Economic impacts and risks of climate change under failure and success of the Paris Agreement

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S1.1. Simplified schematic representation of model structure

CLIMRISK (version 1.0) is an integrated assessment model for the evaluation of the economic impacts and risks of climate change. CLIMRISK integrates and extends well-established models, datasets, techniques and procedures that have been previously evaluated in the literature in a way that allows to produce tailor-made, multidimensional scenarios for supporting decision-making. Climate change damages are the result of the interplay of three different factors: exposure; hazard produced by changes in climate, and; vulnerability of exposure to the projected changes in climate. As discussed in detail in the following sections, CLIMRISK provides significant advances in comparison with current IAMs regarding the representation of all these factors. The main objective of CLIMRISK is to offer decision-makers a simplified and flexible tool that produces tailor-made output to characterize different dimensions of the potential consequences of climate change and of the benefits of active climate policy. CLIMRISK is a spatially explicit, policy evaluation model in which the risks and economic damages of different reference and policy scenarios can be evaluated and compared based on a variety of metrics. Figure S1a provides a representation of the conceptual framework of CLIMRISK, which is structured according to the IPCC conceptual framework of risk of climate-related impacts resulting from the interaction of climate hazards with the exposure and vulnerability of human systems. Figure S1b provides a simplified schematic diagram of the model structure of CLIMRISK that shows its modules and their interactions. The first two are the socioeconomic, and climate modules which produce the basic input for the economic impacts and risk evaluation modules. As described in detail below, in addition to producing GDP and population scenarios, the socioeconomic module determines the grid points that, based on population counts, are likely to contain large urban areas. Determining grid points that contain large urban areas allows to include the effects of the urban heat island effect and to improve the representation of vulnerability of urban areas by using a damage function specifically developed and calibrated for this purpose. A proportion of the total population in such grid points is classified as urban and it is used by the climate module to produce time-dependent projections of local temperature change produced by the effects of the urban heat island. The economic impacts module combines the output of the socioeconomic and climate modules to produce annual aggregated estimates of monetary losses in a variety of sectors and activities. This module offers the user several options of damage functions, including those of the RICE model, as well as two more sets of damage functions that account for 1) local warming and for differences in vulnerability between regions as well as between urban and non-urban areas, and 2) the persistence of climate change impacts. The default set of damage functions in CLIMRISK include regional and urban effects. The risk evaluation module is designed to produce user-defined uni- and multi-variate climate and economic risk measures as well as risk indices that are helpful to spatially identify risk-hotspots where the user’s defined risks converge. In CLIMRISK, as in most spatially detailed IAMs, mitigation policies are exogenous and the model is not designed to produce optimal emission mitigation trajectories through the maximization of a social welfare function, nor to include interregional trade of emissions reduction. For such applications, non-probabilistic models with a much more limited spatial resolution and that focus only on economic impacts, like as DICE/RICE, are commonly used. It is important to consider that while CLIMRISK aims to address some of the limitations of IAMs that have been pointed out in the literature, not all of them can be tackled by a single version of any particular model. The CLIMRISK model is a long-term project that shares a similar approach to that discussed in the literature in the sense that it seeks to incorporate aspects that are not yet in IAMs and to integrate/connect/emulate biophysical models to project future climate impacts in a more realistic manner. This is tackled by means
of modular additions such as CLIMRISK-RIVER\textsuperscript{8} and additions and modifications to the CLIMRISK core model.

![Figure S1. Conceptual framework and simplified model structure of CLIMRISK. Panel a) shows the schematic conceptual framework of CLIMRISK and panel b) a simplified schematic diagram of the model structure. Arrows show the input-output flows between the different concepts/modules.](image)

**S1.2. Socioeconomic and climate modules**

**S1.2.1 Socioeconomic module**

The need for developing socioeconomic scenarios at the regional, national and subnational scales for climate change impact, vulnerability and adaptation assessments has been long recognized\textsuperscript{9,10}. This eventually led to the development of different quantifications of the SRES storylines at finer resolutions\textsuperscript{11–13}. However, at this stage, most of the current SSP quantifications are still available at macro-regions and national levels, with the exception of
some recent spatially-explicit quantifications for population scenarios\textsuperscript{14}. The socioeconomic module of CLIMRISK (Figure S2a) produces spatially explicit global GDP and population projections at a 0.5°x0.5° spatial resolution and annual frequency. As described below, these scenarios are constructed from exogenous information produced by different leading modelling groups that developed the socioeconomic quantifications for the SSP and SRES storylines.

As has been proposed in the literature, the SRES narratives are consistent with those of the SSP and can be interpreted as realizations of one or more SSP storylines\textsuperscript{12,15,16}. This consistency allows to combine different generations of socioeconomic scenarios to produce spatially explicit (0.5°x0.5°) projections. Figure S2a provides a flow chart of how CLIMRISK produces spatially explicit population and GDP scenarios by combining existing quantifications from the SRES and SSP storylines. The SRES scenarios for GDP and population were obtained from the GGI Scenario Database (GGIDB) Version 2.0.1 (http://www.iiasa.ac.at/Research/GGI/DB/\textsuperscript{12,13,17}) for the period 2010-2100 with a decadal frequency and a spatial resolution of 0.5°x0.5°. These population and GDP scenarios are available for the A1/B1, A2, B2 storylines. As a first step, each of these decadal quantifications (maps) of population/GDP was linearly interpolated to an annual frequency and converted to spatial patterns of distribution for each of the 13 regions in CLIMRISK: 1) United States; 2) Western Europe; 3) Japan; 4) Russia; 5) Eurasia; 6) China; 7) India; 8) Middle East; 9) Africa; 10) Latin America; 11) Other High Income countries; 12) Other Asia; 13) Mexico. These regions are the same as those in RICE with the addition of Mexico as a separate region (see Table S17). The spatial patterns are calculated in two steps: 1) the total population/GDP each region/year was obtained by adding the population/GDP of every grid cell in the corresponding region/year; 2) this total value for each variable/region/year was used to normalize the population/GDP values in each grid cell of the corresponding region/variable/year. The method for constructing these spatially explicit scenarios is similar to the pattern scaling technique commonly used to emulate the spatial distribution of climate variables produced by general circulation models\textsuperscript{18,19} although these patterns are not assumed to be constant over time. In mathematical terms, the procedure can be expressed as:

\[
P_{i,j,t}^R = \frac{y_{i,j,t}^{SRES,R}}{\left(\sum_{i,j} y_{i,j,t}^{SRES,R}\right)}
\](S1)

Where \(y\) is the variable of interest (population/GDP), \(P_{i,j,t}^R\) is the spatial pattern for region R and the summation in \(\sum_{i,j} y_{i,j,t}^{SRES,R}\) is over all \(i,j\) combinations of latitude and longitude coordinates in the region \(R\). Note that by construction \(\sum_{i,j} P_{i,j,t}^R = 1\) for each region/variable/year. This is done for each SRES storyline, for each year and variable. An example MATLAB code for calculating the spatial patterns is:

```matlab
for i=1:nperiod
vaREGION(:,:,i)=X(:,:,i).*R_CLIMRISK(:,:,R);
XXA=vaREGION(:,:,i);
VARREGION=nansum(XXA(:));
VARREGIONT(i)=VARREGION;
PatternVARREGION(:,:,i)=vaREGION(:,:,i)./VARREGIONT(i);
end
```

where \(n\text{period}\) is the number of years in the scenario; \(X\) is a three-dimensional matrix of the original GGIDB data (interpolated to annual frequency) for the variable \(va\), in which the first two dimensions express geographical coordinates and the third represents time; \(R\_CLIMRISK\)
is a three-dimensional regional binary mask in which the first two dimensions are geographical coordinates and the third takes the value of 1 if the combination of coordinates falls within the region $R$ and zero otherwise; $R=1,...,13$ are the regions in CLIMRISK; PatternVARREGION is a three-dimensional matrix which contains the proportions of $va$ over the geographical coordinates $i,j$ (the first two dimensions of the matrix) and over time (the third dimension). This is how the intermediate product depicted in Figure S2a as “GDP and POP decadal spatial patterns (0.5°x0.5°)” was created.

