; Bui et al., 2018

4.SM.4.2.5 Feasibility Assessment of Carbon Dioxide Removal Mitigation Options

Table 4.SM.14: Feasibility assessment of carbon dioxide removal mitigation options: bioenergy with carbon dioxide capture and storage (BECCS), and direct air carbon dioxide capture and storage (DACCS). For methodology, see 4.SM.4.1.

		BECCS		**DACCS**	
	Evidence	Robust		Medium	
	Agreement	Medium		Medium	
Economic	Cost-effectiveness		Luckow et al., 2010; De Visser et al., 2011; Fabbri et al., 2011; Koornneef et al., 2012; McLaren, 2012; Kärki et al., 2013; Fornell et al., 2013; Akgul et al., 2014; Johnson et al., 2014; Arasto et al., 2014; Al-Qayim et al., 2015; NRC, 2015; Onarheim et al., 2015; Caldecott et al., 2015; Rochedo et al., 2016; Sanchez and Callaway, 2016; Bhave et al., 2017; Fuss et al., 2018; Honegger and Reiner, 2018		Keith et al., 2006; Pielke, 2009; House et al., 2011; Ranjan and Herzog, 2011; Simon et al., 2011; Holmes and Keith, 2012; Zeman, 2014; Sanz-Pérez et al., 2016; Sinha et al., 2017
	Absence of distributional effects		Arndt et al., 2011; German and Schoneveld, 2012; Creutzig et al., 2013, 2015; Hunsberger et al., 2014; Popp et al., 2014; Persson, 2015; Buck, 2016; Searchinger et al., 2017; Stevanović et al., 2017; Kline et al., 2017; Robledo-Abad et al., 2017	NA	
	Employment and productivity enhancement potential	NE		NA	
Technological	Technical scalability		Azar et al., 2010, 2013; Gough and Upham, 2011; Nemet et al., 2018		Lackner, 2009; Pielke, 2009; Lackner et al., 2012; Nemet and Brandt, 2012; Pritchard et al., 2015; Nemet et al., 2018
	Maturity		McGlashan et al., 2012; McLaren, 2012; Boucher et al., 2014; Fuss et al., 2014; Kemper, 2015; Anderson and		McLaren, 2012; Holmes et al., 2013; Rau et al., 2013; Boot-Handford et al., 2014; NRC, 2015; Agee et al., 2016;

			Peters, 2016; Vaughan and Gough, 2016; Minx et al., 2017; Pang et al., 2017; N.E. Vaughan et al., 2018; Nemet et al., 2018; Strefler et al., 2018c		Nemet et al., 2018
	Simplicity		Möllersten et al., 2003;		Niche markets: Lackner et al., 2012; Hou et al., 2017; Ishimoto et al., 2017
	Absence of risk		IPCC, 2005; Boot-Handford et al., 2014; de Coninck and Benson, 2014; Anderson and Peters, 2016; Vaughan and Gough, 2016; Aminu et al., 2017; Boysen et al., 2017b		IPCC, 2005; Boot-Handford et al., 2014; de Coninck and Benson, 2014; Aminu et al., 2017
Institutional	Political acceptability		BECCS features rarely in policy debates (Boysen et al., 2017a; Fridahl, 2017)	NE	
	Legal and administrative acceptability	LE	Kemper, 2015; Honegger and Reiner, 2018		Boot-Handford et al., 2014; de Coninck and Benson, 2014; Dixon et al., 2015
	Institutional capacity		McLaren, 2012; Frank et al., 2013; Kemper, 2015; Burns and Nicholson, 2017	NE	McLaren, 2012
	Transparency and accountability potential	LE	McLaren, 2012; NRC, 2015; Nemet et al., 2018	LE	McGlashan et al., 2012; McLaren, 2012; Nemet et al., 2018
Socio-cultural	Social co-benefits (health, education)		Knoblauch et al., 2014; Porter et al., 2015; Weldu et al., 2017	NA	
	Public acceptance		Thornley et al., 2009; Gough and Upham, 2011; Wallquist et al., 2012; Mabon et al., 2013; Boot-Handford et al., 2014; Gough et al., 2014; Dowd et al., 2015; Lomax et al., 2015; Boysen et al., 2017b; Fridahl, 2017; Robledo-Abad et al., 2017		Lackner and Brennan, 2009; Mabon et al., 2013; Boot-Handford et al., 2014; Gough et al., 2014; Lomax et al., 2015
	Social and regional inclusiveness	LE	Creutzig et al., 2013, 2015; Robledo-Abad et al., 2017	NE	
	Intergenerational equity	NE		NE	

	Human capabilities	LE	IEA GHG, 2012	LE	IEA GHG, 2012
	Impact on landscapes	NE		NE	
Environmental/ecological	Reduction of air pollution		Knoblauch et al., 2014; Porter et al., 2015; Weldu et al., 2017	NA	
	Reduction of toxic waste	NA		NA	
	Reduction of water use		Gerbens-Leenes et al., 2009; Gheewala et al., 2011; Koornneef et al., 2012a; Smith and Torn, 2013; Hylkema and Rand, 2014; Bonsch et al., 2016; Smith et al., 2016; Wei et al., 2016; Lampert et al., 2016; Mouratiadou et al., 2016; Fajardy and Mac Dowell, 2017; Mathioudakis et al., 2017	NE	
	Improved biodiversity		Lindenmayer and Hobbs, 2004; Barlow et al., 2007; Immerzeel et al., 2014; Creutzig et al., 2015; Dale et al., 2015; Holland et al., 2015; Kline et al., 2015; Santangeli et al., 2016; Tarr et al., 2017	NA	
Geophysical	Physical feasibility (physical potentials)		Bioenergy: Beringer et al., 2011; Klein et al., 2014; Creutzig et al., 2015; Kraxner and Nordström, 2015; Searle and Malins, 2015; Smith et al., 2016; Boysen et al., 2017b; Tokimatsu et al., 2017; Heck et al., 2018) CCS: Dooley, 2013; Selosse and Ricci, 2017		McLaren, 2012; Dooley, 2013; NRC, 2015; Smith et al., 2016; Selosse and Ricci, 2017; Fuss et al., 2018
	Limited use of land		Beringer et al., 2011; Creutzig et al., 2015; NRC, 2015; Smith et al., 2016; Heck et al., 2018		Keith, 2009; Holmes and Keith, 2012; Lackner et al., 2012; NRC, 2015

	Limited use of scarce (geo)physical resources	NE		NE	
	Global spread		Bright et al., 2015; Robledo-Abad et al., 2017		Clarke et al., 2014

Table 4.SM.15: Feasibility assessment of carbon dioxide removal mitigation options: afforestation and reforestation, soil carbon sequestration and biochar, and enhanced weathering. For methodology, see 4.SM.4.1.

		Afforestation and Reforestation		**Soil Carbon Sequestration and Biochar**		**Enhanced Weathering**	
	Evidence	Robust		Robust		Medium	
	Agreement	High		High		Low	
Economic	Cost-effectiveness		Sohngen and Mendelsohn, 2003; Richards and Stokes, 2004; Richards and Stavins, 2005; Nijnik and Halder, 2013; Humpenöder et al., 2014 McLaren, 2012; Caldecott et al., 2015; NRC, 2015		McGlashan et al., 2012; McLaren, 2012; Caldecott et al., 2015; Smith et al., 2016; Fuss et al., 2018 Biochar: Roberts et al., 2010; Shackley et al., 2011; Smith, 2016 Soil carbon sequestration: Smith, 2016		Schuiling and Krijgsman, 2006; Hartmann and Kempe, 2008; Köhler et al., 2010; McLaren, 2012; Renforth, 2012; Hartmann et al., 2013; NRC, 2015; Taylor et al., 2016; Strefler et al., 2018a Ocean alkalinisation: Renforth and Henderson, 2017
	Absence of distributional effects		Lyons and Westoby, 2014; Locatelli et al., 2015		Stringer et al., 2012	NE	
	Employment and productivity enhancement potential		P. Smith et al., 2014		Lal, 2004c; Van Straaten, 2006; Pan et al., 2009; Jeffery et al., 2011	NE	
Technological	Technical scalability		Shvidenko et al., 1997; Polglase et al., 2013; Cunningham et al., 2015; Zhang and Yan, 2015; Nemet et al., 2018		Jiang et al., 2014; Novak et al., 2016; Kammann et al., 2017; Nemet et al., 2018 Biochar: Roberts et al., 2010; Shackley et al., 2011		Hangx and Spiers, 2009; Taylor et al., 2016; Nemet et al., 2018
	Maturity		McLaren, 2012; Gong et al., 2013; NRC, 2015; Zinda et al., 2017; Nemet et al., 2018		McLaren, 2012; Olson, 2013; Olson et al., 2014; Piccoli et al., 2016; Triberti et al., 2016; Vochozka et al., 2016; Nemet et al., 2018		McLaren, 2012; Hartmann et al., 2013; NRC, 2015; Nemet et al., 2018

	Simplicity	NE		NE		NE	
	Absence of risk	NE		NE		NE	
Institutional	Political acceptability	NE		NE		NE	
	Legal and administrative acceptability	NE		NE		NA	
	Institutional capacity		McLaren, 2012; Wang et al., 2016; Wehkamp et al., 2018b Meta analysis until February 2016 (Wehkamp et al., 2018a)	LE	Whitman and Lehmann, 2009; Dilling and Failey, 2013; Stavi and Lal, 2013	LE	McLaren, 2012; Moosdorf et al., 2014; Buck, 2016
	Transparency and accountability potential	LE	McLaren, 2012		Sanderman and Baldock, 2010; McLaren, 2012; Smith et al., 2012; Downie et al., 2014; Jandl et al., 2014; Nemet et al., 2018	NE	McLaren, 2012
Socio-cultural	Social co-benefits (health, education)		Genesio et al., 2016; Ravi et al., 2016	NE		NE	Schuiling and Krijgsman, 2006; Taylor et al., 2016
	Public acceptance		Private landholders: Nijnik and Halder, 2013; Schirmer and Bull, 2014; Trevisan et al., 2016		Glenk and Colombo, 2011; Lomax et al., 2015; Jørgensen and Termansen, 2016	LE	M..J. Wright et al., 2014
	Social and regional inclusiveness		Atela et al., 2014; Sunderlin et al., 2014; Brugnach et al., 2017; Ngendakumana et al., 2017; Turnhout et al., 2017	NE		NE	
	Intergenerational equity	LE	P. Smith et al., 2014	NE		NE	
	Human capabilities	NE		NE		NE	
Environmental/ecological	Reduction of air pollution	NA		NA			Schuiling and Krijgsman, 2006; Taylor et al., 2016
	Reduction of toxic waste	NA		NE		LE	Schuiling and Krijgsman, 2006; Hartmann et al., 2013

	Reduction of water use		Jackson et al., 2005; Smith and Torn, 2013; Deng et al., 2017		Lal, 2004b; Bamminger et al., 2016; Smith, 2016	LE	Kheshgi, 1995; Rau and Caldeira, 1999; Harvey, 2008; Köhler et al., 2013; NRC, 2015
	Improved biodiversity		Díaz et al., 2009; McKinley et al., 2011; Hall et al., 2012; Venter et al., 2012; Greve et al., 2013; Cunningham et al., 2015; Locatelli et al., 2015b; Paul et al., 2016	NE		NA	
Geophysical	Physical feasibility (physical potentials)		Sohngen and Mendelsohn, 2003; Canadell and Raupach, 2008; Strengers et al., 2008; Thomson et al., 2008; van Minnen et al., 2008; Houghton et al., 2015; Sonntag et al., 2016; Griscom et al., 2017		Biochar: Lehmann et al., 2006; Laird et al., 2009; Lee et al., 2010; Woolf et al., 2010; Lenton, 2010; Moore et al., 2010; Pratt and Moran, 2010; McLaren, 2012; Powell and Lenton, 2012; Lomax et al., 2015; Smith, 2016; Paustian et al., 2016 Soil carbon sequestration: Batjes, 1998; Metting et al., 2001; Lal, 2003a, b, 2004a, c, 2010, 2011, 2013; Lal et al., 2007; Smith et al., 2008; Salati et al., 2010; Conant, 2011; Smith, 2012, 2016; Benbi, 2013; Lorenz and Lal, 2014; Powlson et al., 2014; Sommer and Bossio, 2014; Henderson et al., 2015; Lassaletta and Aguilera, 2015; Minasny et al., 2017; Zomer et al., 2017		House et al., 2007; Hartmann and Kempe, 2008; Hangx and Spiers, 2009; Wilson et al., 2009; Köhler et al., 2010, 2013; Morales-Florez et al., 2011; Renforth et al., 2011; Manning and Renforth, 2013; Taylor et al., 2016; Hauck et al., 2016; Strefler et al., 2018a
	Limited use of land		Smith and Torn, 2013; Houghton et al., 2015		Smith, 2016; Fuss et al., 2018		Hartmann et al., 2013; Strefler et al., 2018b Could enhance yields reducing land competition pressure (Edwards et al., 2017; Kantola et al., 2017)

	Limited use of scarce (geo)physical resources	LE	Smith and Torn, 2013	NA		LE	NRC, 2015
	Global spread		Anderson et al., 2011; Arora and Montenegro, 2011; Wang et al., 2014		Biochar: Zimmermann et al., 2012; Sheng et al., 2016		Garcia et al., 2018; Strefler et al., 2018a

4.SM.4.3 Feasibility Assessment of Adaptation Options as Presented in Section 4.5.3

4.SM.4.3.1 Feasibility Assessment of Adaptation Options in Energy System Transitions

Table 4.SM.16: Feasibility assessment of energy system transition adaptation option: power infrastructure, including water. For methodology, see 4.SM.4.1.