The time series of SSP scenarios were obtained from the SSP Public Database (SSPDB) Version 1.1 (https://tntcat.iiasa.ac.at/SSPDb) for the period 2010-2100 with a decadal frequency. In the case of GDP, for each SSP narrative there are different quantifications from three modelling groups (OECD Env-Growth, IIASA, PIK) while for population there is a common quantification for each SSP narrative (OECD Env-Growth). These time series are aggregated from the 32 regions of the SSPDB into the 13 regions of CLIMRISK (see Table 17). The resulting 13 regional GDP/population time series are used to scale the spatial patterns described in the previous paragraph as follows:

First, the 13 regional GDP/population time series are linearly interpolated into annual frequency. Second, the SSP time series and spatial patterns are paired taking into account their compatibility: the SSP3 and SSP4 scenarios were used to scale the A2 spatial patterns; the SSP2 scenarios were used to scale the B2 spatial patterns and; the SSP1 and SSP5 scenarios were used to scale the A1/B1 spatial patterns. This can be expressed as:

$$y_{i,j,t}^{SSP,R} = P_{i,j,t}^R \ast y_t^{SSP,R}$$  \hspace{1cm} (S2)

where $y_{i,j,t}^{SSP,R}$ is the SSP consistent, spatially explicit (0.5°x0.5°) scenario for variable $y$ (population/GDP) for region $R$; $P_{i,j,t}^R$ is the spatial pattern obtained from equation S1 for region $R$ and variable $y$, and $y_t^{SSP,R}$ is the aggregated scenario for the variable $y$ and region $R$ obtained from the SSPDB. Since $\sum_i \sum_j P_{i,j}^R = 1$ then $\sum_i \sum_j y_{i,j}^{SSP,R}$ is exactly equal to $y_t^{SSP,R}$. Equation S2 can be expressed in MATLAB code as:

for i=1:nperiod
vaSSPR(:,:,i)=PatternVARREGION(:,:,i).*AGG_REGCLIMRISK(R,i);
end

where AGG_REGCLIMRISK is $y_t^{SSP,R}$ and vaSSPR is a three-dimensional matrix in which the two first dimensions are geographical coordinates, and the third is time. This matrix is the resulting spatially-explicit, SSP-consistent scenario produced by CLIMRISK for a particular combination of SSP narrative, variable and modelling group (Figure S2a, right). Once the population scenarios have been computed, CLIMRISK provides the option of identifying grid cells that likely contain large urban areas. A binary urban mask is created by assigning a value of 1 if the population in a grid cell at time $t$ exceeds a pre-defined threshold value or zero otherwise. This mask is then used to obtain estimates of urban population counts assuming that a fixed percentage of the total population in the grid cell is urban. In CLIMRISK the urban population equation takes the form:

$$uPOP_{i,j,t} = I\left(POP_{i,j,t}^{SSP} > P^*\right) \ast POP_{i,j,t}^{SSP} \ast \omega$$  \hspace{1cm} (S3)
Where $I(\cdot)$ is the indicator function that takes the value of 1 if the condition $POP_{i,j,t}^{SSP} > P^*$ is satisfied and zero otherwise; $P^*$ is a user-defined population count threshold for defining that the grid cell is assumed to contain large urban areas; $POP_{i,j,t}^{SSP}$ is the population scenario at the grid point $i,j$ and time $t$ and; $\omega$ is the proportion of the population that is assumed urban in a grid cell for which the condition $POP_{i,j,t}^{SSP} > P^*$ has been satisfied. For the calculations presented in our paper, the value of $P^*$ was set to one million persons per grid cell. A sample code for identifying and obtaining the urban population counts is:

$$uPOP = (POP_{MAP}>uTHRESH).*POP_{MAP}.*propPOPu;$$

where $POP_{MAP}$ corresponds to the global population map constructed using equations S1 and S2; $uTHRESH$ is the user-defined population threshold applied to define grid cells that are likely to contain large urban areas; $propPOPu$ is the fixed percentage of population in the identified grid cell that is assumed to be urban and; $uPOP$ is the estimated gridded urban population scenario.

**Figure S2.** Schematic representation of the socioeconomic and climate modules of CLIMRISK. Parts a) and b) describe the socioeconomic and climate modules, respectively. Boxes in broken lines represent exogenous input. Arrows in broken lines denote optional output.

### S1.2.2 Climate module

Figure S2b shows a schematic representation of the climate module in CLIMRISK. The climate module has three components: a global climate model, a regional climate scenarios generator and a calculator based on population counts that approximates urban temperature change. The global climate model used in CLIMRISK is MAGICC6\(^2\)4 (see [http://wiki.magicc.org/](http://wiki.magicc.org/) for a
detailed model description), which has been well described in the literature and has been widely used by the climate change community in a variety of assessments, models and studies (including the IPCC reports)\textsuperscript{25–31}. MAGICC6 is driven by exogenously generated emissions scenarios for a variety of substances including carbon dioxide, methane, nitrous oxide, tropospheric aerosols and halogenated gases. MAGICC6 includes the IPCC’s RCPs and SRES scenarios, and allows for the possibility of user-defined emissions scenarios. This software has a detailed carbon cycle model with a terrestrial (including the effects of CO2 fertilization and the temperature effect on respiration and decomposition) and ocean components. The carbon cycle in MAGICC6 is able to emulate 9 different carbon cycle models examined in the Fourth Assessment Report of the IPCC\textsuperscript{32}. The default option is the CMIP4 BERN\textsuperscript{33} calibration and this is the one used in CLIMRISK. MAGICC6 contains routines for calculating the radiative forcing at the tropopause level after stratospheric temperature adjustment\textsuperscript{34,35} for carbon dioxide, methane, nitrous dioxide, tropospheric and stratospheric ozone, and halogenated gases\textsuperscript{36–40}. The direct and indirect radiative forcings of tropospheric aerosols (sulfate, nitrate, black carbon and organic carbon) are also calculated\textsuperscript{41,42}.

Climate sensitivity is one of the most important sources of uncertainty in global temperature projections and, while this is an emergent property in general circulation models\textsuperscript{43}, it is represented as a parameter in reduced complexity models such as MAGICC\textsuperscript{24,44}. While the climate sensitivity has been extensively studied in the literature, there is high uncertainty regarding its likely range and best estimate values\textsuperscript{45–51}. However, the broad consensus in the climate change community is that the climate sensitivity range extends from 1.5°C to 4.5°C with a best estimate of 3°C\textsuperscript{26,45,52–54}. Moreover, this climate sensitivity range encompasses the range of values shown by the state-of-the-art models included in the Coupled Model Intercomparison Project 5 (CMIP5)\textsuperscript{26,55} and a recent study suggests that the probability of the equilibrium climate sensitivity being below 1.5°C or above 4.5°C is 3% and 1%, respectively\textsuperscript{50}. CLIMRISK uses these consensus estimates and represents them with a triangular probability distribution characterized with 1.5°C and 4.5°C as lower and upper limits, respectively, and a most likely value of 3°C. This selection of best estimate and range of values for the climate sensitivity could be viewed as conservative by some as it excludes the possibility of higher values than 4.5°C. Note that other parameterizations can be used to explore different assumptions about the climate sensitivity range and/or best estimate values. CLIMRISK produces global probabilistic temperature projections by obtaining a realization from a triangular distribution, with parameters as described above, and using this number to overwrite the value of the climate sensitivity parameter in the corresponding input file of MAGICC6. Then MAGICC6 is run to produce a global temperature projection for a particular emissions scenario. This simulation is saved and another realization from the triangular distribution is obtained and the procedure is repeated for the number of desired simulations \(n\). Figure S3 illustrates the global temperature scenarios produced by means of this procedure for \(n=500\) and the RCP8.5 scenario. These simulations are compared in Figure S3 to the observed global temperatures reported by the Hadley Centre (HADCRUT4; magenta)\textsuperscript{i} and NASA (green)\textsuperscript{ii}.

Table S1 compares the likely ranges and best estimates of the global air surface temperature projections included in the Fifth Assessment Report of the IPCC and those produced by MAGICC6 under the procedure described above, for two time-horizons and four RCP scenarios. The procedure in CLIMRISK approximates very closely the central values and the uncertainty ranges depicted in the IPCC report: Table S1 shows that the CLIMRISK likely ranges are contained within those of the IPCC and that there are only slight differences between

\textsuperscript{i} https://www.metoffice.gov.uk/hadobs/hadcrut4/data/current/download.html#regional_series

\textsuperscript{ii} https://data.giss.nasa.gov/gistemp/
the corresponding best estimate values. This is expected since the ability of MAGICC to closely reproduce the output of general circulation models has long been recognized in the literature\textsuperscript{24,26,27,35}.

![Global temperature increase RCP85](image)

Figure S3. Probabilistic simulations of global temperature increase for the historical period and the RCP8.5 scenario. The median of the probabilistic projections is shown in a bold black line, while the individual 500 realizations are shown in dotted coloured lines. The observed global temperatures reported by the Hadley Centre (HADCRUT4) and NASA are shown in magenta and green bold lines, respectively. Temperature changes are with respect to the 1961-1990 reference period.

Table S1. Increases in global temperatures are calculated with respect to the 1986–2005 period. Likely ranges for both in IPCC and CLIMRISK (MAGICC) projections are constructed using percentiles 5\% and 95\%. IPCC projections are taken from Table 2.1 of the Synthesis Report of the IPCC’s Fifth Assessment Report\textsuperscript{56}.

| Scenario | IPCC Mean | Likely range | CLIMRISK (MAGICC) Mean | Likely range |
|----------|-----------|--------------|------------------------|--------------|
| RCP8.5   | 2.0       | 1.4 to 2.6   | 2.08                   | 1.56 to 2.57 |
| RCP6.0   | 1.3       | 0.8 to 1.8   | 1.41                   | 1.02 to 1.77 |
| RCP4.5   | 1.4       | 0.9 to 2.0   | 1.51                   | 1.08 to 1.90 |
| RCP3PD   | 1.0       | 0.4 to 1.6   | 1.07                   | 0.74 to 1.40 |

| Scenario | IPCC Mean | Likely range | CLIMRISK (MAGICC) Mean | Likely range |
|----------|-----------|--------------|------------------------|--------------|
| RCP8.5   | 3.7       | 2.6 to 4.8   | 3.72                   | 2.72 to 4.70 |
| RCP6.0   | 2.2       | 1.4 to 3.1   | 2.40                   | 1.71 to 3.06 |
As depicted in Figure S2b, the global temperature output is used to produce probabilistic regional climate change scenarios of changes in annual temperature (°C) and precipitation (%) for the whole world with a spatial resolution of 0.5°x0.5° by means of pattern scaling techniques. These techniques are well-established in the literature and have been widely used by the climate change community, in particular in impact, adaptation and vulnerability assessments through user-friendly software such as MAGICC/SCENGEN and others.

The basic underlying assumption behind the pattern scaling techniques is that the responses of the climate system to changes in external radiative forcing produce patterns that vary spatially, but that are invariant over time, emission scenario and model characteristics. Furthermore, these responses to changes in external forcing are assumed to be independent from natural variability, which is also a common assumption in a variety of analyses.

These fixed spatial patterns are scaled by global temperature change produced by much simpler climate models to obtain regional climate change scenarios for different variables and emissions scenarios. The pattern scaling techniques can be described by the following equation:

\[ P(i, j, t, e, y) = T(t, e)p(i, j, y) \]  

where \( i, j \) and \( t \) represent longitude, latitude and time, respectively, \( e \) is the emissions scenario, \( y \) is the climate variable of interest and \( T(t) \) is the global annual mean temperature change at time \( t \) under the emission scenario \( e \). \( P(\cdot) \) is the projected field of change for variable \( y \) at time \( t \) and a specific emissions scenario \( e \), while \( p(\cdot) \) is the time/emissions scenario invariant spatial pattern of change for the climate variable \( y \). Note that \( P(\cdot) \) and \( p(\cdot) \) can represent a variety of temporal scales such as annual, seasons or individual months.

The performance of pattern scaling techniques has repeatedly been evaluated in the literature, in general concluding that these techniques produce adequate and robust approximations particularly for 1) variables such as annual/seasonal temperature and precipitation, but their application is likely more limited for other variables such as extreme events and time-scales in which natural variability is dominant; 2) the vast majority of emissions scenarios and models, including low-warming policy scenarios, and; 3) most regions with the exception of those in which local forcing is strong and time-varying.

Even though the pattern scaling techniques provide only an approximation to the AOGCM regional scenarios, they offer important advantages in that these techniques can produce information that would otherwise be hardly attainable given computational efficiency constraints. It has been long recognized that comprehensive probabilistic/risk assessments of future regional climate change and its impacts cannot be realistically produced by means of AOGCM or other high complexity climate models. Pattern scaling techniques are particularly convenient for producing probabilistic scenarios and exploring uncertainty. CLIMRISK uses the pattern scaling of 41 AOGCM for temperature and precipitation based on least squares regression methods. This library of scaling patterns for the CMIP5 experiment was
developed by another research team with the purpose of their use in integrated assessment models and impact assessment models and it is freely available\textsuperscript{64,74}. For a detailed description of the methods used and an evaluation of performance of the patterns for the different models, the reader is referred to the original papers\textsuperscript{63,64}. These scaling patterns were interpolated (bilinear interpolation method) into a common global grid of 0.5°x0.5° which matched that of the socioeconomic projections described above.

CLIMRISK produces probabilistic regional climate change scenarios of changes in annual temperature (°C) and precipitation (%) by imposing a discrete probability distribution with support \{1, ..., 41\}, in which each possible outcome represents one of the 41 AOGCM in the pattern-scaling library. As a first step, a random number is generated from this distribution and the pair of temperature and precipitation scaling patterns associated with that particular AOGCM are then selected. These patterns are then scaled by one of the global temperature change projections obtained using MAGICC6. The scenarios are saved, and the procedure is repeated for the number of desired simulations \(n\). Different discrete probability distributions can be imposed over the pattern-scaling library, and there is an ever-growing body of literature on how to combine AOGCM model output to create probabilistic scenarios and/or to assess multimodel ensemble uncertainty. Some approaches that have been suggested in the literature consist of: 1) assigning probabilities to the different models according to their performance in reproducing past climate\textsuperscript{75–77} and sometimes based on convergence criteria\textsuperscript{78,79} and; 2) choosing a probability distribution that reflects models dependence\textsuperscript{80,81}. However, assigning probabilities to (or weighting) climate models’ output is not a solved problem\textsuperscript{82–85}. Model weighting based on performance metrics is not robust and, for a given set of climate models, it is always possible to find performance metrics that would lead to different model weighting and ranking\textsuperscript{83,86}. Moreover, there is weak (if any) correlation between good performance in reproducing current climate and better results in projecting future climate\textsuperscript{28,87–89}, which is the final objective of assigning weights based on performance. Convergence criteria were designed to assign lower weights to models that produce projections that are in disagreement with the majority of models. The objective of the convergence criteria was to produce more reliable projections and avoid biases due to outlying projections. Nonetheless, it has been shown that it can lead to dismissing uncertainty and reinforcing biases, particularly when models are not independent, and therefore its use has been largely abandoned\textsuperscript{75,90}. Climate models are hardly independent form one another and the lack of independence, in combination with the fact that current climate experiments are “ensembles of opportunity”, can introduce biases when working with ensembles and assigning probabilities to the different models\textsuperscript{82}. The problem is that there is not a clear genealogy of climate models and their degree of dependence must be inferred from their projections, and results are a function of the metrics that are chosen\textsuperscript{80,81,91}. The current version of CLIMRISK uses a uniform distribution to combine the scaling patterns of the different AOGCM, which implies assigning the same probability to each model, as has previously done in the literature\textsuperscript{26,69,87,92}. The uniform distribution follows the Principle of Insufficient Reason which is the maximum entropy distribution in absence of any additional information\textsuperscript{93–95}. Other probability distributions based on performance evaluation or model dependence could be easily implemented in CLIMRISK, but we consider these distributions may be as arbitrary as assigning equal probabilities to each model and may lead to unjustified
dismissal of uncertainty. It has also been argued that some of these methods could be
unmanageable for impact models in practice. The code used in CLIMRISK to produce the
probabilistic regional climate change scenarios can be illustrated as follows:

```matlab
for ii=1:nrep
    x=unidrnd(41);
    Pat_TAS=Pattern_TAS(:,:,x);
    Pat_PCP=Pattern_PCP(:,:,x);
    for i=1:nperiod
        SIMULATIONS_T(:,:,i,ii)=Pat_TAS(:,:)*T_GLOBAL(i,ii);
        SIMULATIONS_PCP(:,:,i,ii)=Pat_PCP(:,:)*T_GLOBAL(i,ii);
    end
end
```