		Power Infrastructure, Including Water	
	Evidence	Medium	
	Agreement	High	
Economic	Microeconomic viability		Kopytko and Perkins, 2011; Inderberg and Løchen, 2012; Brouwer et al., 2015
	Macroeconomic viability		Koch and Vögele, 2009; Kopytko and Perkins, 2011; Soito and Freitas, 2011; Inderberg and Løchen, 2012; Schaeffer et al., 2012; Jahandideh-Tehrani et al., 2014; Brouwer et al., 2015; Cortekar and Groth, 2015; Panteli and Mancarella, 2015; van Vliet et al., 2016
	Socio-economic vulnerability reduction potential		Koch and Vögele, 2009; Soito and Freitas, 2011; Cortekar and Groth, 2015; van Vliet et al., 2016
	Employment and productivity enhancement potential		Inderberg and Løchen, 2012; Cortekar and Groth, 2015; Panteli and Mancarella, 2015; van Vliet et al., 2016
Technological	Technical resource availability		Koch and Vögele, 2009; Soito and Freitas, 2011; Inderberg and Løchen, 2012; Jahandideh-Tehrani et al., 2014; Cortekar and Groth, 2015; Murrant et al., 2015; Panteli and Mancarella, 2015; Parkinson and Djilali, 2015; van Vliet et al., 2016
	Risks mitigation potential (stranded assets, unforeseen impacts)		Koch and Vögele, 2009; Inderberg and Løchen, 2012; Schaeffer et al., 2012; Jahandideh-Tehrani et al., 2014; Cortekar and Groth, 2015; Murrant et al., 2015; Panteli and Mancarella, 2015; Parkinson and Djilali, 2015; van Vliet et al., 2016
Institutional	Political acceptability		Soito and Freitas, 2011; Inderberg and Løchen, 2012; Cortekar and Groth, 2015; Murrant et al., 2015
	Legal and regulatory acceptability		Soito and Freitas, 2011; Inderberg and Løchen, 2012; Cortekar and Groth, 2015; Benson, 2018
	Institutional capacity and administrative feasibility		Eisenack and Stecker, 2012; Inderberg and Løchen, 2012; Cortekar and Groth, 2015; Murrant et al., 2015
	Transparency and accountability potential	LE	Inderberg and Løchen, 2012; Cortekar and Groth, 2015

Socio-cultural	Social co-benefits health, education)	NA	Soito and Freitas, 2011
	Socio-cultural acceptability	NE	Soito and Freitas, 2011; Inderberg and Løchen, 2012
	Social and regional inclusiveness	LE	Soito and Freitas, 2011
	Intergenerational equity	LE	Soito and Freitas, 2011
Environmental/ecolo	Ecological capacity		Koch and Vögele, 2009; Soito and Freitas, 2011; Inderberg and Løchen, 2012; Schaeffer et al., 2012; Jahandideh-Tehrani et al., 2014; Murrant et al., 2015; Parkinson and Djilali, 2015
	Adaptive capacity/resilience		Koch and Vögele, 2009; Soito and Freitas, 2011; Inderberg and Løchen, 2012; Schaeffer et al., 2012; Jahandideh-Tehrani et al., 2014; Cortekar and Groth, 2015; Murrant et al., 2015; Parkinson and Djilali, 2015; van Vliet et al., 2016
Geophysical	Physical feasibility		Koch and Vögele, 2009; Eisenack and Stecker, 2012; Schaeffer et al., 2012; Jahandideh-Tehrani et al., 2014; Brouwer et al., 2015; Cortekar and Groth, 2015; Murrant et al., 2015; Panteli and Mancarella, 2015; Parkinson and Djilali, 2015; van Vliet et al., 2016
	Land use change enhancement potential		Schaeffer et al., 2012; Jahandideh-Tehrani et al., 2014; Parkinson and Djilali, 2015
	Hazard risk reduction potential		Inderberg and Løchen, 2012; Schaeffer et al., 2012; Jahandideh-Tehrani et al., 2014; Brouwer et al., 2015; Cortekar and Groth, 2015; Murrant et al., 2015; Panteli and Mancarella, 2015; Parkinson and Djilali, 2015; van Vliet et al., 2016

4.SM.4.3.2 Feasibility Assessment of Adaptation Options in Land and Ecosystem Transitions

Table 4.SM.17: Feasibility assessment of land and ecosystem transition adaptation options: conservation agriculture, efficient irrigation, efficient livestock systems, agroforestry and community-based adaptation. For methodology, see 4.SM.4.1.

		Conservation Agriculture		**Efficient Irrigation**		**Efficient Livestock Systems**		**Agroforestry**		**Community-based Adaptation**	
	Evidence	Medium		Medium		Limited		Medium		Medium	
	Agreement	Medium		Medium		High		High		High	
Economic	Microeconomic viability		Grabowski and Kerr, 2014; Jat et al., 2014; Pittelkow et al., 2014; Thierfelder et al., 2015, 2017; H. Smith et al., 2017		Olmstead, 2014; Roco et al., 2014; Venot et al., 2014; Varela-Ortega et al., 2016; Bjornlund et al., 2017; Herwehe and Scott, 2017; Mdemu et al., 2017		Thornton and Herrero, 2014; Herrero et al., 2015; Weindl et al., 2015; Ghahramani and Bowran, 2018		Valdivia et al., 2012; K Murthy, 2013; Lasco et al., 2014; Mbow et al., 2014a, b; Brockington et al., 2016; Iiyama et al., 2017; Jacobi et al., 2017; Hernández-Morcillo et al., 2018		Mannke, 2011; Archer et al., 2014; H. Wright et al., 2014; Fernández-Giménez et al., 2015; Dodman et al., 2017a
	Macroeconomic viability		Ndah et al., 2015; Thierfelder et al., 2015; H. Smith et al., 2017		Elliott et al., 2014; Kirby et al., 2014; Olmstead, 2014; Girard et al., 2015; Kahil et al., 2015; Varela-Ortega et al., 2016; Bjornlund et al., 2017; Herwehe and Scott, 2017		Herrero et al., 2015; Weindl et al., 2015; García de Jalón et al., 2017		Valdivia et al., 2012; Lasco et al., 2014; Jacobi et al., 2017; Hernández-Morcillo et al., 2018	NE	
	Socio-economic vulnerability reduction potential		Bhan and Behera, 2014; Pittelkow et al., 2014; Stevenson et al., 2014; Prosdocimi et al., 2016; H. Smith et al., 2017		Burney and Naylor, 2012; Levidow et al., 2014; Roco et al., 2014; Venot et al., 2014; Ashofteh et al., 2017; Bjornlund et al., 2017		Herrero et al., 2015; García de Jalón et al., 2017; Thornton et al., 2018		Valdivia et al., 2012; Brockington et al., 2016; Coq-Huelva et al., 2017; Coulibaly et al., 2017; Iiyama et al., 2017; Jacobi et al., 2017; Quandt et al., 2017		Mannke, 2011; Archer et al., 2014; Reid and Huq, 2014; H. Wright et al., 2014; Fernández-Giménez et al., 2015; Ensor et al., 2016, 2018; Ford et al., 2018
	Employment and productivity		Bhan and Behera, 2014; Grabowski and Kerr, 2014; Kirkegaard et al.,		Burney and Naylor, 2012; Burney et al., 2014; Kirby et al., 2014; Levidow et al., 2014		Briske et al., 2015; García de Jalón et al., 2017	LE	Verchot et al., 2007; Buckeridge et al., 2012		Mannke, 2011; Reid and Huq, 2014; Fernández-Giménez et al., 2015

	enhancement potential		2014; Pittelkow et al., 2014; Stevenson et al., 2014								
Technological	Technical resource availability		Palm et al., 2014; Stevenson et al., 2014; Adenle et al., 2015; H. Smith et al., 2017		Venot et al., 2014; Esteve et al., 2015; Fishman et al., 2015; Azhoni et al., 2017; Mdemu et al., 2017		Descheemaeker et al., 2016; Thornton et al., 2018		Verchot et al., 2007; Valdivia et al., 2012; Mbow et al., 2014a; Iiyama et al., 2017; Jacobi et al., 2017; Hernández-Morcillo et al., 2018	LE	H. Wright et al., 2014; Fernández-Giménez et al., 2015
	Risks mitigation potential		Bhan and Behera, 2014; Palm et al., 2014; Pittelkow et al., 2014		Burney et al., 2014; Fishman et al., 2015; Jägermeyr et al., 2015; Blanc et al., 2017		Briske et al., 2015; Thornton and Herrero, 2015; Thornton et al., 2018		Verchot et al., 2007; Jacobi et al., 2017; Abdulai et al., 2018; Hernández-Morcillo et al., 2018; Sida et al., 2018	NA	
Institutional	Political acceptability		Adenle et al., 2015; Dougill et al., 2017; Westengen et al., 2018		Burney and Naylor, 2012; Esteve et al., 2015	NE			Buckeridge et al., 2012; Mbow et al., 2014b; Jacobi et al., 2017	NA	
	Legal and regulatory acceptability	NE		NA		NE			Place et al., 2012; Mbow et al., 2014a, b; Jacobi et al., 2017; Hernández-Morcillo et al., 2018	NA	
	Institutional capacity and administrative feasibility		Bhan and Behera, 2014; Harvey et al., 2014; Kassam et al., 2014; Adenle et al., 2015; Baudron et al., 2015; Ndah et al., 2015; Li et al., 2016; Dougill et al., 2017; H. Smith et al., 2017		Burney and Naylor, 2012; Burney et al., 2014; Levidow et al., 2014; Venot et al., 2014; Kahil et al., 2015; Azhoni et al., 2017; Mdemu et al., 2017		Herrero et al., 2015; Descheemaeker et al., 2016		Buckeridge et al., 2012; Place et al., 2012; Jacobi et al., 2017; Hernández-Morcillo et al., 2018		Mannke, 2011; Archer et al., 2014; Ayers et al., 2014; H. Wright et al., 2014; Reid and Huq, 2014; Sovacool et al., 2015; Fernández-Giménez et al., 2015; Scolobig et al., 2015; Ensor et al., 2016, 2018; Reid, 2016; Ford et al., 2018
	Transparency and	LE	Brouder and Gomez-Macpherson, 2014;		Levidow et al., 2014; Azhoni et al., 2017	NA		NE			Archer et al., 2014; Reid and Huq, 2014; Fernández-Giménez et

	accountability potential		Palm et al., 2014; Challinor et al., 2018								al., 2015; Sovacool et al., 2015
Socio-cultural	Social co-benefits (health, education)		Pittelkow et al., 2014; H. Smith et al., 2017; Pradhan et al., 2018	LE	Venot et al., 2014; Mdemu et al., 2017		Herrero et al., 2015; Thornton and Herrero, 2015; Thornton et al., 2018		Brockington et al., 2016; Varela-Ortega et al., 2016; Clark and Tilman, 2017; Coq-Huelva et al., 2017; Coulibaly et al., 2017; Jacobi et al., 2017; Quandt et al., 2017; Thierfelder et al., 2017; Hernández-Morcillo et al., 2018		Mannke, 2011; Archer et al., 2014; Ayers et al., 2014; Wise et al., 2014; H. Wright et al., 2014; Fernández-Giménez et al., 2015; Sovacool et al., 2015; Ensor et al., 2016, 2018; Ford et al., 2018
	Socio-cultural acceptability		Giller et al., 2015; Ndah et al., 2015; Thierfelder et al., 2015		Roco et al., 2014; Venot et al., 2014; Girard et al., 2015; Mdemu et al., 2017		Herrero et al., 2015; Ghahramani and Bowran, 2018; Thornton et al., 2018		Jarvis et al., 2008; Valdivia et al., 2012; Coq-Huelva et al., 2017; Iiyama et al., 2017; Jacobi et al., 2017; Hernández-Morcillo et al., 2018		Mannke, 2011; Green et al., 2014; Reid and Huq, 2014; Wise et al., 2014; H. Wright et al., 2014; Fernández-Giménez et al., 2015; Ensor et al., 2016, 2018; Ford et al., 2018
	Social and regional inclusiveness		Brouder and Gomez-Macpherson, 2014; Pittelkow et al., 2014; Ndah et al., 2015; H. Smith et al., 2017		Burney and Naylor, 2012; Jägermeyr et al., 2015		Briske et al., 2015; García de Jalón et al., 2017; Thornton et al., 2018		Valdivia et al., 2012; Iiyama et al., 2017; Jacobi et al., 2017		Archer et al., 2014; H. Wright et al., 2014; Fernández-Giménez et al., 2015; Sovacool et al., 2015; Ensor et al., 2016, 2018; Ford et al., 2018
	Intergenerational equity	NA		NA		NA		NE			H. Wright et al., 2014; Fernández-Giménez et al., 2015
Environmental/	Ecological capacity		Bhan and Behera, 2014; Palm et al., 2014; Thierfelder et al., 2015; Prosdocimi et al., 2016		Kirby et al., 2014; Pfeiffer and Lin, 2014; Fishman et al., 2015; Jägermeyr et al., 2015		Lemaire et al., 2014; Herrero et al., 2015; Thornton et al., 2018		Lusiana et al., 2012; K Murthy, 2013; Lasco et al., 2014; Barral et al., 2015; Coq-Huelva et al., 2017; Quandt et al., 2017; Hernández-Morcillo et al., 2018; Sida et al., 2018	LE	H. Wright et al., 2014; Fernández-Giménez et al., 2015

	Adaptive capacity/resilience		Aleksandrova et al., 2014; Grabowski and Kerr, 2014; Kirkegaard et al., 2014; Pittelkow et al., 2014; Stevenson et al., 2014; Thierfelder et al., 2015; Li et al., 2016; H. Smith et al., 2017; Pradhan et al., 2018		Burney and Naylor, 2012; Burney et al., 2014; Levidow et al., 2014; Jägermeyr et al., 2015; Fader et al., 2016; Varela-Ortega et al., 2016; Ashofteh et al., 2017; Hong and Yabe, 2017		Bell et al., 2014; Havet et al., 2014; Lemaire et al., 2014; Thornton and Herrero, 2014; Briske et al., 2015; Herrero et al., 2015; Weindl et al., 2015; Ghahramani and Bowran, 2018		Sendzimir et al., 2011; Lusiana et al., 2012; K Murthy, 2013; Lasco et al., 2014; Mbow et al., 2014a; Varela-Ortega et al., 2016; Clark and Tilman, 2017; Coq-Huelva et al., 2017; Thierfelder et al., 2017; Coulibaly et al., 2017; Quandt et al., 2017; Hernández-Morcillo et al., 2018		Mannke, 2011; Archer et al., 2014; Ayers et al., 2014; H. Wright et al., 2014; Reid and Huq, 2014; Wise et al., 2014; Fernández-Giménez et al., 2015; Ensor et al., 2016, 2018; Ford et al., 2018; Singh, 2018
Geophysical	Physical feasibility		Stevenson et al., 2014; Giller et al., 2015; Thierfelder et al., 2017		Levidow et al., 2014; Fishman et al., 2015; Jägermeyr et al., 2015		Weindl et al., 2015; Thornton et al., 2018		Coulibaly et al., 2017; Hernández-Morcillo et al., 2018	NA	
	Land use change enhancement potential		Grabowski and Kerr, 2014; Stevenson et al., 2014; Giller et al., 2015; Prosdocimi et al., 2016; Cui et al., 2018; Pradhan et al., 2018		Fader et al., 2016		Briske et al., 2015; Weindl et al., 2015		Lasco et al., 2014; Mbow et al., 2014a; Coulibaly et al., 2017; Hernández-Morcillo et al., 2018	LE	H. Wright et al., 2014
	Hazard risk reduction potential	NE		NA		NA			Lasco et al., 2014; Mbow et al., 2014a; Coulibaly et al., 2017; Abdulai et al., 2018; Hernández-Morcillo et al., 2018		Mannke, 2011; Archer et al., 2014; H. Wright et al., 2014; Fernández-Giménez et al., 2015; Ensor et al., 2016, 2018; Ford et al., 2018

Table 4.SM.18: Feasibility assessment of land and ecosystem transition adaptation options: ecosystem restoration and avoided deforestation, biodiversity management, coastal defence and hardening, and sustainable aquaculture. For methodology, see 4.SM.4.1.

		Ecosystem Restoration and Avoided Deforestation		Biodiversity Management		Coastal Defence and Hardening		Sustainable Aquaculture	
	Evidence	Robust		Medium		Robust		Limited	
	Agreement	Medium		Medium		Medium		Medium	
Economic	Microeconomic viability		Dang Phan et al., 2014; Ingalls and Dwyer, 2016; Rakatama et al., 2017; Spencer et al., 2017		Rodrigues et al., 2009; Alagador et al., 2014; Mantyka-Pringle et al., 2016; Gómez-Aíza et al., 2017; Reside et al., 2017b; Monahan and Theobald, 2018		Firth et al., 2014; Barbier, 2015a; Elliott and Wolanski, 2015; Diaz, 2016; Betzold and Mohamed, 2017		Boonstra and Hanh, 2015; Joffre et al., 2015; FAO, 2016; FAO et al., 2017; Pérez-Escamilla, 2017
	Macroeconomic viability		Dang Phan et al., 2014; Rakatama et al., 2017; Spencer et al., 2017; Turnhout et al., 2017; Well and Carrapatoso, 2017	NE		LE	Hinkel et al., 2014; Estrada et al., 2017	LE	UNEP, 2013; Edwards, 2015; Moffat, 2017
	Socio-economic vulnerability reduction potential		Atela et al., 2015; Elmqvist et al., 2015; Camps-Calvet et al., 2016; Ingalls and Dwyer, 2016; McPhearson et al., 2016; Collas et al., 2017; Ngendakumana et al., 2017; Spencer et al., 2017		Rodrigues et al., 2009; Berrang-Ford et al., 2012; Pullin et al., 2013; Brockington and Wilkie, 2015; Newbold et al., 2015; Oldekop et al., 2016; Griscom et al., 2017; Milman and Jagannathan, 2017; Terraube et al., 2017; Essl and Mauerhofer, 2018		Rabbani et al., 2010a, b; Gutiérrez et al., 2012; Arkema et al., 2013, 2017; Neumann et al., 2015; Sovacool et al., 2015; Sutton-Grier et al., 2015; Betzold and Mohamed, 2017		Bell et al., 2011; Smith et al., 2013; Orchard et al., 2015; Béné et al., 2016; Jennings et al., 2016; Mycoo, 2017; Ahmed et al., 2018
	Employment and productivity enhancement potential		Ingalls and Dwyer, 2016; Spencer et al., 2017; Turnhout et al., 2017	NE		NE			Sánchez et al., 2002; De Silva and Davy, 2010; Ahmed et al., 2014; Boonstra and Hanh, 2015; Lacoue-Labarthe et al., 2016; Asiedu et al., 2017a

Technological	Technical resource availability		Ingalls and Dwyer, 2016; Spencer et al., 2017; Turnhout et al., 2017		Nadeau et al., 2015; Schmitz et al., 2015; Thomas and Gillingham, 2015; K.R. Jones et al., 2016; Urban et al., 2016; Milman and Jagannathan, 2017; Reside et al., 2017b		Arkema et al., 2013; Bosello and De Cian, 2014; Smajgl et al., 2015; Hauer et al., 2016; Betzold and Mohamed, 2017; Williams et al., 2018		UNEP, 2013; Ahmed et al., 2014, 2018; Brillant, 2014; Edwards, 2015; Lucas, 2015; Fidelman et al., 2017
	Risks mitigation potential	LE	Spencer et al., 2017; Turnhout et al., 2017	LE			Firth et al., 2014; Sovacool et al., 2015; André et al., 2016; Cashman and Nagdee, 2017; Brown et al., 2018; Storlazzi et al., 2018; Williams et al., 2018		Boonstra and Hanh, 2015; Blanchard et al., 2017
Institutional	Political acceptability		Sunderlin et al., 2014; Ingalls and Dwyer, 2016; Ngendakumana et al., 2017	LE	Milman and Jagannathan, 2017; Essl and Mauerhofer, 2018		Duvat, 2013; Nordstrom, 2014; Sovacool et al., 2015; Betzold and Mohamed, 2017		Brander, 2007; Bell et al., 2011; Bell and Taylor, 2015; FAO, 2016; Weatherdon et al., 2016; Asiedu et al., 2017a; Ertör and Ortega-Cerdà, 2017
	Legal and regulatory acceptability	LE	Sunderlin et al., 2014; Turnhout et al., 2017		Dallimer and Strange, 2015; K.R. Jones et al., 2016; Drielsma et al., 2017; Essl and Mauerhofer, 2018; Monahan and Theobald, 2018; Triviño et al., 2018	NE		LE	Broitman et al., 2017; Fidelman et al., 2017
	Institutional capacity and administrative feasibility		Jagger et al., 2014; Sunderlin et al., 2014; Wallbott, 2014; Atela et al., 2015; Ingalls and Dwyer, 2016; Ngendakumana et al., 2017; Spencer et al., 2017; Turnhout et al., 2017; Well and Carrapatoso, 2017; Wehkamp et al., 2018a		Dallimer and Strange, 2015; Thomas and Gillingham, 2015; K.R. Jones et al., 2016; Essl and Mauerhofer, 2018; Monahan and Theobald, 2018		Hallegatte et al., 2013; Spalding et al., 2014; Mills et al., 2016; Estrada et al., 2017	LE	Ahmed et al., 2014; Broitman et al., 2017; Fidelman et al., 2017
	Transparency and accountability potential		Jagger et al., 2014; Sunderlin et al., 2014; Atela et al., 2015; Ingalls and Dwyer, 2016; Ngendakumana et al., 2017;	LE		NE		NE	

			Turnhout et al., 2017; Well and Carrapatoso, 2017; Wehkamp et al., 2018a						
Socio-cultural	Social co-benefits (health, education)		Sunderlin et al., 2014; Jagger et al., 2014; Atela et al., 2015; Elmqvist et al., 2015; Camps-Calvet et al., 2016; Ingalls and Dwyer, 2016; McPhearson et al., 2016; Turnhout et al., 2017; Collas et al., 2017; Li et al., 2017; Ngendakumana et al., 2017; Spencer et al., 2017		Rodrigues et al., 2009; Berrang-Ford et al., 2012; Pullin et al., 2013; Brockington and Wilkie, 2015; Oldekop et al., 2016; Clark and Tilman, 2017; Terraube et al., 2017; Essl and Mauerhofer, 2018		Sovacool et al., 2015; Sutton-Grier et al., 2015; Arkema et al., 2017; Betzold and Mohamed, 2017	LE	Weatherdon et al., 2016; Fidelman et al., 2017
	Socio-cultural acceptability		Sunderlin et al., 2014; Wallbott, 2014; Atela et al., 2015; Ingalls and Dwyer, 2016; Ngendakumana et al., 2017; Spencer et al., 2017		Pullin et al., 2013; Brockington and Wilkie, 2015; Oldekop et al., 2016; Milman and Jagannathan, 2017		Sovacool et al., 2015; Gibbs, 2016; Morris et al., 2016; Betzold and Mohamed, 2017; Marengo et al., 2017	LE	Asiedu et al., 2017a; Fidelman et al., 2017
	Social and regional inclusiveness	LE	Ingalls and Dwyer, 2016; Spencer et al., 2017		Pullin et al., 2013; Brockington and Wilkie, 2015; Oldekop et al., 2016; Milman and Jagannathan, 2017; Terraube et al., 2017	NA		NE	
	Intergenerational equity		Ingalls and Dwyer, 2016; Ngendakumana et al., 2017; Spencer et al., 2017	NE		NE		NA	
Environmental/ecological	Ecological capacity		Sunderlin et al., 2014; Spencer et al., 2017; Turnhout et al., 2017		Rodrigues et al., 2009; Virkkala et al., 2014; Thomas and Gillingham, 2015; Gillingham et al., 2015; Nadeau et al., 2015; Schmitz et al., 2015; Feeley and Silman, 2016; Gaüzère et al., 2016; Greenwood et al., 2016; Gómez-Aíza et al., 2017; Mingarro and Lobo, 2018; Monahan and Theobald, 2018		Bilkovic and Mitchell, 2013; Spalding et al., 2014; Joffre et al., 2015; Sutton-Grier et al., 2015		David et al., 2015; Joffre et al., 2015; Blanchard et al., 2017; Broitman et al., 2017; Ahmed et al., 2018

	Adaptive capacity/resilien ce		Sunderlin et al., 2014; Ingalls and Dwyer, 2016; Ngendakumana et al., 2017; Spencer et al., 2017; Turnhout et al., 2017		Rodrigues et al., 2009; Pullin et al., 2013; Oldekop et al., 2016; Gómez-Aíza et al., 2017; Terraube et al., 2017; Monahan and Theobald, 2018	LE	Spalding et al., 2014; Orchard et al., 2015; Fidelman et al., 2017		Boonstra and Hanh, 2015; Orchard et al., 2015; Blanchard et al., 2017; Fidelman et al., 2017; Cinner et al., 2018
Geophysical	Physical feasibility		Dang Phan et al., 2014; Sunderlin et al., 2014; Ngendakumana et al., 2017; Spencer et al., 2017; Turnhout et al., 2017	NE			Duvat, 2013; Hinkel et al., 2014; Smith et al., 2015; André et al., 2016; Cooper et al., 2016; Vousdoukas et al., 2016; Arkema et al., 2017		David et al., 2015; S. Adhikari et al., 2018; Ahmed et al., 2018
	Land use change enhancement potential		Dang Phan et al., 2014; Sunderlin et al., 2014; Ingalls and Dwyer, 2016; Ngendakumana et al., 2017; Turnhout et al., 2017; Houghton and Nassikas, 2018; Wehkamp et al., 2018a	LE	Schmitz et al., 2015; Reside et al., 2017a, b	LE	Sutton-Grier et al., 2015	LE	Mialhe et al., 2016
	Hazard risk reduction potential		Ingalls and Dwyer, 2016; Spencer et al., 2017	NE			Luisetti et al., 2013; Firth et al., 2014; Spalding et al., 2014; Barbier, 2015b; Sutton-Grier et al., 2015; André et al., 2016; Narayan et al., 2016; Arkema et al., 2017; Fu and Song, 2017		Joffre et al., 2015; Blanchard et al., 2017; Daly et al., 2017; Hung et al., 2018

4.SM.4.3.3 Feasibility Assessment of Adaptation Options in Urban and Infrastructure System Transitions

Table 4.SM.19: Feasibility assessment of urban and infrastructure transition adaptation options: sustainable land use and urban planning, and sustainable water management. For methodology, see 4.SM.4.1.

		Sustainable Land Use and Urban Planning		**Sustainable Water Management**	
	Evidence	Medium		Robust	
	Agreement	Medium		Medium	
Economic	Microeconomic viability		Eberhard et al., 2011, 2016; Kiunsi, 2013; Watkins, 2015; Archer, 2016; Eisenberg, 2016; Ewing et al., 2016; Ziervogel et al., 2016a, 2017; Hess and Kelman, 2017; Mavhura et al., 2017		Liu et al., 2014; Lamond et al., 2015; Voskamp and Van de Ven, 2015; Xue et al., 2015; Costa et al., 2016; Mguni et al., 2016; Poff et al., 2016; Ossa-Moreno et al., 2017; Vincent et al., 2017; Xie et al., 2017
	Macroeconomic viability		Eberhard et al., 2011, 2016; Measham et al., 2011; Aerts et al., 2014; Jaglin, 2014; Beccali et al., 2015; Boughedir, 2015; Watkins, 2015; Ziervogel et al., 2016a, 2017; Chu et al., 2017; Hess and Kelman, 2017	NE	
	Socio-economic vulnerability reduction potential		Measham et al., 2011; Eberhard et al., 2011, 2016; Kiunsi, 2013; Aerts et al., 2014; Jaglin, 2014; Boughedir, 2015; Broto et al., 2015; Carter et al., 2015; Archer, 2016; Shi et al., 2016; Ziervogel et al., 2016a, 2017; Hetz, 2016; Mavhura et al., 2017		Villarroel Walker et al., 2014; Ziervogel and Joubert, 2014; Brown and McGranahan, 2016; Chu et al., 2016; Chant et al., 2017; Dodman et al., 2017a, b; Ossa-Moreno et al., 2017; Gunasekara et al., 2018
	Employment and productivity enhancement potential		Eberhard et al., 2011, 2016; Measham et al., 2011; Watkins, 2015; Archer, 2016; Ziervogel et al., 2016a	NE	
Technological	Technical resource availability		Aerts et al., 2014; Kettle et al., 2014; Beccali et al., 2015; Boughedir, 2015; Archer, 2016; Woodruff and Stults, 2016; Mavhura et al., 2017; Siders, 2017; Stults and Woodruff, 2017		Liu et al., 2014; Lamond et al., 2015; Voskamp and Van de Ven, 2015; Costa et al., 2016; Mguni et al., 2016; Soz et al., 2016; Xie et al., 2017
	Risks mitigation potential		Measham et al., 2011; Kiunsi, 2013; Aerts et al., 2014; Boughedir, 2015; Eisenberg, 2016; Siders, 2017; Stults and Woodruff, 2017		Liu et al., 2014; Lamond et al., 2015; Voskamp and Van de Ven, 2015; Costa et al., 2016; Mguni et al., 2016; Xie et al., 2017; Gunasekara et al., 2018
Institutional	Political acceptability		Measham et al., 2011; Aerts et al., 2014; Rivera and Wamsler, 2014; Boughedir, 2015; Carter et al., 2015; Landauer et al., 2015; Araos et al., 2016b; Woodruff and Stults, 2016; Hetz,		Leck et al., 2015; Padawangi and Douglass, 2015; Chen and Chen, 2016; Mguni et al., 2016

			2016; Siders, 2017; Chu et al., 2017; Di Gregorio et al., 2017b; Mahlkow and Donner, 2017		
	Legal and regulatory acceptability		Measham et al., 2011; Eberhard et al., 2011, 2016; Aerts et al., 2014; Rivera and Wamsler, 2014; Boughedir, 2015; Landauer et al., 2015; Carter et al., 2015; King et al., 2016; Eisenberg, 2016; Dhar and Khirfan, 2017; Di Gregorio et al., 2017b; Francesch-Huidobro et al., 2017; Hess and Kelman, 2017		Bettini et al., 2015; Deng and Zhao, 2015; Hill Clarvis and Engle, 2015; Leck et al., 2015; Lemos, 2015; Margerum and Robinson, 2015; Padawangi and Douglass, 2015; Chen and Chen, 2016
	Institutional capacity and administrative feasibility		Eberhard et al., 2011, 2016; Measham et al., 2011; Kiunsi, 2013; Aerts et al., 2014; Jaglin, 2014; Rivera and Wamsler, 2014; Archer et al., 2014; Landauer et al., 2015; Boughedir, 2015; Broto et al., 2015; Carter et al., 2015; Araos et al., 2016b; Hetz, 2016; Archer, 2016; Shi et al., 2016; Woodruff and Stults, 2016; Ziervogel et al., 2016a; Campos et al., 2016; Di Gregorio et al., 2017b; Francesch-Huidobro et al., 2017; Mahlkow and Donner, 2017; Mavhura et al., 2017; Siders, 2017; Tait and Euston-Brown, 2017; Chu et al., 2017; Dhar and Khirfan, 2017		Ziervogel and Joubert, 2014; Bettini et al., 2015; Deng and Zhao, 2015; Hill Clarvis and Engle, 2015; Lamond et al., 2015; Lemos, 2015; Margerum and Robinson, 2015)
	Transparency and accountability potential		Eberhard et al., 2011, 2016; Measham et al., 2011; Kettle et al., 2014; Broto et al., 2015; Landauer et al., 2015; Shi et al., 2016; Woodruff and Stults, 2016; Chu et al., 2017; Stults and Woodruff, 2017	NE	
Socio-cultural	Social co-benefits (health, education)		Eberhard et al., 2011, 2016; Archer et al., 2014; Kettle et al., 2014; Parnell, 2015; Watkins, 2015; Beccali et al., 2015; Landauer et al., 2015; Archer, 2016; Ziervogel et al., 2016a, 2017; Campos et al., 2016; Hess and Kelman, 2017; Chu et al., 2018		Liu et al., 2014; Lamond et al., 2015; Leck et al., 2015; Padawangi and Douglass, 2015; Voskamp and Van de Ven, 2015; Costa et al., 2016; Mguni et al., 2016; Nur and Shrestha, 2017; Xie et al., 2017; Gunasekara et al., 2018
	Socio-cultural acceptability		Kiunsi, 2013; Aerts et al., 2014; Jaglin, 2014; Kettle et al., 2014; Archer et al., 2014; Parnell, 2015; Watkins, 2015; Broto et al., 2015; Carter et al., 2015; Archer, 2016; Newman et al., 2016; Shi et al., 2016; Ziervogel et al., 2016a, 2017; Campos et al., 2016; Eberhard et al., 2016; Ewing et al., 2016; Siders, 2017; Stults and Woodruff, 2017; Chu et al., 2017, 2018		Lamond et al., 2015; Leck et al., 2015; Padawangi and Douglass, 2015; Nur and Shrestha, 2017; Xie et al., 2017
	Social and regional inclusiveness		Eberhard et al., 2011, 2016; Jaglin, 2014; Kettle et al., 2014; Archer et al., 2014; Parnell, 2015; Watkins, 2015; Broto et al., 2015; Araos et al., 2016b; Archer, 2016; King et al., 2016; Shi et al., 2016; Ziervogel et al., 2016a, 2017; Campos et al., 2016; Mahlkow and Donner, 2017; Mavhura et al., 2017; Chu et al., 2017, 2018; Dhar and Khirfan, 2017		Rasul and Sharma, 2016