where `Pattern_TAS` and `Pattern_PCP` are three-dimensional matrices containing the
scaling pattern libraries for temperature and precipitation, respectively, in which the first two
dimensions are geographical coordinates and the third dimension identifies the AOGCM.
`unidrnd(41)` is a pseudo-random number generator function for generating a realization `x`
from a discrete uniform distribution with parameters $U(1,41)$. Once the value of `x` has been
obtained, `Pat_TAS` and `Pat_PCP` are the scaling patterns for temperature and precipitation,
respectively, from a particular AOGCM and these patterns are scaled using a realization of the
global temperature projections `T_GLOBAL` for the selected length of years (`nperiod`) that
wants to be simulated. The resulting scenarios for temperature and precipitation are stored in
four-dimensional matrices `SIMULATIONS_T` and `SIMULATIONS_PCP` in which the two
first dimensions are geographical coordinates, the third is time and the fourth corresponds to
`nrep` which is the number of desired simulations defined above as `n`. Note that for each pair
of the `nrep` temperature and precipitation scenarios, a new realization of the uniform
distribution is drawn and a pair of AOGCM scaling patterns is chosen.

Additionally, CLIMRISK’s climate module includes a calculator based on population counts
that approximates urban temperature change. This option is only used in the economic impacts
module when the urban damage function is chosen. The local temperature change produced by
urbanization consists of a simple approximation based on empirical relationships of the form
$a \times Pop^b$, where `Pop` represent the urban population, and $a$, $b$ are fixed parameters. This
functional form originates from a variety of studies, and has previously been applied in an
IAM estimating economic impacts of climate change in cities. CLIMRISK uses the
parameter values calibrated for annual temperatures and for US cities with a population greater
than 100,000 inhabitants reported in Table 5 of Karl et al. In particular, $b=0.45$ and for the
baseline results we use the central estimate of $a =1.74 \times 10^{-3}$. For the sensitivity analysis
presented in this paper, the upper and lower values of the 95% confidence interval for $a$
reported by Karl et al. were used ($a =2.18 \times 10^{-3}$ and $a =1.30 \times 10^{-3}$, respectively) The change
in local annual temperatures due to the UHI in CLIMRISK is calculated using \( uPOP \), defined above as the estimated gridded urban population scenario, using the following code:

\[
UHI = ((uPOP \times 1000000)^b) \times a;
\]

The approach in CLIMRISK may underestimate the total warming if in reality the total effect of the UHI effect and climate change exceed the sum of its parts. It has been suggested that heat waves, which can become more frequent due to climate change, increase the difference between urban and rural temperatures\(^{102}\). But, because these measurements are based on two sites, they cannot confidently be extrapolated to large-scale applications. On the other hand CLIMRISK could overestimate the temperature effect if mitigating variables, like wind and vegetation would be different in other parts of the world than the US cities. The use of more complex modelling approaches, such as the use of an AOGCM, would provide more reliable estimates of the UHI effect under climate change scenarios. However, IAMs, like CLIMRISK, have to work with more simplified modelling approaches. To examine if this simplified approach gives reasonable approximations of the UHI effect as estimated by more complex climate models, we compare our results with those of the Oleson et al. (2011). Results show that our estimates are very close to those obtained with that climate model study. Using a global climate model, the annual UHI effect averaged over urban areas for the period 1980-1999 is 1.12\(^{\circ}\)C\(^{103}\). In the mid-century (2046-2065) it is 57\% of global warming caused by greenhouse gas emissions following the A2 scenario and keeping population and urbanization constant. The simplified approach of modelling the UHI effect in CLIMRISK gives very similar results to those of this complex global climate model. The annual UHI effect averaged over urban areas in CLIMRISK at the start of our socioeconomic modelling period (2010) is 1.06\(^{\circ}\)C, which is about 54\% of global warming caused by greenhouse gas emissions (1.95\(^{\circ}\)C) by mid-century reported for the A2 scenario\(^{103}\). In CLIMRISK the total future warming at the city level at a particular point in time is determined as the sum of the change in annual mean temperature from global warming and the change in annual mean temperature due to urban heat island effect. Tables S9-S10 show that the main findings about climate impacts are robust to using the 95\% confidence lower and upper bound estimates of the UHI effect by Karl et al.\(^{100}\), which are \( a=1.30 \times 10^{-3} \) and \( a=2.18 \times 10^{-3} \), respectively.

**S1.3. Economic impacts module**

Figure S4 shows a schematic representation of the economic impact module of CLIMRISK. This module uses the output from the socioeconomic and climate modules as input for three main sets of regional damage functions. CLIMRISK’s spatially explicit resolution allows the use of more specific damage functions that represent more adequately the differences in vulnerability at subnational scales. This contributes to a better quantification of the expected impacts of climate change at the grid, regional and global scales. At this subnational scale, urban areas have been shown to be of particular importance for assessing the costs and risks of climate change due to factors such as high exposure and local warming. Cities account for about 80\% of global GDP, 50\% of global population and are expected to contribute to a substantial share of the total economic damages at the national, regional and global
This warrants special efforts for improving the representation in urban areas in IAMs to advance the assessment of the aggregate economic impacts of climate change at all spatial scales. CLIMRISK explicitly address urban areas in all of its modules, including the incorporation of a damage function specifically developed and calibrated for urban areas\textsuperscript{101}. The default set of damage functions in CLIMRISK account for differences in vulnerability between regions as well as between urban and non-urban areas. This is achieved by including a specific damage function for urban areas and region-specific damage functions for areas not predominantly urban.

As described in what follows, CLIMRISK uses the RICE model\textsuperscript{5,106} regional damage functions, an urban damage function, and a modification of both types of damage functions that accounts for persistence and impact dynamics\textsuperscript{101,107}. These sets of damage functions encompass conservative and high-damage estimates that are available in the literature\textsuperscript{108} and allows to represent the uncertainty in climate-induced damages without requiring a higher computational cost associated with the use of stochastic damage functions\textsuperscript{109}. We first discuss how CLIMRISK adapts the regional functions in RICE to work at a spatially explicit scale. CLIMRISK regional damage functions are based on modified versions of those in the RICE model\textsuperscript{5,106}, which is one of the most commonly used and studied regional economic integrated assessment models. The economic impact module includes two other types of damage functions that were developed in previous papers by the authors: 1) to account for UHI warming by developing an urban damage function\textsuperscript{101} and; 2) by modifying the standard damage functions (such as those in RICE, and the urban damage function) to include the persistence of impacts of climate change\textsuperscript{108}. The inclusion of these two aspects that are omitted in the other IAMs leads to higher costs from climate change in CLIMRISK projections in comparison with RICE/DICE. A similar effect on the economic costs of climate change would not be found in other leading IAMs since none of them accounts for both UHI effects and persistence.
The RICE damage functions are quadratic in global temperature change:

\[ D_{r,t} = a_{1,r} T_t + a_{2,r} T_t^2 \]  
\[ I_{r,t} = Y_{r,t} D_{r,t} \]