	Intergenerational equity		Parnell, 2015; King et al., 2016; Shi et al., 2016; Chu et al., 2017; Ziervogel et al., 2017		Tacoli et al., 2013; Xue et al., 2015; Poff et al., 2016
Environmental/ ecological	Ecological capacity		Kiunsi, 2013; Aerts et al., 2014; Kettle et al., 2014; King et al., 2016; Ziervogel et al., 2016a; Mavhura et al., 2017		Ziervogel and Joubert, 2014; Lamond et al., 2015; Soz et al., 2016
	Adaptive capacity/ resilience		Eberhard et al., 2011, 2016; Kiunsi, 2013; Aerts et al., 2014; Kettle et al., 2014; Rivera and Wamsler, 2014; Archer et al., 2014; Jaglin, 2014; Parnell, 2015; Watkins, 2015; Carter et al., 2015; Archer, 2016; King et al., 2016; Shi et al., 2016; Ziervogel et al., 2016a, 2017; Hetz, 2016; Stults and Woodruff, 2017; Chu et al., 2017; Hess and Kelman, 2017		Angotti, 2015; Bell et al., 2015; Biggs et al., 2015; Gwedla and Shackleton, 2015; Lwasa et al., 2015; Chen and Chen, 2016; Yang et al., 2016; Sanesi et al., 2017; Gunasekara et al., 2018
Geophysical	Physical feasibility		Aerts et al., 2014; Boughedir, 2015; Hetz, 2016; King et al., 2016; Newman et al., 2016; Woodruff and Stults, 2016; Ziervogel et al., 2016a; Stults and Woodruff, 2017		Ziervogel and Joubert, 2014; Lamond et al., 2015; Soz et al., 2016
	Land use change enhancement potential		Kiunsi, 2013; Landauer et al., 2015; Parnell, 2015; Hetz, 2016; Newman et al., 2016; Mavhura et al., 2017		Lamond et al., 2015; Leck et al., 2015; Padawangi and Douglass, 2015; Rasul and Sharma, 2016; Soz et al., 2016
	Hazard risk reduction potential		Kiunsi, 2013; Aerts et al., 2014; Watkins, 2015; Boughedir, 2015; Archer, 2016; Woodruff and Stults, 2016; Eisenberg, 2016; Hetz, 2016; King et al., 2016; Mahlkow and Donner, 2017; Mavhura et al., 2017; Stults and Woodruff, 2017		Liu et al., 2014; Angotti, 2015; Bell et al., 2015; Voskamp and Van de Ven, 2015; Biggs et al., 2015; Gwedla and Shackleton, 2015; Lamond et al., 2015; Lwasa et al., 2015; Mguni et al., 2016; Yang et al., 2016; Chen and Chen, 2016; Costa et al., 2016; Sanesi et al., 2017; Xie et al., 2017; Gunasekara et al., 2018

Table 4.SM.20: Feasibility assessment of urban and infrastructure transition adaptation options: green infrastructure and ecosystem services, and building codes and standards. For methodology, see 4.SM.4.1.

		Green Infrastructure and Ecosystem Services		Building Codes and Standards	
	Evidence	Medium		Limited	
	Agreement	High		Medium	
Economic	Microeconomic viability		Elmqvist et al., 2015; Soderlund and Newman, 2015; McPhearson et al., 2016; Zinia and McShane, 2018		Steenhof and Sparling, 2011; Bendito and Barrios, 2016; Ruparathna et al., 2016; Mavhura et al., 2017; Wells et al., 2018
	Macroeconomic viability	LE	Culwick and Bobbins, 2016		Steenhof and Sparling, 2011; Aerts et al., 2014; Späth and Rohracher, 2015; Chandel et al., 2016; Shapiro, 2016; Hess and Kelman, 2017; Wells et al., 2018
	Socio-economic vulnerability reduction potential		Tallis et al., 2011; Elmqvist et al., 2015; Soderlund and Newman, 2015; Camps-Calvet et al., 2016; McPhearson et al., 2016; Panagopoulos et al., 2016; Stevenson et al., 2016; Li et al., 2017; R. White et al., 2017; Zinia and McShane, 2018		Steenhof and Sparling, 2011; FEMA, 2014; Bendito and Barrios, 2016; Hess and Kelman, 2017; Reckien et al., 2017
	Employment and productivity enhancement potential	NE		NE	
Technological	Technical resource availability	NA			Steenhof and Sparling, 2011; Aerts et al., 2014; Bendito and Barrios, 2016; Chandel et al., 2016; Ruparathna et al., 2016; Garsaball and Markov, 2017; Tait and Euston-Brown, 2017; Wells et al., 2018
	Risks mitigation potential (stranded assets, unforeseen impacts)		Tallis et al., 2011; Elmqvist et al., 2013b, 2015; Buckeridge, 2015; Soderlund and Newman, 2015; Camps-Calvet et al., 2016; McPhearson et al., 2016; Panagopoulos et al., 2016; Stevenson et al., 2016; R. White et al., 2017; Li et al., 2017; Zinia and McShane, 2018		Aerts et al., 2014; Ruparathna et al., 2016
Institutional	Political acceptability	LE	Brown and McGranahan, 2016; Ziervogel et al., 2016b		Aerts et al., 2014; Späth and Rohracher, 2015; Chandel et al., 2016; Eisenberg, 2016; Shapiro, 2016; Tait and Euston-Brown, 2017; Wells et al., 2018
	Legal and regulatory acceptability		Brown and McGranahan, 2016; Ziervogel et al., 2016b; Collas et al., 2017; Li et al., 2017; Sirakaya et al., 2018		Steenhof and Sparling, 2011; Burch et al., 2014; Späth and Rohracher, 2015; Eisenberg, 2016; Ruparathna et al., 2016; Shapiro, 2016; Hess and Kelman, 2017; Stults and Woodruff, 2017

	Institutional capacity and administrative feasibility		Brown and McGranahan, 2016; Culwick and Bobbins, 2016; Ziervogel et al., 2016b; Collas et al., 2017; Li et al., 2017; Prudencio and Null, 2018		Aerts et al., 2014; Chandel et al., 2016; Eisenberg, 2016; Shapiro, 2016; Garsaball and Markov, 2017; Hess and Kelman, 2017; Mavhura et al., 2017; Stults and Woodruff, 2017; Tait and Euston-Brown, 2017
	Transparency and accountability potential	LE	Li et al., 2017		Steenhof and Sparling, 2011; Aerts et al., 2014; Späth and Rohracher, 2015; Chandel et al., 2016; Shapiro, 2016
Socio-cultural	Social co-benefits (health, education)		Beatley, 2011; Tallis et al., 2011; Elmqvist et al., 2013b, 2015; Liu et al., 2014; Demuzere et al., 2014; Lamond et al., 2015; Mullaney et al., 2015; Norton et al., 2015; Skougaard Kaspersen et al., 2015; Soderlund and Newman, 2015; Voskamp and Van de Ven, 2015; Buckeridge, 2015; Beaudoin and Gosselin, 2016; Green et al., 2016; McPhearson et al., 2016; Mguni et al., 2016; Brown and McGranahan, 2016; Panagopoulos et al., 2016; Stevenson et al., 2016; Camps-Calvet et al., 2016; Costa et al., 2016; Culwick and Bobbins, 2016; Li et al., 2017; Lin et al., 2017; Xie et al., 2017; Collas et al., 2017; Zinia and McShane, 2018	NE	
	Socio-cultural acceptability		Beatley, 2011; Elmqvist et al., 2015; Beaudoin and Gosselin, 2016; Brown and McGranahan, 2016; Camps-Calvet et al., 2016; McPhearson et al., 2016; Ziervogel et al., 2016b; Collas et al., 2017; Li et al., 2017; Zinia and McShane, 2018		Späth and Rohracher, 2015; Bendito and Barrios, 2016; Eisenberg, 2016; Tait and Euston-Brown, 2017
	Social and regional inclusiveness		Tallis et al., 2011; Elmqvist et al., 2013b, 2015; Buckeridge, 2015; Beaudoin and Gosselin, 2016; Brown and McGranahan, 2016; Panagopoulos et al., 2016; Stevenson et al., 2016; Ziervogel et al., 2016b; Camps-Calvet et al., 2016; Culwick and Bobbins, 2016; McPhearson et al., 2016; R. White et al., 2017; Collas et al., 2017; Li et al., 2017; Prudencio and Null, 2018		Parnell, 2015; Shapiro, 2016; Mavhura et al., 2017; Reckien et al., 2017
	Intergenerational equity		Elmqvist et al., 2013b, 2015; Liu et al., 2014; Lamond et al., 2015; Skougaard Kaspersen et al., 2015; Voskamp and Van de Ven, 2015; Costa et al., 2016; McPhearson et al., 2016; Mguni et al., 2016; Xie et al., 2017	NE	
Environmental/ecological	Ecological capacity		Liu et al., 2014; Lamond et al., 2015; Skougaard Kaspersen et al., 2015; Costa et al., 2016; Mguni et al., 2016; Xie et al., 2017	NE	
	Adaptive capacity/ resilience		Beatley, 2011; Elmqvist et al., 2013b, 2015; Voskamp and Van de Ven, 2015; Beaudoin and Gosselin, 2016; Brown and		Steenhof and Sparling, 2011; Aerts et al., 2014; Bendito and Barrios, 2016

			McGranahan, 2016; Camps-Calvet et al., 2016; McPhearson et al., 2016; Panagopoulos et al., 2016; Collas et al., 2017; Li et al., 2017; Zinia and McShane, 2018		
Geophysical	Physical feasibility		Liu et al., 2014; Lamond et al., 2015; Skougaard Kaspersen et al., 2015; Voskamp and Van de Ven, 2015; Costa et al., 2016; Mguni et al., 2016; Collas et al., 2017; Xie et al., 2017	NE	
	Land use change enhancement potential		Tallis et al., 2011; Elmqvist et al., 2013b; Buckeridge, 2015; Culwick and Bobbins, 2016; Panagopoulos et al., 2016; Stevenson et al., 2016; Collas et al., 2017; R. White et al., 2017		Bendito and Barrios, 2016; Reckien et al., 2017
	Hazard risk reduction potential		Nowak et al., 2006; Tallis et al., 2011; Elmqvist et al., 2013b, 2015; Buckeridge, 2015; Soderlund and Newman, 2015; Brown and McGranahan, 2016; Panagopoulos et al., 2016; Stevenson et al., 2016; Ziervogel et al., 2016b; Camps-Calvet et al., 2016; Culwick and Bobbins, 2016; McPhearson et al., 2016; R. White et al., 2017; Collas et al., 2017; Li et al., 2017; Zinia and McShane, 2018		Steenhof and Sparling, 2011; FEMA, 2014; Bendito and Barrios, 2016; Garsaball and Markov, 2017; Reckien et al., 2017

4.SM.4.3.4 Feasibility Assessment of Adaptation Options in Industrial System Transitions

Table 4.SM.21: Feasibility assessment of industrial system transition adaptation option: intensive industry infrastructure resilience and water management. For methodology, see 4.SM.4.1.

		Intensive Industry Infrastructure Resilience and Water Management	
	Evidence	Limited	
	Agreement	High	
Economic	Microeconomic viability	NE	
	Macroeconomic viability	NE	
	Socio-economic vulnerability reduction potential		
	Employment and productivity enhancement potential	NE	
Technological	Technical resource availability		Koch and Vögele, 2009; Jahandideh-Tehrani et al., 2014; Murrant et al., 2015; Parkinson and Djilali, 2015
	Risks mitigation potential		Jahandideh-Tehrani et al., 2014; Murrant et al., 2015; Parkinson and Djilali, 2015
Institutional	Political acceptability	LE	Murrant et al., 2015
	Legal and regulatory acceptability	NE	
	Institutional capacity and administrative feasibility	LE	Eisenack and Stecker, 2012; Murrant et al., 2015
	Transparency and accountability potential	NE	
Socio-cultural	Social co-benefits (health, education)	NA	
	Socio-cultural acceptability	NE	
	Social and regional inclusiveness	NA	

	Intergenerational equity	NA	
Environmental/ecological	Ecological capacity		Jahandideh-Tehrani et al., 2014; Murrant et al., 2015; Parkinson and Djilali, 2015
	Adaptive capacity/resilience		Jahandideh-Tehrani et al., 2014; Murrant et al., 2015; Parkinson and Djilali, 2015
Geophysical	Physical feasibility		Eisenack and Stecker, 2012; Jahandideh-Tehrani et al., 2014; Murrant et al., 2015; Parkinson and Djilali, 2015
	Land use change enhancement potential	LE	Jahandideh-Tehrani et al., 2014; Parkinson and Djilali, 2015
	Hazard risk reduction potential		Jahandideh-Tehrani et al., 2014; Murrant et al., 2015; Parkinson and Djilali, 2015

4.SM.4.3.5 Feasibility Assessment of Overarching Adaptation Options

Table 4.SM.22: Feasibility assessment of overarching adaptation options: disaster risk management, risk spreading and sharing, climate services and indigenous knowledge. For methodology, see 4.SM.4.1.

		Disaster Risk Management		**Risk Spreading and Sharing**		**Climate Services**		**Indigenous Knowledge**	
	Evidence	Medium		Medium		Medium		Medium	
	Agreement	High		Medium		High		High	
Economic	Microeconomic viability		IPCC, 2012; Mavhura et al., 2013; Yu and Gillis, 2014; Johnson and Abe, 2015; Mawere and Mubaya, 2015; Archer, 2016; Kull et al., 2016; Rose, 2016; Watanabe et al., 2016		Panda et al., 2013; Weinhofer and Busch, 2013; Thornton and Herrero, 2014; Falco et al., 2014; Lashley and Warner, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Nicola, 2015; Annan and Schlenker, 2015; Bogale, 2015; García Romero and Molina, 2015; Greatrex et al., 2015; Akter et al., 2016, 2017; Jin et al., 2016; Surminski et al., 2016; Patel et al., 2017; Shively, 2017; Farzaneh et al., 2017; Glaas et al., 2017; Jensen and Barrett, 2017		Vaughan and Dessai, 2014; Snow et al., 2016; Lechthaler and Vinogradova, 2017; Webber, 2017; Ouédraogo et al., 2018		Berkes et al., 2000; Nakashima et al., 2012; Leonard et al., 2013; McNamara and Prasad, 2014; Pearce et al., 2015; Mapfumo et al., 2016; Altieri and Nicholls, 2017; Nunn et al., 2017; Ruiz-Mallén et al., 2017; Crate et al., 2017; Ingty, 2017; Kihila, 2017; Magni, 2017
	Macroeconomic viability		IPCC, 2012; Hinkel et al., 2014; Anacona et al., 2015; Johnson and Abe, 2015; Boughedir, 2015;		Cook and Dowlatabadi, 2011; Falco et al., 2014; García Romero and		Brasseur and Gallardo, 2016; Rodrigues et al., 2016		Berkes et al., 2000; Leonard et al., 2013; Mapfumo et al., 2016; Ingty, 2017; Magni,

			Howes et al., 2015; Archer, 2016; Kull et al., 2016; Rose, 2016; Diaz, 2016; Haeberli et al., 2016, 2017; Kelman, 2017; de Leon and Pittock, 2017		Molina, 2015; Joyette et al., 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Wolfrom and Yokoi-Arai, 2015; Surminski et al., 2016; Glaas et al., 2017; Jenkins et al., 2017; Jensen and Barrett, 2017				2017; Nunn et al., 2017; Ruiz-Mallén et al., 2017
	Socio-economic vulnerability reduction potential		IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Boeckmann and Rohn, 2014; Anacona et al., 2015; Howes et al., 2015; Johnson and Abe, 2015; Kelman et al., 2015; Mawere and Mubaya, 2015; Boughedir, 2015; Archer, 2016; Kull et al., 2016; Muñoz et al., 2016; Rose, 2016; Watanabe et al., 2016; Diaz, 2016; Haeberli et al., 2016, 2017; Wallace, 2017; de Leon and Pittock, 2017; Granderson, 2017; Nahayo et al., 2018; Brundiers, 2018		Mills, 2007; Panda et al., 2013; Thornton and Herrero, 2014; Falco et al., 2014; Annan and Schlenker, 2015; Lashley and Warner, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Nicola, 2015; Bogale, 2015; Wolfrom and Yokoi-Arai, 2015; García Romero and Molina, 2015; Greatrex et al., 2015; Jin et al., 2016; O'Hare et al., 2016; Surminski et al., 2016; Akter et al., 2017; Patel et al., 2017; Surminski and Thieken, 2017; Farzaneh et al., 2017; Glaas et al., 2017; Hansen et al., 2017; Jensen and Barrett, 2017		Kadi et al., 2011; Jancloes et al., 2014; Vaughan and Dessai, 2014; Lobo et al., 2017		Berkes and Jolly, 2002; Forbes et al., 2009; Nakashima et al., 2012; Leonard et al., 2013; McNamara and Prasad, 2014; Ford et al., 2014; MacDonald et al., 2015b; Pearce et al., 2015; Harper et al., 2015; Mapfumo et al., 2016; Mistry and Berardi, 2016; Clark et al., 2016; Altieri and Nicholls, 2017; Archer et al., 2017; Magni, 2017; Nunn et al., 2017; Ruiz-Mallén et al., 2017; Russell-Smith et al., 2017; Thornton and Comberti, 2017; Williams et al., 2017; Ingty, 2017; Kihila, 2017

	Employment and productivity enhancement potential		Terrier et al., 2011, 2015; IPCC, 2012; Mavhura et al., 2013; Yu and Gillis, 2014; Johnson and Abe, 2015; Mawere and Mubaya, 2015; Archer, 2016; Haeberli et al., 2016, 2017; Kull et al., 2016; Rose, 2016		Panda et al., 2013; Falco et al., 2014; Thornton and Herrero, 2014; Bogale, 2015; Greatrex et al., 2015; Lashley and Warner, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Nicola, 2015; Hansen et al., 2017; Jensen and Barrett, 2017	NE			Berkes et al., 2000; Nakashima et al., 2012; Leonard et al., 2013; Pearce et al., 2015; Harper et al., 2015; Clark et al., 2016; Altieri and Nicholls, 2017; Archer et al., 2017; Ruiz-Mallén et al., 2017; Russell-Smith et al., 2017; Ingty, 2017; Kihila, 2017; Magni, 2017
Technological	Technical resource availability		IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Yu and Gillis, 2014; Boeckmann and Rohn, 2014; Anacona et al., 2015; Johnson and Abe, 2015; Mawere and Mubaya, 2015; Boughedir, 2015; Howes et al., 2015; Allen et al., 2016; Kaya et al., 2016; Kull et al., 2016; Muñoz et al., 2016; Archer, 2016; Diaz, 2016; Haeberli et al., 2016, 2017; Wang et al., 2018		Falco et al., 2014; García Romero and Molina, 2015; Joyette et al., 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Akter et al., 2016; Surminski et al., 2016; Adiku et al., 2017; Jensen and Barrett, 2017		Dinku et al., 2014; Jancloes et al., 2014; Gebru et al., 2015; Weisse et al., 2015; Brasseur and Gallardo, 2016; Cortekar et al., 2016; Singh et al., 2016; Snow et al., 2016; Vaughan et al., 2016; Kihila, 2017		Berkes et al., 2000; Ford et al., 2010; Nakashima et al., 2012; Cunsolo Willox et al., 2013; Leonard et al., 2013; Pearce et al., 2015; Johnson et al., 2015; MacDonald et al., 2015a; Sherman et al., 2016; Altieri and Nicholls, 2017; Magni, 2017; Nunn et al., 2017; Russell-Smith et al., 2017; Inamara and Thomas, 2017; Ingty, 2017; Kihila, 2017
	Risks mitigation potential		IPCC, 2012; Mavhura et al., 2013; Yu and Gillis, 2014; Boughedir, 2015; Mawere and Mubaya, 2015; Howes et al., 2015; Johnson and Abe, 2015; Kelman et al.,		Mills, 2007; Cook and Dowlatabadi, 2011; Panda et al., 2013; Weinhofer and Busch, 2013; Thornton and Herrero, 2014; Falco		Rogers and Tsirkunov, 2010; WMO, 2015		Nakashima et al., 2012; McNamara and Prasad, 2014; Mapfumo et al., 2016; Kihila, 2017; Magni, 2017

			2015; Archer, 2016; Muñoz et al., 2016; Rose, 2016; Haeberli et al., 2016, 2017; Kull et al., 2016; Wallace, 2017; Kita, 2017		et al., 2014; Annan and Schlenker, 2015; Lashley and Warner, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Nicola, 2015; Fabian, 2015; Wolfrom and Yokoi-Arai, 2015; García Romero and Molina, 2015; Greatrex et al., 2015; Surminski et al., 2016; Jin et al., 2016; Surminski and Eldridge, 2017; Surminski and Thieken, 2017; Farzaneh et al., 2017; Hansen et al., 2017; Jensen and Barrett, 2017				
Institutional	Political acceptability		Carey, 2005, 2008; IPCC, 2012; Boughedir, 2015; Johnson and Abe, 2015; Archer, 2016; Kull et al., 2016; Muñoz et al., 2016; Haeberli et al., 2016; Ruiz-Rivera and Lucatello, 2017; Granderson, 2017; Kelman, 2017; Kita, 2017; Rosendo et al., 2018		García Romero and Molina, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Glaas et al., 2017; Jenkins et al., 2017; Jensen and Barrett, 2017		Gebru et al., 2015; Vincent et al., 2015; Cortekar et al., 2016; Singh et al., 2016; Snow et al., 2016; Harjanne, 2017; Webber, 2017		Nakashima et al., 2012; Leonard et al., 2013; Ford et al., 2015; Hooli, 2016; Mistry and Berardi, 2016; Fernández-Llamazares et al., 2017; Russell-Smith et al., 2017; Williams et al., 2017; Ingty, 2017; Kihila, 2017; Magni, 2017; Ruiz-Mallén et al., 2017
	Legal and regulatory acceptability		IPCC, 2012; Boughedir, 2015; Howes et al., 2015; Johnson and Abe,		Falco et al., 2014; Thornton and Herrero, 2014;		Mantilla et al., 2014; Coulibaly et		Berkes et al., 2000; Nakashima et al., 2012; Leonard et al.,

			2015; Kelman et al., 2015; Kull et al., 2016; Muñoz et al., 2016; van der Keur et al., 2016; Haeberli et al., 2016, 2017; Kaya et al., 2016; de Leon and Pittock, 2017; Kita, 2017; Ruiz-Rivera and Lucatello, 2017; Serrao-Neumann et al., 2017; Wallace, 2017; Kelman, 2017; Rosendo et al., 2018		Wolfrom and Yokoi-Arai, 2015; García Romero and Molina, 2015; Joyette et al., 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Surminski et al., 2016; Adiku et al., 2017; Glaas et al., 2017; Hansen et al., 2017; Jenkins et al., 2017; Jensen and Barrett, 2017		al., 2015; Lobo et al., 2017		2013; Hiwasaki et al., 2014; Ford et al., 2015; Hooli, 2016; Ruiz-Mallén et al., 2017; Russell-Smith et al., 2017; Ingty, 2017; Kihila, 2017; Magni, 2017; Mccubbin et al., 2017
	Institutional capacity and administrative feasibility		Carey, 2008; IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Boughedir, 2015; Kelman et al., 2015; Mawere and Mubaya, 2015; Howes et al., 2015; Johnson and Abe, 2015; Archer, 2016; Kull et al., 2016; Muñoz et al., 2016; Rose, 2016; van der Keur et al., 2016; Watanabe et al., 2016; Haeberli et al., 2016, 2017; Kita, 2017; Ruiz-Rivera and Lucatello, 2017; Serrao-Neumann et al., 2017; Wallace, 2017; Granderson, 2017; Kelman, 2017; Nahayo et al., 2018; Rosendo et al., 2018		Cook and Dowlatabadi, 2011; Weinhofer and Busch, 2013; Thornton and Herrero, 2014; Falco et al., 2014; Joyette et al., 2015; Lashley and Warner, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Wolfrom and Yokoi-Arai, 2015; García Romero and Molina, 2015; Greatrex et al., 2015; Akter et al., 2016; Surminski et al., 2016; Adiku et al., 2017; Surminski and Eldridge, 2017; Glaas et al., 2017; Hansen et al., 2017; Jenkins		Dinku et al., 2014; Wood et al., 2014; Jancloes et al., 2014; Vaughan and Dessai, 2014; Vincent et al., 2015; Brasseur and Gallardo, 2016; Vaughan et al., 2016; Lourenço et al., 2016; Snow et al., 2016; Trenberth et al., 2016; Harjanne, 2017; Räsänen et al., 2017; Singh et al., 2017		Berkes et al., 2000; Nakashima et al., 2012; Hiwasaki et al., 2014, 2015; Oteros-Rozas et al., 2015; Ford et al., 2015; Johnson et al., 2015; Sherman et al., 2016; Mistry and Berardi, 2016; Fernández-Llamazares et al., 2017; Ruiz-Mallén et al., 2017; Russell-Smith et al., 2017; Williams et al., 2017; Granderson, 2017; Kihila, 2017; Magni, 2017

			et al., 2017; Jensen and Barrett, 2017		
	Transparency and accountability potential	Carey, 2005; IPCC, 2012; Howes et al., 2015; Johnson and Abe, 2015; Kaya et al., 2016; Kita, 2017; Ruiz-Rivera and Lucatello, 2017; Rosendo et al., 2018	Thornton and Herrero, 2014; García Romero and Molina, 2015; Greatrex et al., 2015; Joyette et al., 2015; Lashley and Warner, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Jin et al., 2016; Adiku et al., 2017; Hansen et al., 2017; Jensen and Barrett, 2017	Vaughan and Dessai, 2014; Harjanne, 2017; Hewitson et al., 2017	Berkes et al., 2000; Nakashima et al., 2012; Leonard et al., 2013; Green and Minchin, 2014; Hiwasaki et al., 2014; Ford et al., 2015; Johnson et al., 2015; Oteros-Rozas et al., 2015; Mistry and Berardi, 2016; Russell-Smith et al., 2017; Magni, 2017; Rapinski et al., 2018
Socio-cultural	Social co-benefits (health, education)	IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Samaddar et al., 2015; Mawere and Mubaya, 2015; Archer, 2016; Watanabe et al., 2016; Haeberli et al., 2016; Kull et al., 2016; Rose, 2016; Brundiers, 2018; Nahayo et al., 2018	Panda et al., 2013; Thornton and Herrero, 2014; Greatrex et al., 2015; Lashley and Warner, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Adiku et al., 2017; Glaas et al., 2017; Hansen et al., 2017; Jensen and Barrett, 2017	Rogers and Tsirkunov, 2010; Kadi et al., 2011; Hunt et al., 2017	Ford, 2012; Leonard et al., 2013; McNamara and Prasad, 2014; Ford et al., 2014; Green and Minchin, 2014; Cunsolo Willox et al., 2015; Durkalec et al., 2015; MacDonald et al., 2015a, b; Harper et al., 2015; Hiwasaki et al., 2015; Mapfumo et al., 2016; Mistry and Berardi, 2016; Hooli, 2016; Magni, 2017; Kihila, 2017
	Socio-cultural acceptability	Carey, 2005; IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Anacona et al., 2015; Mawere and Mubaya, 2015;	Lashley and Warner, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Bogale, 2015; García Romero and	Sivakumar et al., 2014; Vincent et al., 2015; Brasseur and Gallardo, 2016; Cortekar et al., 2016; Carr and	Natcher et al., 2007; Ford et al., 2010; Cunsolo Willox et al., 2012; Nakashima et al., 2012; Adger et al., 2013; Leonard et al.,

			Samaddar et al., 2015; Archer, 2016; Muñoz et al., 2016; Rose, 2016; van der Keur et al., 2016; Watanabe et al., 2016; Kaya et al., 2016; Kull et al., 2016; Serrao-Neumann et al., 2017; de Leon and Pittock, 2017; Granderson, 2017; Kita, 2017		Molina, 2015; Greatrex et al., 2015; Jin et al., 2016; Adiku et al., 2017; Akter et al., 2017; Farzaneh et al., 2017; Glaas et al., 2017; Hansen et al., 2017; Jensen and Barrett, 2017		Onzere, 2017; Singh et al., 2017; Webber and Donner, 2017; Guido et al., 2018		2013; Green and Minchin, 2014; MacDonald et al., 2015a; Hiwasaki et al., 2015; Johnson et al., 2015; Mapfumo et al., 2016; Hooli, 2016; Tschakert et al., 2017; Kihila, 2017; Flynn et al., 2018
	Social and regional inclusiveness		Carey, 2005; IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Samaddar et al., 2015; Mawere and Mubaya, 2015; Archer, 2016; Rose, 2016; Watanabe et al., 2016; Kaya et al., 2016; Kull et al., 2016; de Leon and Pittock, 2017; Granderson, 2017; Kita, 2017; Nahayo et al., 2018		Falco et al., 2014; Bogale, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; García Romero and Molina, 2015; Greatrex et al., 2015; Joyette et al., 2015; Akter et al., 2016; Surminski et al., 2016; Jin et al., 2016; Shively, 2017; Farzaneh et al., 2017; Hansen et al., 2017; Jensen and Barrett, 2017		Expert judgement Sivakumar et al., 2014; Carr and Onzere, 2017; Webber and Donner, 2017		Berkes et al., 2000; Nakashima et al., 2012; Adger et al., 2013; Leonard et al., 2013; Green and Minchin, 2014; McNamara and Prasad, 2014; MacDonald et al., 2015a; Mistry and Berardi, 2016; Hooli, 2016; Nunn et al., 2017; Ruiz-Mallén et al., 2017; Ingty, 2017; Magni, 2017; Flynn et al., 2018
	Intergenerational equity		IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Mawere and Mubaya, 2015; Archer, 2016; Kaya et al., 2016; Granderson, 2017; Nahayo et al., 2018		Linnerooth-Bayer and Hochrainer-Stigler, 2015; O'Hare et al., 2016; Jensen and Barrett, 2017	NA			Berkes et al., 2000; Ford et al., 2010; Nakashima et al., 2012; Leonard et al., 2013; McNamara and Prasad, 2014; Hiwasaki et al., 2015; MacDonald et al., 2015a; Tschakert et al., 2017; Kihila,

									2017; Magni, 2017; Nunn et al., 2017
Environmental/ecological	Ecological capacity		IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Kelman et al., 2015; Mawere and Mubaya, 2015; Archer, 2016; Haeberli et al., 2016; Kull et al., 2016	NA		NA			Berkes et al., 2000; Forbes et al., 2009; Leonard et al., 2013; McNamara and Prasad, 2014; MacDonald et al., 2015b; Altieri and Nicholls, 2017; Russell-Smith et al., 2017; Tschakert et al., 2017; Ingty, 2017; Kihila, 2017; Magni, 2017; Nunn et al., 2017
	Adaptive capacity/ resilience		IPCC, 2012; Mavhura et al., 2013; McNamara and Prasad, 2014; Boeckmann and Rohn, 2014; Yu and Gillis, 2014; Anacona et al., 2015; Johnson and Abe, 2015; Kelman et al., 2015; Mawere and Mubaya, 2015; Howes et al., 2015; Archer, 2016; Kaya et al., 2016; Kull et al., 2016; Muñoz et al., 2016; Rose, 2016; Watanabe et al., 2016; Haeberli et al., 2016, 2017; Kelman, 2017; Wallace, 2017; de Leon and Pittock, 2017; Granderson, 2017; Brundiers, 2018		Mills, 2007; Panda et al., 2013; Thornton and Herrero, 2014; Falco et al., 2014; Bogale, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Nicola, 2015; Wolfrom and Yokoi-Arai, 2015; García Romero and Molina, 2015; Greatrex et al., 2015; Lashley and Warner, 2015; O'Hare et al., 2016; Surminski et al., 2016; Jin et al., 2016; Adiku et al., 2017; Hansen et al., 2017; Jenkins et al., 2017; Jensen and Barrett, 2017		L. Jones et al., 2016; Lourenço et al., 2016; Singh et al., 2017; C.J. White et al., 2017		Berkes et al., 2000; Forbes et al., 2009; Ford et al., 2010; Nakashima et al., 2012; Leonard et al., 2013; McNamara and Prasad, 2014; Pearce et al., 2015; Hiwasaki et al., 2015; Savo et al., 2016; Sherman et al., 2016; Mapfumo et al., 2016; Altieri and Nicholls, 2017; Nunn et al., 2017; Russell-Smith et al., 2017; Kihila, 2017; Magni, 2017; Mccubbin et al., 2017