where \( D_{t,r} \) represents the percent of GDP lost in region \( r \), \( T_t \) is the global temperature change in time \( t \), \( Y_{r,t} \) is the region’s GDP, \( I_{r,t} \) are the economic impacts, and \( a_{1,r}, a_{2,r} \) are fixed parameters taken from RICE2010 (Table S20). Figure S5a shows the percentage loss of GDP per °C of increase in global temperatures for the different regions in RICE and for the urban damage function in equation S11. The RICE damage functions are driven by global temperature since the DICE/RICE climate module projects temperature change at this scale. CLIMRISK uses a modified version of these damage functions in order to take advantage of the spatial resolution of its temperature and socioeconomic scenarios. In the economic impacts module, temperature changes (at the global and grid scales) are expressed with respect to 1900 since this is the reference period for the RICE damage functions\(^5,106\). Due to the computational burden, CLIMRISK uses the median of the ensemble of the 41 scaling patterns for temperature\(^60,92,95,110\) combined with the median, 2.5 and 97.5 percentiles of the global temperature projections to calculate the economic losses. In CLIMRISK the economic impacts are calculated twice using the regional RICE damage functions: first, based on global temperature projections and then based on regional (0.5ºx0.5º) temperature projections. These pairs of calculated economic impacts per region are used to construct a scaling factor that ensures that at the regional level the calculated economic impacts based on regional temperatures (CLIMRISK) are exactly the same as those produced when global temperatures are used (RICE). In this way, the information about how temperature changes and GDP are distributed within each of the 13 regions in CLIMRISK is taken into account, while the aggregated damages for each of the 13 regions are constrained to be exactly the same as those projected by the RICE model. The procedure to calculate the economic impacts in CLIMRISK can be summarized as follows:

\[ I_{r,t,i,j}^s = Y_{r,t,i,j} D_{r,t,i,j} S_{r,t} \]  

where \( I_{r,t,i,j}^s \), \( Y_{r,t,i,j} \), \( D_{r,t,i,j} \) are the scaled economic impact, GDP and the percent of GDP lost in time \( t \) for each grid point \( i,j \), in the region \( r \). \( S_{r,t} \) is a scaling factor that ensures the economic impacts projected for region \( r \) are the same under both the regional damage functions driven by global and grid point temperatures. This scaling factor is given by:

\[ S_{r,t} = \frac{I_{r,t}}{I_{r,t}^s} \]
where \( I_{r,t}^* \) is the sum of the product \( Y_{r,t,i,j}D_{r,t,i,j} \) over all of the grid points \( i,j \) in region \( r \). Equation S7 can also be interpreted as dividing \( Y_{r,t,i,j}D_{r,t,i,j} \) by the regional total \( I_{r,t} \) which would provide the spatial pattern of how the economic damages are distributed within the region \( r \) at time \( t \), and then scaling the pattern by \( I_{r,t} \) which is the total damage for region \( r \) at time \( t \) projected by the RICE damage function based on global temperature change. Note that both the scaled and the original RICE damaged function do not distinguish differences regarding the sectoral or geographical origin of aggregate GDP for which the sensitivity to climate change may vary. In RICE the damage function for region \( r \) impose the same sensitivity to climate change for each GDP unit that is aggregated into the regional GDP, regardless of how the contributions of the different sectors (or geographic areas) change in time and with various socioeconomic scenarios assumptions. In the case of the spatially explicit damage function in equation S7, the damage function for region \( r \) is applied to all grid cells within it, regardless of geographical or sectoral differences. However, as discussed below, CLIMRISK is the first IAM that distinguishes urban areas and that accounts for spatial differences in exposure and climate hazard within regions. As such, the model accounts for differences in vulnerability and sectoral composition between both regions and, at grid cell level, urban and nonurban land uses. This is important for analyzing subnational scales and for providing better estimates of the costs of climate change at all spatial scales, including global, due to the large share of total costs urban areas are expected to bare. Computable general equilibrium models may be more suitable for capturing trade effects of climate change related impacts than integrated assessment models, while the latter provide a more complete picture of aggregate impacts including non-market effects.

Figure S5b compares the globally aggregated damages (percentage loss of global GDP) obtained using the damage functions in CLIMRISK with those obtained with other damage functions that have been used in the literature. As it is explained in the second part of this section, the results of some of the sets of the damage functions in CLIMRISK depend on the warming trajectory and/or on population projections. As such, to be able to compare the results that can be obtained using CLIMRISK with other damage functions, a combination of RCP and SSP scenarios must be selected. For this purpose, we chose the RCP8.5-SSP5 over the period 2010-2100. The results from some of the damage functions included in Howard and Sterner\textsuperscript{112} that produce the largest and smallest losses are used to compare with those of CLIMRISK. As can be seen from Figure S5b, the globally aggregated damages from the regional RICE damage functions in CLIMRISK (the most conservative damage function in CLIMRISK) are slightly lower than those produced by the DICE-2013R damage function\textsuperscript{113} and similar to those that correspond to Tol 2014 damage function\textsuperscript{114}. The damage functions in CLIMRISK that consider the effects of the UHI and/or of the persistence impacts of climate change of produce higher damages than DICE-2013R and Tol 2014, and in the case in which both effects are considered, the damages are similar to those produced by the most extreme damage function considered in Howard and Sterner\textsuperscript{112}. CLIMRISK damage functions are able to encompass a wide range of the uncertainty in climate change economic losses as reflected by the literature. The damage functions in CLIMRISK that consider UHI and persistence effects are described in detail later in this section.
The procedure to implement the proposed scaling procedure in equations S7 and S8 is illustrated with an example code:

First, the impacts per region (illustrated here for region1) are calculated using global temperatures as in the original RICE model:

```matlab
IMPACT_AGG_REGION1 = T_GLOBAL .* PARAM_REGION1(1,1) + T_GLOBAL_SQ .* PARAM_REGION1(1,2);
IMPACT_AGG_REGION1 = IMPACT_AGG_REGION1 / 100;
```

where `IMPACT_AGG_REGION1` represents the percent of GDP lost as a product of global temperature (`T_GLOBAL`) increase for region1; `T_GLOBAL_SQ` is the squared value of global temperature change; `PARAM_REGION1` is a column vector of parameters for the linear and quadratic terms in equation S5. To obtain the projected losses as monetary quantities, the GDP projection for each region is multiplied by the percent of GDP lost calculated using equation S5:

```matlab
for i=1:nperiod
    IMPACT_AGG_REGION1_dollars(i) = IMPACT_AGG_REGION1(i) .* AGG_GDP_REGION1(i);
end
```

where `nperiod` represents the number of years for which the economic impacts are calculated; `AGG_GDP_REGION1(i)` is the regional GDP for region1 in the year `i`; and `IMPACT_AGG_REGION1_dollars(i)` is the aggregated monetary losses caused by climate change for region1 in year `i`.

As a second step, the economic impacts are calculated using the temperature changes at the grid scale as follows:

```matlab
IMPACT_REGION1 = DTEMP_REGION1 .* PARAM_REGION1(1,1) + DTEMP_REGION1_SQ .* PARAM_REGION1(1,2);
IMPACT_REGION1 = IMPACT_REGION1 / 100;
```

where `DTEMP_REGION1` and `DTEMP_REGION1_SQ` are the temperature change and the temperature change squared fields; `PARAM_REGION1` is the same column vector of parameters for the linear and quadratic terms used above; and `IMPACT_REGION1` represents the percent of GDP lost as a product of regional (0.5ºx0.5º) temperature increase. To obtain the projected losses as monetary quantities, the spatially explicit GDP projection is multiplied by the calculated percent of GDP lost for each grid cell and for each year:

```matlab
for i=1:nperiod
    IMPACT_REGION1_dollars(:,:,i) = IMPACT_REGION1(:,:,i) .* GDP_REGION1(:,:,i);
end
```
where \( \text{GDP\_REGION1} \) is a three-dimensional matrix of GDP of region1 and \( \text{IMPACT\_REGION1\_dollars} \) is also a three-dimensional matrix of GDP lost due to temperature increase at the grid scale. In both matrices, the two first dimensions refer to geographical coordinates and the third one is time. The aggregated GDP lost per region for each year is then obtained by summing over all grid points within each region and regional time series of aggregated losses are constructed:

\[
\text{for } i=1: n\text{period} \\
\text{TOTAL\_IMPACT\_REGION1\_dollars1} = \text{IMPACT\_REGION1\_dollars}(:,:,i); \\
\text{TOTAL\_IMPACT\_REGION1\_dollars(i)} = \text{nansum(TOTAL\_IMPACT\_REGION1\_dollars1(:));}
\]

where \( \text{TOTAL\_IMPACT\_REGION1\_dollars} \) are the aggregated annual monetary losses for region1. The scaling factor in equation S8 and scaled economic impacts \( I^s_{r,t,i,j} \) in equation S7 are calculated as follows:

\[
\text{CORR\_REGION1} = (\text{IMPACT\_AGG\_REGION1\_dollars}./\text{TOTAL\_IMPACT\_REGION1\_dollars});
\]