Geophysical	Physical feasibility		IPCC, 2012; Yu and Gillis, 2014; McNamara and Prasad, 2014; Anacona et al., 2015; Boughedir, 2015; Kelman et al., 2015; Archer, 2016; Muñoz et al., 2016; Diaz, 2016; Haeberli et al., 2016, 2017; Kull et al., 2016	NA			Sivakumar et al., 2014; Snow et al., 2016; C.J. White et al., 2017	NE	
	Land use change enhancement potential	NA			Panda et al., 2013; Annan and Schlenker, 2015; Greatrex et al., 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Hansen et al., 2017; Jenkins et al., 2017; Jensen and Barrett, 2017	NA			Berkes et al., 2000; Nakashima et al., 2012; Leonard et al., 2013; McNamara and Prasad, 2014; Pearce et al., 2015; Hiwasaki et al., 2015; MacDonald et al., 2015b; Reyes-García et al., 2016; Mistry and Berardi, 2016; Altieri and Nicholls, 2017; Kihila, 2017; Magni, 2017
	Hazard risk reduction potential		Carey, 2005, 2008; IPCC, 2012; Mavhura et al., 2013; Boeckmann and Rohn, 2014; McNamara and Prasad, 2014; Yu and Gillis, 2014; Anacona et al., 2015; Howes et al., 2015; Johnson and Abe, 2015; Kelman et al., 2015; Mawere and Mubaya, 2015; Boughedir, 2015; Archer, 2016; Kaya et		Mills, 2007; Falco et al., 2014; Annan and Schlenker, 2015; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Wolfrom and Yokoi-Arai, 2015; García Romero and Molina, 2015; Greatrex et al., 2015; Lashley and Warner, 2015; Surminski et al., 2016; Jin et al., 2016; Patel et al.,		Rogers and Tsirkunov, 2010; Lourenço et al., 2016; Singh et al., 2017		Berkes et al., 2000; Nakashima et al., 2012; Leonard et al., 2013; Mistry and Berardi, 2016; Altieri and Nicholls, 2017; Magni, 2017; Nunn et al., 2017; Russell-Smith et al., 2017

			al., 2016; Kull et al., 2016; Muñoz et al., 2016; Rose, 2016; Watanabe et al., 2016; Diaz, 2016; Haeberli et al., 2016, 2017; Kelman, 2017; Kita, 2017; Milner et al., 2017; Wallace, 2017; Brundiers, 2018		2017; Surminski and Eldridge, 2017; Surminski and Thieken, 2017; Farzaneh et al., 2017; Glaas et al., 2017; Hansen et al., 2017; Jensen and Barrett, 2017				

Table 4.SM.23: Feasibility assessment of overarching adaptation options: education and learning, population health and health system adaptation, social safety nets and human migration. For methodology, see 4.SM.4.1.

		Education and Learning		**Population Health and Health System Adaptation**		**Social Safety Nets**		**Human Migration**	
	Evidence	Medium		Medium		Medium		Medium	
	Agreement	High		High		Medium		Low	
Economic	Microeconomic viability		Rumore et al., 2016; Lutz and Muttarak, 2017		Toloo et al., 2013; Burton et al., 2014; Hoy et al., 2014; Paterson et al., 2014; K.R. Smith et al., 2014; Confalonieri et al., 2015; Araos et al., 2016a; Hess and Ebi, 2016; Ebi and del Barrio, 2017; Gilfillan et al., 2017; Paavola, 2017		Shiferaw et al., 2014; Devereux et al., 2015		Birk and Rasmussen, 2014; Betzold, 2015; Ionesco et al., 2016; Musah-Surugu et al., 2018
	Macroeconomic viability		Hoffmann and Muttarak, 2017; Lutz and Muttarak, 2017		Ebi et al., 2004; Hess et al., 2012; Hosking and Campbell-Lendrum, 2012; Lesnikowski et al., 2013; Toloo et al., 2013; Bowen et al., 2013; K.R. Smith et al., 2014; Hoy et al., 2014; Austin et al., 2015; Watts et al., 2015; WHO, 2015; Araos et al., 2016a; Paz et al., 2016; Hess and Ebi, 2016; Nitschke et al., 2017; Paavola, 2017; Ebi and del Barrio, 2017; Gilfillan et al., 2017		Devereux et al., 2015		Grecequet et al., 2017; Hino et al., 2017
	Socio-economic vulnerability reduction potential		Frankenberg et al., 2013; K.C., 2013; Striessnig et al., 2013; van der Land and Hummel, 2013; Muttarak and Lutz, 2014; Rumore et al., 2016; Hoffmann and Muttarak, 2017; Lutz and Muttarak, 2017		Ebi et al., 2004, 2016; Hess et al., 2012; Hosking and Campbell-Lendrum, 2012; Panic and Ford, 2013; Toloo et al., 2013; Bowen et al., 2013; K.R. Smith et al., 2014; Boeckmann and Rohn, 2014; Austin et al., 2015; Watts et al., 2015; WHO, 2015; Confalonieri et al., 2015; Araos et al., 2016a; Hess and Ebi, 2016; Paz et al., 2016; Benmarhnia et al., 2016; Gilfillan et al., 2017; Nitschke et al., 2017;		Davies et al., 2013; Weldegebriel and Prowse, 2013; Berhane et al., 2014; Eakin et al., 2014; Leichenko and Silva, 2014; Devereux, 2016; Lemos et al., 2016; Godfrey-Wood and Flower, 2017; Schwan and Yu, 2017		Birk and Rasmussen, 2014; Adger et al., 2015; Betzold, 2015; Grecequet et al., 2017; Melde et al., 2017; World Bank, 2017

					Paavola, 2017; Sen et al., 2017; Ebi and del Barrio, 2017; Ebi and Hess, 2017				
	Employment and productivity enhancement potential		van der Land and Hummel, 2013; Muttarak and Lutz, 2014; Lutz and Muttarak, 2017		Bowen et al., 2013; Toloo et al., 2013; Burton et al., 2014; Hoy et al., 2014; K.R. Smith et al., 2014; Benmarhnia et al., 2016; Paz et al., 2016; Gilfillan et al., 2017; Nitschke et al., 2017		Davies et al., 2013; Berhane et al., 2014; Shiferaw et al., 2014	NA	
Technological	Technical resource availability		Chaudhury et al., 2013; Baird et al., 2014; Cloutier et al., 2015; Rumore et al., 2016		Hess et al., 2012; Lesnikowski et al., 2013; Panic and Ford, 2013; Toloo et al., 2013; Bowen et al., 2013; Hoy et al., 2014; Paterson et al., 2014; Rumsey et al., 2014; K.R. Smith et al., 2014; Burton et al., 2014; Austin et al., 2015; WHO, 2015; Confalonieri et al., 2015; Araos et al., 2016a; Paz et al., 2016; Benmarhnia et al., 2016; Ebi et al., 2016; Hess and Ebi, 2016; Nitschke et al., 2017; Paavola, 2017; Sheehan et al., 2017; Ebi and del Barrio, 2017; Ebi and Hess, 2017		Kim and Yoo, 2015		Birk and Rasmussen, 2014; Gemenne and Blocher, 2017; Melde et al., 2017
	Risks mitigation potential		Wamsler et al., 2012; Frankenberg et al., 2013; K.C., 2013; Striessnig et al., 2013; van der Land and Hummel, 2013; Muttarak and Lutz, 2014; Harteveld and Suarez, 2015; Lutz and Muttarak, 2017		Boeckmann and Rohn, 2014; Paterson et al., 2014; Benmarhnia et al., 2016; Hess and Ebi, 2016; Nitschke et al., 2016; Ebi and del Barrio, 2017; Ebi and Hess, 2017		Davies et al., 2013; Rurinda et al., 2014; Shiferaw et al., 2014; Devereux, 2016		Adger et al., 2015; Grecequet et al., 2017; Tadgell et al., 2017
Institutional	Political acceptability	LE	Butler et al., 2015, 2016b; Cloutier et al., 2015		Hess et al., 2012; Lesnikowski et al., 2013; Bowen et al., 2013; Hoy et al., 2014; Rumsey et al., 2014; K.R. Smith et al., 2014; Burton et al., 2014; Austin et al., 2015; Watts et		Porter et al., 2014; Rurinda et al., 2014; Wilhite et al., 2014; Brooks, 2015; Kim and Yoo, 2015; Ravi and		Kothari, 2014; Methmann and Oels, 2015; Brzoska and Fröhlich, 2016; Gemenne and Blocher, 2017; Grecequet et al.,

					al., 2015; WHO, 2015; Confalonieri et al., 2015; Araos et al., 2016a; Hess and Ebi, 2016; Benmarhnia et al., 2016; Ebi et al., 2016; Sen et al., 2017; Ebi and del Barrio, 2017; Gilfillan et al., 2017; Green et al., 2017		Engler, 2015; Schwan and Yu, 2017)		2017; Yamamoto et al., 2017; Matthews and Potts, 2018
	Legal and regulatory acceptability	NE			Hess et al., 2012; Lesnikowski et al., 2013; Burton et al., 2014; Austin et al., 2015; Watts et al., 2015; WHO, 2015; Araos et al., 2016a; Ebi et al., 2016; Hess and Ebi, 2016; Paz et al., 2016; Shimamoto and McCormick, 2017; Ebi and del Barrio, 2017; Gilfillan et al., 2017		Rurinda et al., 2014; Devereux et al., 2015		Wilmsen and Webber, 2015; Tadgell et al., 2017; Ahmed, 2018; World Bank, 2018
	Institutional capacity and administrative feasibility		Wamsler et al., 2012; Chaudhury et al., 2013; Odemerho, 2014; Cloutier et al., 2015; Butler et al., 2016a, b		Ebi et al., 2004, 2016; Hess et al., 2012; Lesnikowski et al., 2013; Panic and Ford, 2013; Toloo et al., 2013; Bowen et al., 2013; Hoy et al., 2014; Nigatu et al., 2014; Paterson et al., 2014; Rumsey et al., 2014; Burton et al., 2014; Austin et al., 2015; Watts et al., 2015; WHO, 2015; Confalonieri et al., 2015; Araos et al., 2016a; Hess and Ebi, 2016; Benmarhnia et al., 2016; Paz et al., 2016; Xiao et al., 2016; Gilfillan et al., 2017; Green et al., 2017; Nitschke et al., 2017; Sheehan et al., 2017; Shimamoto and McCormick, 2017; Ebi and del Barrio, 2017; Ebi and Hess, 2017		Davies et al., 2013; Rurinda et al., 2014; Wilhite et al., 2014; Ravi and Engler, 2015; Schwan and Yu, 2017		Betzold, 2015; Methmann and Oels, 2015; Brzoska and Fröhlich, 2016; Gemenne and Blocher, 2017; Grecequet et al., 2017; Yamamoto et al., 2017; Matthews and Potts, 2018; Thomas and Benjamin, 2018
	Transparency and accountability potential		Chaudhury et al., 2013; Odemerho, 2014; Ensor and Harvey, 2015; Harteveld and Suarez, 2015; Chung Tiam Fook, 2017; Myers et al., 2017; Flynn et al., 2018		Hess et al., 2012; Hosking and Campbell-Lendrum, 2012; Lesnikowski et al., 2013; Panic and Ford, 2013; Hoy et al., 2014; Boeckmann and Rohn, 2014; Austin et al., 2015; Araos et al., 2016a;		Masud-All-Kamal and Saha, 2014; Devereux et al., 2015; Masiero, 2015; Ravi and Engler, 2015; Schwan and Yu, 2017		Methmann and Oels, 2015; Brzoska and Fröhlich, 2016; Tadgell et al., 2017

					Benmarhnia et al., 2016; Ebi et al., 2016; Sheehan et al., 2017; Ebi and del Barrio, 2017; Ebi and Hess, 2017; Gilfillan et al., 2017				
Socio-cultural	Social co-benefits (health, education)		Wamsler et al., 2012; Frankenberg et al., 2013; K.C., 2013; van der Land and Hummel, 2013; Muttarak and Lutz, 2014; Chung Tiam Fook, 2017; Hoffmann and Muttarak, 2017; Lutz and Muttarak, 2017		Bowen et al., 2013; K.R. Smith et al., 2014; Hoy et al., 2014; Austin et al., 2015; Watts et al., 2015; Confalonieri et al., 2015; Ebi et al., 2016; Hess and Ebi, 2016; Paz et al., 2016; Ebi and del Barrio, 2017; Paavola, 2017; Shimamoto and McCormick, 2017		Berhane et al., 2014; Leichenko and Silva, 2014; Rurinda et al., 2014; Shiferaw et al., 2014; Verguet et al., 2015; Devereux, 2016; Lemos et al., 2016		Kothari, 2014; Bettini et al., 2016; Gioli et al., 2016; Bhagat, 2017; Melde et al., 2017; Schwan and Yu, 2017; World Bank, 2018
	Socio-cultural acceptability		Chaudhury et al., 2013; Sharma et al., 2013; Demuzere et al., 2014; Odemerho, 2014; Ensor and Harvey, 2015; Butler et al., 2016a; Myers et al., 2017; Flynn et al., 2018		Hess et al., 2012; Bowen et al., 2013; Toloo et al., 2013; K.R. Smith et al., 2014; Hoy et al., 2014; Confalonieri et al., 2015; Watts et al., 2015; WHO, 2015; Ebi et al., 2016; Hess and Ebi, 2016; Paz et al., 2016; Ebi and del Barrio, 2017; Nitschke et al., 2017; Sen et al., 2017	LE	Rurinda et al., 2014; Wilhite et al., 2014		Martin et al., 2014; Brzoska and Fröhlich, 2016; Jha et al., 2017; Kelman et al., 2017; Huntington et al., 2018
	Social and regional inclusiveness		Wamsler et al., 2012; Muttarak and Lutz, 2014; Suarez et al., 2014; Ensor and Harvey, 2015; Ford et al., 2016, 2018		Hosking and Campbell-Lendrum, 2012; Bowen et al., 2013; Panic and Ford, 2013; Toloo et al., 2013; K.R. Smith et al., 2014; Burton et al., 2014; Hoy et al., 2014; Watts et al., 2015; WHO, 2015; Confalonieri et al., 2015; Benmarhnia et al., 2016; Paz et al., 2016; Ebi et al., 2016; Hess and Ebi, 2016; Sen et al., 2017; Ebi and del Barrio, 2017; Paavola, 2017	NA			Kothari, 2014; Kelman, 2015; Schwan and Yu, 2017; Matthews and Potts, 2018; World Bank, 2018
	Intergenerational equity	LE	Striessnig et al., 2013		Ebi et al., 2004; Confalonieri et al., 2015; Benmarhnia et al., 2016; Ebi and del Barrio, 2017; Paavola, 2017)	NA			Wilmsen and Webber, 2015
Environm	Ecological capacity	NA		NA		NA			Niven and Bardsley, 2013; Birk and Rasmussen, 2014
	Adaptive capacity/resilience		K.C., 2013; Sharma et al., 2013; Striessnig et al., 2013;		Hess et al., 2012; Toloo et al., 2013; K.R. Smith et al., 2014; Confalonieri		Davies et al., 2013; Weldegebriel and		Birk and Rasmussen, 2014; Adger et al., 2015;

			Frankenberg et al., 2013; Baird et al., 2014; Lutz et al., 2014; Muttarak and Lutz, 2014; Suarez et al., 2014; Tschakert et al., 2014; Butler and Adamowski, 2015; Oteros-Rozas et al., 2015; Pearce et al., 2015; Ensor and Harvey, 2015; Janif et al., 2016; Butler et al., 2016a, b; Star et al., 2016; Vinke-de Kruijf and Pahl-Wostl, 2016; Harvey et al., 2017; Hoffmann and Muttarak, 2017; Lutz and Muttarak, 2017; Myers et al., 2017; Chung Tiam Fook, 2017; Cochrane et al., 2017; Flynn et al., 2018; Ford et al., 2018		et al., 2015; Watts et al., 2015; WHO, 2015; Benmarhnia et al., 2016; Hess and Ebi, 2016; Paz et al., 2016; Ebi and del Barrio, 2017; Nitschke et al., 2017; Paavola, 2017; Sen et al., 2017		Prowse, 2013; Eakin et al., 2014; Rurinda et al., 2014; Shiferaw et al., 2014; Lemos et al., 2016; Schwan and Yu, 2017		Grecequet et al., 2017; Melde et al., 2017; Tadgell et al., 2017; World Bank, 2018
Geophysical	Physical feasibility	NA		NA		NA			Niven and Bardsley, 2013; Hino et al., 2017; Matthews and Potts, 2018
	Land use change enhancement potential	NA		NA		NA		LE	Matthews and Potts, 2018
	Hazard risk reduction potential		Wamsler et al., 2012; Frankenberg et al., 2013; K.C., 2013; Striessnig et al., 2013; Muttarak and Lutz, 2014; Suarez et al., 2014; Harteveld and Suarez, 2015; Hoffmann and Muttarak, 2017; Lutz and Muttarak, 2017	NA			Jones et al., 2010; Davies et al., 2013		Birk and Rasmussen, 2014; Cattaneo and Peri, 2016; Grecequet et al., 2017; Tadgell et al., 2017; Crnčević and Orlović Lovren, 2018; World Bank, 2018

4.SM.5 Adaptation and Mitigation Synergies and Trade-offs as Discussed in Section 4.5.4

Mitigation options may affect the feasibility of adaptation options, and the other way around. Table 4.SM.24 provides examples of possible positive impacts (synergies) and negative impacts (trade-offs) of mitigation options for adaptation. Table 4.SM.25 lists examples of synergies and trade-offs of adaptation options for mitigation.

4.SM.5.1 Mitigation Options with Adaptation Synergies and Trade-offs

Table 4.SM.24: Mitigation options with adaptation synergies and trade-offs identified.

System	Mitigation Option	Synergies	Trade-offs
Energy system transitions	Wind energy (on-shore and off-shore)	Resilience can be increased by wind, solar and bioenergy due to distributed grids (Parkinson and Djilali, 2015), given that energy security standards are in place (Almeida Prado et al., 2016). The use of residential batteries can increase resilience, especially after extreme weather events (Qazi and Young Jr., 2014; Liu et al., 2017). A shift from coal-generated to natural gas-generated electricity could decrease water consumption (DeNooyer et al., 2016).	Renewable energy infrastructure that does not follow security standards can increase vulnerability (Ley, 2017).
	Solar photovoltaic (PV)		
	Bioenergy		
	Electricity storage		
	Power sector CCS	NE	Some renewable energy technologies, carbon dioxide capture and storage (CCS), and concentrating solar power technologies have substantial water demand associated with their operation (Fricko et al., 2016). In particular, lower power plant efficiency due to CCS increases the vulnerability to water constraints in most regions (McCollum et al., 2013; van Vliet et al., 2016).
	Nuclear energy	Increased safety and protection standards can improve the climate risk profiles (Schneider et al., 2017).	Increased safety and protection standards will increase costs, making some electricity systems less reliable (Jacobson and Delucchi, 2009; Lovins et al., 2018).
Land and ecosystem transitions	Reduced food wastage and efficient food production	Reducing food loss and waste can decrease pressure of deforestation (FAO, 2013a), pressure on land use for agriculture (Foley et al., 2011; Hiç et al., 2016), and provide long-term food security (Bajželj et al., 2014).	NA
	Dietary shifts	Shift from animal- to plant-related diets can significantly decrease land use and biodiversity loss due to a decrease in pressure on land use by livestock production (Newbold et al., 2015; Ramankutty et al., 2018; Sparovek et al., 2018) along with health benefits (Tilman and Clark,	Shift from animal- to plant-related diets will require improvement of mixed crop-livestock systems, which are more difficult to manage well and need higher capital to be established (Ramankutty et al., 2018).

		2014; Westhoek et al., 2014; Hallström et al., 2017; Song et al., 2017).	
	Sustainable intensification of agriculture	Agroforestry practices increase soil carbon stocks and above-ground biomass as well as diversify incomes, reducing financial risk, and provide shade for protection from rising temperatures (Harvey et al., 2014). Agroforestry can sustain or increase food production in some systems, increasing farmers' resilience to climate change (Jones et al., 2012). Mixed agroforestry systems may simultaneously meet the water, food, energy and income needs of densely populated rural and peri-urban areas (van Noordwijk et al., 2016).	Sustainable intensification can increase offsite impacts from fertilizer, herbicide and pesticide use (Stevens and Quinton 2009), increase costs and increase climate risk. No-tillage without pairing with other agronomic practices can reduce crop yields. No-till agriculture can reduce GHG emissions but increase pesticide concentrations (Stevens and Quinton, 2009). Adaptation gains made through improved irrigation efficiency can be undermined by shifts to water-intensive crops for mitigation (e.g., shifting to bioenergy crops) (Chaturvedi et al., 2015). Conservation agriculture reduces yields 3–5 years after adoption, but enhances productivity and carbon sequestration over longer periods (Harvey et al., 2014). Agroforestry can, in some dry environments, increase competition with crops and pastures, decreasing productivity, and reduce catchment water yield (Schrobback et al., 2011). Fast-growing tree monocultures or biofuel crops may enhance carbon stocks but reduce downstream water availability and decrease availability of agricultural land (Harvey et al., 2014). Agricultural intensification that improves crop productivity can increase incomes but undermine local livelihoods and well-being as seen in shifts to intensified sugarcane production in Ethiopia or more intensive land use in Southeast Asia (Liao and Brown, 2018).
	Ecosystem restoration	Sustainable water management – restored/healthy ecosystems provide water storage and filtration services (Jones et al., 2012). Restoration of mangroves and coastal wetlands to sequester (blue) carbon increases carbon sinks, reduces coastal erosion and protects from storm surges, and otherwise mitigates impacts of sea level rise and extreme weather along the coast line (Alongi, 2008; Siikamäki et al.,	A focus on mitigation, for example, through REDD+, can result in conservation-priority sites with lower carbon densities to end up without REDD+ protection (Phelps et al., 2012; Murray et al., 2015; Turnhout et al., 2017; Reside et al., 2018). Potential conflict with biodiversity goals in habitat restoration and forest production efforts (Felton et al., 2016).

		2012; Romañach et al., 2018). Blue biofuels do not compete for land and water and are not global food staples (posing less of a food security issue). Most farms do not use fertilizer and could even remove excess nutrients, decreasing eutrophication (Turner et al., 2009; Duarte et al., 2013). Stabilization and support of fisheries can add value to marine biodiversity (Turner et al., 2009). Carbon offset funds provide opportunities for protection and restoration of native ecosystems, with corresponding gains for biodiversity and reductions in carbon (Reside et al., 2017). Coupled with biodiversity and conservation interventions, ecosystem restoration and avoided deforestation can complement habitat provision (Felton et al., 2016). Forests (through REDD+) can support economies dependent on climate-sensitive sectors including agriculture, fisheries and energy (Somorin et al., 2016; Few et al., 2017). REDD+ has the potential to promote sustainable development activities through the cash-flow from donors/international funds to local forest stakeholders (West, 2016). Tropical reforestation for climate change mitigation can help to protect rural economies from impacts of climate variation, reduce impacts of climatic variation on water cycle and associated human uses, reduce local impacts of extreme weather events and reduce climate impacts on biodiversity (Locatelli et al., 2015b).	Some projects worldwide do not target REDD+ projects on adaptation or resilience, nor local contexts, in some cases leaving negative livelihoods impacts (McElwee et al., 2016; Few et al., 2017). In some cases, there is a perception of the inability to reconcile development and environmental interests (Pham et al., 2017). Local benefits, especially for indigenous communities, will only be accrued if land tenure is respected and legally protected, which is not often the case for indigenous communities (Brugnach et al., 2017).
	Novel technologies	Breeding animals with lower emissions per unit of dry matter intake can reduce GHG emissions; when integrated within broader breeding programmes, this can offer synergies with breeding for improved adaptation to local conditions (Pickering et al., 2015; Nguyen et al., 2016).	May have consumer health concerns that need evaluation and addressing (Barrows et al., 2014; Fraser et al., 2016).

Urban and infrastructure system transitions	Land-use and urban planning	Potential for synergies in urban planning at policy, organizational and practical levels (e.g., urban regeneration, retrofitting, urban greening) (Landauer et al., 2015). Spatial planning can enhance adaptation, mitigation and sustainable development (Hurlimann and March, 2012; Davidse et al., 2015; King et al., 2016; Francesch-Huidobro et al., 2017). Through the use of integrated approaches there is potential synergy in land-use planning (e.g., maintenance of urban forests, urban greening) (Newman et al., 2017). Urban densification to reduce emissions can go along with regenerative qualities for green spaces and reduced urban heat islands and flooding impacts by employing biophilic urbanism design (Beatley, 2011; Newman et al., 2017).	Potential conflicts include urban densification to reduce emissions which can intensify heat island effects and increase surface run-off, and may compete with a desire to expand green space and restore local ecosystems (Landauer et al., 2015; Di Gregorio et al., 2017b; Endo et al., 2017; Ürge-Vorsatz et al., 2018), though demonstrations of biophilic urbanism show this can be managed (Beatley, 2011; Newman et al., 2017). In water-scarce regions, there may be trade-offs between mitigation measures that require water – such as localized cooling – and the population's water needs (Georgescu et al., 2015).
	Sustainable and resilient transport systems	Cities can re-urbanize in ways that promote transport sector adaptation and mitigation (Newman et al., 2017; Salvo et al., 2017; Gota et al., 2018). Cities that reduce the use of private cars and develop sustainable transport systems can simultaneously benefit from reduced air pollution, congestion and road fatalities while reducing overall energy intensity in the urban transport sector (Goodwin and Van Dender, 2013; Newman and Kenworthy, 2015; Wee, 2015). Non-motorized transport use is associated with lower emissions and better public health in cities. Urbanization and improved access to basic services correlate with lower short-term morbidity, such as fever, cough and diarrhea (Ahmad et al., 2017). Promoting energy-efficient mobility systems, for instance by a 10% increase in bicycling, could lower chronic conditions like diabetes and cardio-vascular diseases for 0.3 million people while also abating emissions (Ahmad et al., 2017).	In middle and low income countries urban density of informal settlements is typically associated with a range of water and vector-borne health risks that undermine benefits of energy efficiency; these may provide a notable exception to the adaptive advantages of urban density (Mitlin and Satterthwaite, 2013; Lilford et al., 2017) unless new approaches using leapfrog technology are used to upgrade slums in situ (Teferi and Newman, 2017).
	Sharing schemes in transportation	Greater use of sharing schemes can make transportation from vulnerable areas more equitable and ordered (Gomez et al., 2015; Ambrosino et al., 2016; Kent and Dowling, 2016).	Highly ICT-dependent sharing schemes may not be resilient during disasters, but this can be managed via local shared

			mobility systems related to local social capital (Mathbor, 2007; Bhakta Bhandari, 2014; McCloud et al., 2014).
	Public transport	Greater use of public transport enables more mass exit strategies from disasters (Wolshon et al., 2013).	Highly ICT-dependent public transport may not be resilient during disasters but this can be managed via local shared mobility systems related to local social capital (Mathbor, 2007; Bhakta Bhandari, 2014; McCloud et al., 2014).
	Smart grids	Greater resilience in electricity due to system feedback to damaged areas and other grid enhancements due to more localised data (Blaabjerg et al., 2004; IRENA, 2013; IEA, 2017c; Majzoobi and Khodaei, 2017).	NA
	Efficient appliances	Energy efficiency appliances (including lighting and ICT) reduce energy consumption and improve grid reliability (Chaturvedi and Shukla, 2014). They can provide demand response to absorb variation in the electricity supply due to disruption. In addition, when coupled with PV and storage, efficient appliances can secure energy supply when energy networks are down due to storms, hurricanes and other climate-induced events.	NA
	Low/zero-energy buildings	Building codes not only improve energy efficiency through insulation and air-tightness in buildings but also make them more capable of maintaining an indoor temperature during heat waves or power losses, to shelter people from heat waves and provide structural capability to withstand extreme weather and flooding (Houghton, 2011; King et al., 2016). Other examples of synergies are green roofs that provide insulation, cooling and rain water harvesting (Razzaghmanesh et al., 2016).	NE
Industrial system transitions	Energy efficiency	Reduced competition for resources (Hennessey et al., 2017).	Water-energy trade-offs exist in the production process adjustment, which is conventionally promoted as a key energy-saving measure in the iron and steel industry (C. Wang et al., 2017).
	Bio-based and circularity	Reduced competition for resources (Hennessey et al., 2017). Biomass production for industry, if well-managed, can diversify local livelihoods, enhance incomes and strengthen local institutions (Locatelli et al., 2015b).	NE
	Electrification and hydrogen	NA	Greater reliance on variable and weather-dependent sources of electricity (Philibert, 2017).
	Industrial CCUS	NA	Cooling requirements for carbon dioxide capture put pressure on adaptation (Magneschi et al., 2017).

Carbon dioxide removal	Bioenergy with CCS (BECCS)	Bioenergy, if well-managed, can diversify local livelihoods, enhance incomes and strengthen local institutions (Locatelli et al., 2015b). Combining BECCS with soil carbon management, agroforestry and afforestation can remove carbon dioxide, while limiting adverse impacts on water, food and biodiversity (Burns and Nicholson, 2017; Stoy et al., 2018).	Bioenergy plantations can decrease food security, compete for land and provide short-term benefits for only a few stakeholders (Locatelli et al., 2015a).
	Afforestation and reforestation	Reforestation connecting fragmented forests reduces exposure to forest edge disturbances (Pütz et al., 2014). Reforestation and coastal restoration are associated with improved water filtration, ground water recharge and flood control (Ellison et al., 2017; Griscom et al., 2017). Reduce flooding through decreased peak river flow, improved water quality and groundwater recharge (Berry et al., 2015). Increase diversity and habitat availability (when properly managed) (Berry et al., 2015). Tree planting led to more resilient livestock by providing shade and shelter (Hayman et al., 2012). Forestry, if well-managed, can diversify local livelihoods, enhance incomes and strengthen local institutions (Locatelli et al., 2015a). Afforestation of degraded areas can produce large synergies between mitigation and adaptation through their impact on farmer livelihoods (Rahn et al., 2014).	Water: increases water demand, reducing catchment yield (Berry et al., 2015). Biodiversity: species and habitat loss due to monocultures, chemical inputs or forest management (Berry et al., 2015). Loss of agricultural land (Berry et al., 2015). Forest plantations can decrease food security, compete for land and provide short-term benefits for only a few stakeholders (Locatelli et al., 2015a). Local benefits, especially for indigenous communities, will only be accrued if land tenure is respected and legally protected, which is not often the case for indigenous communities (Brugnach et al., 2017).
	Soil carbon sequestration and biochar	With agroforestry, carbon dioxide is sequestered through the additional trees planted, and tree products provide livelihood to communities (Verchot et al., 2007; Nair et al., 2009; Branca et al., 2013; Lasco et al., 2014; Mbow et al., 2014a; P. Smith et al., 2014). Soil organic carbon may foster crop resilience to climate change (Aguilera et al., 2013). Biochar application to soil sequesters carbon dioxide and at the same time increases crop productivity by up to 10% (Jeffery et al., 2011) and	Biochar amendments lead to plant growth and thus may down-regulate plant defence genes, increasing the vulnerability against insects, pathogens and drought (Viger et al., 2015).

		can improve the soil's water balance (Bamminger et al., 2016).	
	Enhanced weathering	NE	Potential adverse health effects because of air particles (Taylor et al., 2016).