\[
\text{IMPACT\_DOLLARS\_CORR\_REGION1}(:,:,i) = \text{IMPACT\_REGION1\_dollars}(:,:,i).*\text{CORR\_REGION1}(i)
\]

where \( \text{IMPACT\_DOLLARS\_CORR\_REGION1} \) is a three-dimensional matrix of scaled economic impacts for region1, in which the two first dimensions are geographical coordinates and the third one is time. Figure S6a shows the differences between the projected economic impacts using global temperature change (equations S5 and S6) and those using regional temperatures (equations S7 and S8). These differences are negligible in comparison with the size of the projected impacts (the largest one in absolute value amounts to -$0.04 dollars) and arise from numerical and rounding errors.
Figure S5. Temperature-damage relationships of damage functions in CLIMRISK and other studies. Panel a) shows the percentage loss of GDP per °C of increase in global temperatures for each region in the RICE model, and for the urban damage function in equation S11. Panel b) compares globally aggregated damages (percentage loss of global GDP) in CLIMRISK under the RCP8.5 scenario (2010-2100) with those obtained with other damage functions that have been used in the literature. Globally aggregated losses are represented with R for the regional RICE damage functions in CLIMRISK; with RP for the damage functions that include the persistence of impacts of climate change; with RU for the damage functions that include the UHI effects; with RPU for the damage functions that include both the persistence of impacts of climate change and the UHI effects. The damage functions from Howard and Sterner\cite{112} are: DICE-2013R\cite{113}; Tol 2014\cite{114}; Preferred non-catastrophic (PNC); Preferred total plus catastrophic (PC); Preferred total plus productivity (PC).

CLIMRISK includes another set of regional damage functions that extend the original RICE equations to include the temporal dynamics of climate change impacts. Commonly, damage functions in most IAMs assume that climate impacts have no persistence, and that they only affect the period when they occur. The omission of impact dynamics can be interpreted as assuming an autonomous, unlimited, costless and effective reactive adaptation capacity. It has been well documented that macroeconomic time series show high levels of persistence, and that impacts in human and natural systems tend to dissipate only after a certain period of time\cite{107}. The persistence of impacts is incorporated into the projection of the costs of climate change for each region by means of the following equation:

\[ I_{r,t}^P = Y_{r,t}D_{r,t} + \alpha_r I_{r,t-1}^P \]  \hspace{1cm} (S9)

for \( t > 1 \) and \( I_{r,t=1}^P = Y_{r,t=1}D_{r,t=1} \)

where \( I_{r,t}^P \) represents the aggregated economic losses including the effects of persistence for region \( r \) and \( 0 \leq \alpha_r \leq 1 \). The values of the persistence parameter \( \alpha_r \) in CLIMRISK are reported in Table S21 and are based on recent estimates of the persistence of shocks in GDP\cite{107}. 

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While these damage functions in CLIMRISK account for the persistence of impacts of climate change, neither RICE nor CLIMRISK include the dynamics of impacts within or between regions.

The code for implementing equation S9 can be illustrated for region1 as follows:

Set the initial value equal to the economic losses during the first year using the original RICE impact function:

\[
\text{IMPACT\_AGG\_REGION1\_dollars\_Persistence}(1) = \text{IMPACT\_AGG\_REGION1\_dollars}(1)
\]

then the following recursive equation is used to calculate the economic losses including the effects of the persistence of impacts of climate change:

\[
\text{for } i=2: \text{nperiod}
\]

\[
\text{IMPACT\_AGG\_REGION1\_dollars\_Persistence}(i) = \text{IMPACT\_AGG\_REGION1\_dollars}(i) + \alpha_{\text{REGION1}} \times \text{IMPACT\_AGG\_REGION1\_dollars\_Persistence}(i-1);
\]

where \(\alpha_{\text{REGION1}}\) is the value of the parameter \(\alpha_r\) for the corresponding region. The economic damages at the grid scale are calculated using equation S7 but replacing the scaling factor \(S_{\text{r,t}}\) with:

\[
S_{\text{r,t}}^{\text{p}} = \frac{l_{r,t}^{\text{p}}}{I_{r,t}^{\text{r}}}
\]

Figure S6b shows the differences between the projected economic impacts using global temperature change and including persistence (equations S9) and those using regional temperatures (equations S7 with the scaling factor in S10). As in the previous case, these differences are negligible in comparison with the size of the projected impacts (the largest one in absolute value amounts to -$0.38 dollars) and arise from numerical and rounding errors.
Figure S6. Differences in projecting economic losses using global and grid scale temperature change projections and the proposed scaling factor. Panel a) shows the differences in projections for the 13 regions in CLIMRISK using equations S5, S6 and S7, S8. Panel b) shows the differences in projections for the 13 regions in CLIMRISK using equations S5, S6 and S7, S10.

CLIMRISK default set of damage functions take into account the effects of changes in urban climate due to urbanization processes, the differences in vulnerability between regions, as well as between urban and nonurban areas. Urban areas can experience much higher impacts from climate change than other parts of the world. This is in part due to the large concentrations of exposure in these areas (in terms of GDP and population) and to the existence of local climate
change due to the urbanization process\textsuperscript{101,104,105}. The omission of the interactions between local and global climate change can bias the assessments of the economic impacts of climate change at the national, regional and global levels\textsuperscript{101}. CLIMRISK tackles this problem by including a recently proposed damage function designed for urban areas and by projecting local temperature change due to the urban heat island effect\textsuperscript{101}. The damage function for urban areas is:

\[
D_{T,U}^{i,j,t} = 0.9 \left( \frac{T_{i,j,t} + U_{i,j,t}}{2.5} \right)^2
\]  
(S11)

where \(T_{i,j,t}\) and \(U_{i,j,t}\) represent changes in annual temperature in each grid point due to global and local climate change, respectively. Using the population projections in S1.2, urban and non-urban masks were created based on a population count threshold \(P^*\) as follows:

\[
I_{u,i,j,t} = I\left(POP_{i,j,t} > P^*\right)
\]
(S12)

\[
Imu_{i,j,t} = I\left(POP_{i,j,t} \leq P^*\right) = -(Iu_{i,j,t} - 1)
\]
(S13)

where \(Iu\) and \(Imu\) are the urban and non-urban masks, respectively, and \(I(\cdot)\) is the indicator function which takes the value of 1 if the condition \((\cdot)\) is met and zero otherwise. The default proportions of urban and non-urban GDP in urban grid cells is 80% urban and 20% non-urban. As such, two different damage functions are applied to grid points that are considered to contain urban areas: for 80% of the GDP in the urban grid cells equation S11 is used and equation S7 is used for the remaining 20% of GDP. The resulting quantities are added to obtain the total economic losses in grid cells identified as containing large urban areas:

\[
uTImp_{i,j,t} = uTImp_{i,j,t} * Y_{i,j,t} * \theta * Iu_{i,j,t} + Imu_{i,j,t} * (1 - \theta)Iu_{i,j,t}
\]
(S14)

Where \(uTImp_{i,j,t}\) is the total economic losses in urban grid cells, \(Y_{i,j,t}\) is a three-dimensional of GDP, \(\theta\) is a scalar of the proportion of urban GDP in urban grid cells, \(Imu_{i,j,t}\) is as defined in equation S7 summed over all regions, and \(Iu_{i,j,t}\) is defined by equation S12. To obtain the economic losses for urban and non-urban grid points, the following equation is used:

\[
TImp_{i,j,t} = uTImp_{i,j,t} + Imu_{i,j,t} * Imu_{i,j,t}
\]
(S15)

That is, the calculated economic losses for urban grid cells replace those projected using S7 that did not consider the effects of the UHI. The code for implementing this procedure can be illustrated as follows:

A set of masks are created for defining urban and non-urban grid cells:

\[
IuPOP=\text{double}((\text{POP\_MAP}>\text{uTHRESH}));
\]

\[
\text{InonuPOP}=-1*(IuPOP-1);
\]