4.SM.5.2 Adaptation Options with Mitigation Synergies and Trade-Offs

Table 4.SM.25: Adaptation options with mitigation synergies and trade-offs identified.

System	Adaptation Option	Synergies	Trade-offs
Energy system transitions	Power infrastructure, including water	Some adaptation options can help improve system efficiency and reliability (Cortekar and Groth, 2015; van Vliet et al., 2016). Synergies with Sustainable Development Goals, poverty and well-being (Dagnachew et al., 2018; Fuso Nerini et al., 2018; Gi et al., 2018).	A shift from open-loop to closed-loop cooling technologies could decrease withdrawals, with the trade-off of increasing water consumption for power generation (DeNooyer et al., 2016).
Land and ecosystem transitions	Conservation agriculture	Agroecological practices can reduce farm-scale carbon footprint significantly (Rakotovao et al., 2017). Practices, such as improved soil conservation practices in coffee agroforestry systems and improved slash and mulch agroforestry in bean-maize cultivation, have low carbon footprint reduction potential and medium carbon sequestration potential (Rahn et al., 2014). Land and water management adaptation measures have mitigation co-benefits through soil/atmospheric carbon sequestration, reduced emissions, soil nitrification and reduced use of inorganic fertilisers (Chandra et al., 2016). Conservation agriculture reduces yields 3–5 years after adoption, but enhances productivity and carbon sequestration over longer periods (Harvey et al., 2014). For conservation agriculture and efficient irrigation, synergies are regionally differentiated (Lobell et al., 2013).	Technologies enhancing farm productivity (such as adding fertilizers) might improve adaptive capacity through higher incomes but at the same time drive GHG emissions (Harvey et al., 2014; Thornton et al., 2017). In some cases, conservation agriculture practices can increase emissions (Gupta et al., 2016).
	Efficient irrigation	Improving irrigation efficiency has adaptation and mitigation co-benefits (Zou et al., 2012; Adenle et al., 2015; Suckall et al., 2015; Win et al., 2015). Efficient irrigation practices such as drip irrigation have, on average, 80% lower N_2O emissions than sprinkler systems. Drip irrigation combined with optimized fertilization reduces direct N_2O emissions by up to 50% (Sanz-	Micro-irrigation technologies such as drip and sprinkler irrigation increase irrigation efficiency but increase energy demand (Rasul and Sharma, 2016). Biomass production for biofuels may contribute to regional water shortages, salinization and water logging (Beringer et al., 2011).

		Cobena et al., 2017). Solar-powered drip irrigation significantly increases household income and nutritional intake, enables households to meet daily water needs and saves 0.86 tons of carbon emissions each year against a liquid fuel (e.g., kerosene) alternative (Suckall et al., 2015).	
	Efficient livestock systems	Strong synergies between climate change adaptation and mitigation in the livestock sector (Weindl et al., 2015; Rivera-Ferre et al., 2016) but these are differentiated by region and type of livestock system (Locatelli et al., 2015a; Thornton et al., 2017). For example, shifting from grazing to mixed livestock systems increase productivity while reducing GHG emissions, by gains in feed and forage productivity through more intensive inputs and management (Rivera-Ferre et al., 2016). Shifting towards mixed crop-livestock systems is a resource- and cost-efficient option (Herrero et al., 2015; Weindl et al., 2015; Thornton et al., 2018). Reducing livestock diseases can improve the productivity of livestock systems and increase their resilience to stresses while reducing the emissions intensity of livestock production (Bartley et al., 2016; FAO and NZAGRC, 2017). Adaptation through livestock supplementation and reducing stocking densities can reduce methane emissions (Locatelli et al., 2015a). Improved grassland management and appropriate stocking density can help to increase soil carbon stocks (Rivera-Ferre et al., 2016; Thornton et al., 2017).	Increased productivity of livestock systems generally increases overall food production and absolute GHG emissions, albeit at lower emissions per unit of food (Gerber et al., 2013; FAO and NZAGRC, 2017). Shifting to rangeland for feed can strongly increase tropical deforestation (Weindl et al., 2015). Shifting to mixed crop-livestock systems is expected to cause additional GHG emissions (Weindl et al., 2015). Providing cooling and ventilation systems for livestock (as an adaptation to higher temperatures) can increase GHG emissions (Locatelli et al., 2015a). Some adaptation options such as interregional livestock trading can increase carbon dioxide emissions through transportation (Rivera-Ferre et al., 2016).
	Agroforestry	Sequesters carbon through accumulation in woody biomass and soil (Lasco et al., 2014). Reduces GHG emissions through reduced deforestation and fossil fuel consumption (Lasco et al., 2014). Coupling native forest regeneration in concert with sugarcane bioethanol production can significantly increase carbon storage in the bioenergy production system and preserve biodiversity (Rodrigues et al., 2009; Buckeridge et al., 2012). The use of fertilizer-fixing trees can improve soil fertility through nitrogen	Lower carbon sequestration potential compared with natural forest and secondary forest (Lasco et al., 2014).

		fixation, by increasing supply of nutrients for crop production (Coulibaly et al., 2017). Integrating crop, livestock and forestry systems, such as in Brazil (Gil et al., 2015), can come with significant benefits for local farmers and ecosystems, for example, by rehabilitation of degraded pasturelands, which can also decrease emissions.	
	Food loss and waste management	Waste materials can be transformed into products with marketable value (Papargyropoulou et al., 2014), improving economic gain and stimulating decrease of food waste and loss.	NA
	Community-based adaptation	NE. Most literature addresses synergies with sustainable development, poverty and equity.	NE. Most literature addresses trade-offs with sustainable development, poverty and equity.
	Ecosystem restoration and avoided deforestation	Tropical reforestation as an adaptation measure can also result in significant carbon storage under climate-smart strategies (Locatelli et al., 2015b). Habitat restoration, afforestation and reforestation and urban trees and greenspace all lead to carbon sequestration (Berry et al., 2015).	Failure to consider mitigation in adaptation initiatives may lead to adaptation measures that increase GHG emissions, which is one type of maladaptation (Porter et al., 2014b; Kongsager et al., 2016).
	Biodiversity management	Biodiversity has value in terms of ecosystem services as well as protection/defence against invading species and disease organisms. Maintaining for high levels of biodiversity also recognises the fact that many species, biological processes and molecules in nature are as yet unexplored, yet have potential to provide enormous benefits to human beings (Knowlton et al., 2010; Pereira et al., 2010; Onaindia et al., 2013; Pistorious and Kiff, 2017; Price et al., 2018).	Areas with greatest potential for protecting biodiversity may not overlap with areas with most potential for carbon sequestration (Phelps et al., 2012; Essl and Mauerhofer, 2018).
	Coastal defence and hardening	NE	An alternative strategy is not to 'defend' using hardening structures along coastlines, but rather to retreat as sea levels rise and storm surges go further inland. The strategy of 'retreat' tends to make economic sense while at the same time accommodating the transition from terrestrial to marine systems (e.g., migration of salt marsh, mangroves and seagrass towards the land as sea levels rise) (C.J. Brown et al., 2016; Mills et al., 2016). There has been an increasing focus on natural barriers to storm surge and erosion, such as mangroves, oyster banks, coral reefs and seagrass meadows. Within these broad options, there are trade-offs that involve direct human intervention (e.g., coastal hardening, seawalls and artificial reefs) (Rinkevich, 2014, 2015; André et al., 2016; Cooper et al.,

			2016; Narayan et al., 2016), while there are others that exploit the opportunities for increasing coastal protection by involving naturally occurring oyster banks, coral reefs, mangroves, seagrass and other ecosystems (UNEP-WCMC, 2006; Scyphers et al., 2011; Zhang et al., 2012; Ferrario et al., 2014; Cooper et al., 2016). Protection using materials such as concrete to provide a barrier against the ocean. These structures can be installed quickly but the trade-off is that they have a range of negative consequences such as being expensive, interrupting natural ecosystems (Mills et al., 2016; Wernberg et al., 2016), being short-term solutions to the long-term problem of sea level rise and intensifying storm systems (Brooke et al., 1992; Building Futures and ICE, 2010; Mills et al., 2016).
	Sustainable aquaculture	NE	Regulating and avoiding loss of coastal ecosystems such as mangroves and seagrass, while at the same time developing food materials that have much lower impact on the environment (Schlag, 2010; Asiedu et al., 2017a, b).
	Fisheries restoration	Development of more sustainable practices also has benefits for ocean ecosystems in general. Fish play a crucial role in everything from maintaining ecological balances through their feeding habits to playing important roles within nutrient cycles in a range of habitats (Holmlund and Hammer, 1999).	NE
	Coastal and marine biodiversity management	NE	Planning for multiple objectives (e.g., biodiversity protection and carbon sequestration) increases the complexity of planning processes and data needs, accompanied by an increase in technical capacity by planners .
	Integrated coastal zone management	Mangroves serve as sinks for carbon, through accumulation of living biomass and through litter and dead wood deposition, including the trapping of sediments delivered from the uplands (Romañach et al., 2018).	NE
Urban and infrastructure system transitions	Sustainable land-use and urban planning	Potential for synergies in urban planning at policy, organizational and practical levels, for example, urban regeneration or retrofitting policies and urban greening (Landauer et al., 2015; Ürge-Vorsatz et al., 2018), including generating a shared sense of risks and promoting local participation (Archer et al., 2014; Kettle et al., 2014; Campos et al., 2016; Siders, 2017).	Promotion of green spaces to reduce flood risk and heat island effects may reduce potential for the promotion of urban densification (Landauer et al., 2015; Di Gregorio et al., 2017b; Endo et al., 2017; Ürge-Vorsatz et al., 2018).

		Urban planning can enhance adaptation, mitigation and sustainable development (Hurlimann and March, 2012; Davidse et al., 2015; King et al., 2016; Francesch-Huidobro et al., 2017). Land-use management for co-benefits can result in carbon sequestration (Duguma et al., 2014; Woolf et al., 2018).	
	Sustainable water management	Strong co-benefits to the implementation of demand-side management measures, such as reducing leakages and water loss (Wang et al., 2011; Deng and Zhao, 2015), while minimizing the need to address the environmental and energy implications of supply measures such as desalination (Miller et al., 2015).	Increasing water quality is linked to increasing energy use in the water sector (Rothausen and Conway, 2011; Mamais et al., 2015).
	Green infrastructure and ecosystem services	Urban canopy is a cooling mechanism that can help decrease heat and water stress (Hines, 2017).	Not considering the role green cover and vegetation has within the heat-water-vegetation nexus can worsen heat and water stress (Hines, 2017).
	Building codes and standards	Sustainable construction materials, reduced building energy consumption and construction designed to reduce the urban heat island effects can have adaptation and mitigation benefits (Steenhof and Sparling, 2011; Aerts et al., 2014; Stewart, 2015; Shapiro, 2016; Ürge-Vorsatz et al., 2018).	NE
Industrial system transitions	Intensive industry infrastructure resilience and water management	Some adaptation options can help improve system efficiency when implementing water management and cooling practices.	NE
Overarching adaptation options	Disaster risk management	Incorporating environmental considerations into recovery decision-making (Amin Hosseini et al., 2016), implementing disaster risk management plans and increasing ex-ante resilience to disasters are important to reduce the extent of rebuilding following disasters, and the emissions associated with recovery. Post-disaster recovery can help rebuild in a more resilient way with less GHG emissions, or to ‘build back better’, particularly where immediate impact is substantial but not overwhelming (Guarnacci, 2012; Mochizuki and Chang, 2017). Effective disaster risk management may reduce the need for international	The urgency of recovery and the surge in demand for construction materials have been observed to promote unsustainable behaviours, including deforestation (Nazara and Resosudarmo, 2007; Chang et al., 2010) or uncontrolled extraction of sand and gravel (Abrahams, 2014). ‘Build back better’ requires capacity, time and mechanisms for balancing competing desires and perspectives that are not necessarily available after severe disasters, and may be challenged by both local and external influences in the rebuilding process (Abrahams, 2014; O’Hare et al., 2016; Paidakaki and Moulaert,

		transport of materials and other forms of aid, which can be emissions-intensive (Abrahams, 2014).	2017).
	Risk spreading and sharing	In response to the substantial risk posed to the insurance industry by climate change (Bank of England, 2015; Glaas et al., 2017), insurance companies are mobilizing their role as investment managers to promote climate mitigation; for example, in 2014, insurance companies pledged to invest 420 billion USD over five years in renewable energy, energy efficiency and sustainable agriculture projects (Fabian, 2015; Webster and Clarke, 2017).	Agricultural insurance may have unintended impacts, promoting the intensification of land use in some cases (Annan and Schlenker, 2015; Müller and Kreuer, 2016; Müller et al., 2017).
	Climate services	Climate services aid adaptation decision-making and can help mitigate GHGs through improving farm practices (e.g., matching fertilizer use with existing weather conditions so that less GHGs are emitted) (Thornton et al., 2017).	NE
	Indigenous knowledge	Revitalization of traditional management of agriculture may simultaneously increase resilience, improve biodiversity and reduce emissions by eliminating agrochemical inputs production to food production (Nyong et al., 2007; Niggli et al., 2009; Altieri and Nicholls, 2017). Recognizing and supporting indigenous management of blue carbon habitats (Vierros, 2017) and grasslands (Dong, 2017; Russell-Smith et al., 2017) and utilizing new technologies to revitalize traditional forms of energy provision (Thornton and Comberti, 2017) can provide mitigation and adaptation benefits.	Projects that use a single dimension of indigenous knowledge (e.g., savannah burning for carbon sequestration) without considering the full context of that knowledge risk limiting associated adaptation-mitigation synergies and losing the complexities of indigenous knowledge systems (Mistry et al., 2016).
	Population health and health system	Forest retention and urban agricultural land are forms of urban green infrastructure that can simultaneously mediate floods, promote healthy lifestyles and reduce emissions and air pollution. (Nowak et al., 2006; Tallis et al., 2011; Elmqvist et al., 2013a; Buckeridge, 2015; Culwick and Bobbins, 2016; Panagopoulos et al., 2016; Stevenson et al., 2016; R. White et al., 2017).	The use of air conditioners to meet health standards could result in increased emissions (Ürge-Vorsatz et al., 2018).
	Social safety nets	Public work programmes structured to address climate risks; for example, Ethiopia's Productive Safety Net Programme has been used to employ locals suffering from food insecurity to work on watershed management interventions, sequestering carbon in the soil and reducing GHG emissions (Jirka et al., 2015).	Where cash transfers to households to build adaptive capacity are not conditional, limited increases in purchasing power can prompt families to invest in additional consumption, transport or agricultural equipment as part of a general risk reduction strategy (Lemos et al., 2016; Nelson et al., 2016); aggregated, these individual investments could lead to increased emissions.

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