Where \(\text{POP\_MAP}\) is a three-dimensional matrix (geographical coordinates, time) of population projections that corresponds to a particular SSP scenario, and \(\text{uTHRESH}\) is the selected
population count threshold $P^*$. The temperature change caused by urbanization (UHI) in urban grid cells is added to the corresponding grid cells in the global gridded temperature projections and a global grid of temperature change in which all non-urban cells have values equal to zero is created:

\[
T_{\text{INPUT\_u}} = T_{\text{INPUT\_GCM}} + \text{UHI};
\]

\[
u_{Tu} = T_{\text{INPUT\_u}} \cdot (I_{uPOP});
\]

using these temperature change projections, the fraction of GDP lost ($uImp$) is calculated using equation S11 and then the economic losses ($uImp\_Dollar$) are calculated as:

\[
uImp = ((uTu/2.5)^2) \cdot 0.9/100;
\]

\[
uImp\_Dollar = uImp \cdot \text{GDP\_MAP} \cdot \text{propGDPu};
\]

where $\text{GDP\_MAP}$ is a three-dimensional matrix of GDP projections (geographical coordinates, time) that corresponds to the particular SSP scenario analyzed, $\text{propGDPu}$ is the proportion of urban GDP in urban grid cells. To calculate the non-urban impacts in urban grid cells and to include the impacts in all other cells calculated using equation S7, another mask is defined. In this three-dimensional mask, urban grid cells are assigned the value of $(1 - \theta)$, i.e., 0.20, and non-urban grid cells a value of 1.

\[
I_{uPOP20} = I_{uPOP} \cdot (1 - \text{propGDPu}) + I_{nonuPOP};
\]

The non-urban economic losses in urban and non-urban cells ($\text{ImpNONu}$) are:

\[
\text{ImpNONu} = \text{IMPACT\_DOLLARS\_CORR} \cdot \text{I}\text{uPOP20};
\]

Where $\text{IMPACT\_DOLLARS\_CORR}$ is $I_{i,j,t}$, defined in equation S7, summed over all regions.

The total (urban and non-urban) economic losses ($\text{ImpDollars\_u}$) are obtained as:

\[
\text{ImpDollars\_u} = \text{ImpNONu} + uImp\_\text{Dollar};
\]

The economic losses per region are then obtained by multiplying $\text{ImpDollars\_u}$ by the mask that corresponds to each region. For region1, the example code is:

for i=1:nperiod

\[
\text{TOTAL\_IMPACT\_REGION1\_dollars1\_ul} = \text{ImpDollars\_u}(::,i) \cdot \text{Region\_CLIMRIS\_K}(::,1);
\]

\[
\text{TOTAL\_IMPACT\_REGION1\_grid}(::,i) = \text{TOTAL\_IMPACT\_REGION1\_dollars1\_ul};
\]

\[
\text{TOTAL\_IMPACT\_REGION1\_dollars1\_ul}(i) = \text{nansum}(\text{TOTAL\_IMPACT\_REGION1\_dollars1\_ul}(::));
\]
end
where \( \text{Region\_CLIMRISK} \) is a three-dimensional matrix (geographical coordinates, region) that contains a mask for each of the 13 regions in CLIMRISK, \( \text{TOTAL\_IMPACT\_REGION1\_grid} \) is a three-dimensional matrix (geographical coordinates, time) of annual gridded economic losses for region1, and \( \text{TOTAL\_IMPACT\_REGION1\_dollars\_u} \) is a time series of aggregated economic losses for region1.

**S1.4 Risk evaluation module**

Projecting what the consequences of climate change could be during this century is a complex, multidimensional task related with uncertainty. The economic costs of climate change are only one dimension of the risks this phenomenon poses. Therefore, if taken in isolation, these estimates can provide a poor, and incomplete, assessment of climate change consequences. CLIMRISK is the first economic integrated assessment model to include climate-economy risk measures to complement the projection of the economic impacts of climate change.

Figure S7 shows a schematic representation of the risk evaluation module in CLIMRISK. This module allows to estimate a variety of user-defined climate and economic risk measures at the grid scale. The climate related risk measures are based on the capacity of CLIMRISK climate module to create probabilistic scenarios for temperature and precipitation at the grid cell scale. These risk measures are based on threshold values of change in these variables that are chosen by the user to reflect her own perceptions of risk.

![Figure S7. Schematic representation of the risk evaluation module of CLIMRISK. Boxes in broken lines represent exogenous input.](diagram)

Univariate risk measures include estimating the probability of exceeding thresholds in annual temperature and precipitation change. In the case of temperature change projections, an
indicator function is used to identify in which grid cells, years and simulations in the matrix $T_{i,j,t,\text{sim}}$ (see Section S1.2.2) the user-defined threshold $T^*$ is exceeded:

$$ I_{\text{Threshold}} = I(T_{i,j,t,\text{sim}} > T^*) $$  \hspace{1cm} (S16)

where $I_{\text{Threshold}}$ is a four-dimensional matrix in which the entries take the value 1 if the threshold is exceeded and zero otherwise. In the case of precipitation change projections $P_{i,j,t,\text{sim}}$, the threshold of interest $P^*$ can be either positive or negative, therefore the indicator function is applied as follows:

$$ I_{\text{Threshold}} = \begin{cases} I(P_{i,j,t,\text{sim}} > P^*) & \text{if } P^* > 0 \\ I(P_{i,j,t,\text{sim}} < P^*) & \text{otherwise} \end{cases} $$  \hspace{1cm} (S17)

Estimates of the probabilities of exceeding the thresholds $T^*$ and $P^*$ can be obtained by summing over the simulation number dimension $\text{sim}$:

$$ P_{\text{Threshold}} = P(T_{i,j,t} > T^*) = \frac{\sum^n_{\text{sim}=1} I_{\text{Threshold}}}{n} $$  \hspace{1cm} (S18)

$$ P_{\text{Threshold}} = P(P_{i,j,t} > P^*) = \frac{\sum^n_{\text{sim}=1} I_{\text{Threshold}}}{n} \text{ if } P^* > 0 $$  \hspace{1cm} (S19a)

$$ P_{\text{Threshold}} = P(P_{i,j,t} < P^*) = \frac{\sum^n_{\text{sim}=1} I_{\text{Threshold}}}{n} \text{ if } P^* \leq 0 $$  \hspace{1cm} (S19b)

Where $P_{\text{Threshold}}$ and $P_{\text{Threshold}}$, are three-dimensional matrices (geographical coordinates, time) of probabilities. And the joint probability of both thresholds being exceeded $P_{\text{Threshold}}$ and $P_{\text{Threshold}}$ can be estimated as:

$$ I_{\text{Threshold}} = I(I_{\text{Threshold}} + I_{\text{Threshold}} > 1) $$  \hspace{1cm} (S20)

$$ P_{\text{Threshold}} = P(\text{exceeding both thresholds}) = \frac{\sum^n_{\text{sim}=1} I_{\text{Threshold}}}{n} $$  \hspace{1cm} (S21)

The code for implementing these procedures is illustrated below:

For temperature:

```plaintext
ISIMULATIONS_T = SIMULATIONS_T > T_THRESHOLD;
P_THRESHOLD_T = sum(ISIMULATIONS_T, 4) / nrep;
P_THRESHOLD_T = squeeze(P_THRESHOLD_T);
```

where $T_THRESHOLD$ is the threshold $T^*$, $SIMULATIONS_T$ is $T_{i,j,t,\text{sim}}$, $ISIMULATIONS_T$ corresponds to $I_{\text{Threshold}}$ and $P_THRESHOLD_T$ to $P_{\text{Threshold}}$. 

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For precipitation:

\[
\text{if PCP\_THRESHOLD}>0
\]

\[
\text{ISIMULATIONS\_PCP}=\text{SIMULATIONS\_PCP}>\text{PCP\_THRESHOLD};
\]

\[
\text{else}
\]

\[
\text{ISIMULATIONS\_PCP}=\text{SIMULATIONS\_PCP}<\text{PCP\_THRESHOLD};
\]

\[
\text{end}
\]

\[
\text{P\_THRESHOLD\_PCP}=\text{sum}(\text{ISIMULATIONS\_PCP},4)/\text{nrep};
\]

\[
\text{P\_THRESHOLD\_PCP}=\text{squeeze}(\text{P\_THRESHOLD\_PCP});
\]

**where** \(\text{PCP\_THRESHOLD}\) is the threshold \(P^*\), \(\text{SIMULATIONS\_PCP}\) is \(P_{i,t,\text{sim}}\), \(\text{ISIMULATIONS\_PCP}\) corresponds to \(I\text{Threshold}P_{i,t,\text{sim}}\) and \(\text{P\_THRESHOLD\_PCP}\) to \(P\text{Threshold}P_{i,t}\).

For temperature and precipitation:

\[
\text{if PCP\_THRESHOLD}>0
\]

\[
\text{ISIMULATIONS\_TP}= (\text{SIMULATIONS\_T}>\text{T\_THRESHOLD}) \& (\text{SIMULATIONS\_PCP}>\text{PCP\_THRESHOLD});
\]

\[
\text{else}
\]

\[
\text{ISIMULATIONS\_TP}= (\text{SIMULATIONS\_T}>\text{T\_THRESHOLD}) \& (\text{SIMULATIONS\_PCP}<\text{PCP\_THRESHOLD});
\]

\[
\text{end}
\]

\[
\text{P\_THRESHOLD\_TP}=\text{sum}(\text{ISIMULATIONS\_TP},4)/\text{nrep};
\]

\[
\text{P\_THRESHOLD\_TP}=\text{squeeze}(\text{P\_THRESHOLD\_TP});
\]

**where** \(\text{ISIMULATIONS\_TP}\) corresponds to \(I\text{Threshold}T\&P_{i,t,\text{sim}}\) and \(\text{P\_THRESHOLD\_TP}\) to \(P\text{Threshold}T\&P_{i,t}\).

The estimates of probabilities of exceeding critical thresholds are used to estimate the expected dates when such thresholds would be attained. For this purpose, the user is required to define a probability value \(\gamma\) (i.e., percent of simulations for which the threshold(s) is (are) exceeded) for which the threshold(s) is (are) declared to have been exceeded. In CLIMRISK this value is called **confidence level** and can vary with the risk tolerance of different users. Note that the value of \(\gamma\) can vary for different variables. For the estimates presented in this paper, the date at which a threshold is declared to be reached requires that at least 50% of the climate simulations are at or over the threshold. The dates for exceeding risk thresholds are calculated as follows.
An indicator function is used to define in which grid cells and years the confidence level \( \gamma \) is attained or exceeded:

\[
IAT_{i,j,t} = I(P\text{Threshold}_{i,j,t} \geq \gamma) \quad (S22)
\]

\[
IAP_{i,j,t} = I(P\text{Threshold}_{P,i,j,t} \geq \gamma) \quad (S23)
\]

\[
IAT&P_{i,j,t} = I(P\text{Threshold}_{T&P,i,j,t} \geq \gamma) \quad (S24)
\]

where \( IAT_{i,j,t}, IAP_{i,j,t} \) and \( IAT&P_{i,j,t} \) are three-dimensional (geographical coordinates, time) matrices in which the entries take the value 1 if the confidence level \( \gamma \) is attained or exceeded and zero otherwise.

The estimated dates for exceeding the risk threshold are obtained by mapping into a year index the first occurrence of the value 1 in the time dimension of each pair of geographical coordinates in the \( IAT_{i,j,t}, IAP_{i,j,t} \) or \( IAT&P_{i,j,t} \) matrices.

The code for implementing the calculation of dates is illustrated below.

The matrices \( IAT_{i,j,t}, IAP_{i,j,t} \) and \( IAT&P_{i,j,t} \) are calculated:

\[
\text{AREA}_T = P\text{Threshold}_T \geq \text{GAMMA}_T; \\
\text{AREA}_PCP = P\text{Threshold}_PCP \geq \text{GAMMA}_PCP; \\
\text{AREA}_{TP} = \text{AREA}_T + \text{AREA}_PCP; \\
\text{AREA}_{TP} = \text{AREA}_{TP} > 1;
\]

Where \( \text{GAMMA}_T \) and \( \text{GAMMA}_PCP \) are the confidence levels \( \gamma \) selected for temperature and precipitation, respectively.

The dates for reaching the thresholds are calculated as follows:

For temperature:

\[
[~, \text{IDate}_T] = \max(\text{AREA}_T, [], 3); \\
\text{IDate}_T = \text{IDate}_T + \text{first} - 1; \\
\text{DATE}_T = \text{IDate}_T;
\]

For precipitation:

\[
[~, \text{IDate}_PCP] = \max(\text{AREA}_PCP, [], 3); \\
\text{IDate}_PCP = \text{IDate}_PCP + \text{first} - 1; \\
\text{DATE}_UPCP = \text{IDate}_PCP;
\]

For temperature and precipitation:
\[ \text{AREA}\_TP = \max(AREA\_TP, [], 3); \]

\[ \text{IDate}\_TP = \text{IDate}\_TP + \text{first} - 1; \]

\[ \text{DATE}\_TP = \text{IDate}\_TP; \]

Where $\text{first}$ corresponds to the first year in the period being analyzed.

The damage estimates produced by the economic impacts module are used to produce additional risk measures. The economic risk measures in the present version of CLIMRISK include the date for reaching a given percent loss in GDP or for experiencing economic losses of a certain magnitude. These risk measures can be computed for all of the damage functions described in Section S1.3. The method for calculating this economic risk measures is similar to the climatic risk measures presented above and is briefly described below.

The first step to calculate the dates for reaching a critical threshold in economic damage variables is to define an indicator function to identify the grid cells where this condition is met.

\[
\begin{align*}
\text{IAL}_{i,j,t} & = I(I^s_{r,t,i,j} \geq L^*) \\
\text{IAGDP}_{i,j,t} & = I(D_{r,t,i,j} \geq \psi^*)
\end{align*}
\]

where $\psi^*$ and $L^*$ are the user-defined thresholds in percent loss of GDP and in magnitude of losses, respectively; $I^s_{r,t,i,j}$ and $D_{r,t,i,j}$ are three-dimensional matrix (geographical coordinates, time) of the projected economic losses and the percent of GDP lost, respectively, obtained by any of the damage functions in section S1.3. The estimated dates for exceeding the risk threshold are obtained by mapping into a year index the first occurrence of the value 1 in the time dimension of each pair of geographical coordinates in the $\text{IAL}_{i,j,t}$ or $\text{IAGDP}_{i,j,t}$ matrices.

The calculation of dates can be implemented as follows:

First, the grid cells and years in which the condition is met are calculated and the results are stored in three-dimensional matrices (geographical coordinates, time).

\[ \text{AREA}\_\text{IMPGDP} = \text{IMP}\_\text{GDP} \geq \text{THRESH}\_\text{IMP}; \]

\[ \text{AREA}\_\text{LOSSES} = \text{IMPACT}\_\text{DOLLARS}\_\text{CORR} \geq \text{THRESH}\_\text{LOSSES}; \]

These matrices are used to identify the year when the condition is first met.

\[ \text{IDATE}\_\text{GDP} = \max(\text{AREA}\_\text{IMPGDP}, [], 3); \]

\[ \text{DATE}\_\text{GDP} = \text{IDATE}\_\text{GDP} + \text{first} - 1; \]
where THRESH_IMP and THRESH_LOSSES are $\psi^*$ and $L^*$, respectively; IMP_GDP IMPACT_DOLLARS_CORR, AREA_IMP_GDP, and AREA_LOSSES are $I^5_{r,t,i,j}$, $D_{r,t,i,j}$, $IAGDP_{i,j,t}$ and $IAL_{i,j,t}$ respectively.

Note that all these risk measures can be presented as static snapshots or dynamic simulations in which the changes in the levels of risk for each grid cell can be shown as a function of time. This is because all risk measures presented above are three-dimensional matrices which contain a map of the risk measure for each time-step.

In addition, CLIMRISK allows to combine the previously defined climatic and economic risk measures to produce multivariate indices that aim to help in the adaptation decision-making process and in defining critical path planning for climate change mitigation policy. The procedure for doing this in the current version of CLIMRISK is to add the individual risk measures as described in the following example. Consider the multivariate risk index that combines a set of user-defined thresholds in temperature and precipitation change per grid cell $T^*$ and $P^*$, and a threshold in economic losses $L^*$. The multivariate risk index is obtained as:

$$RI_{i,j,t} = \omega_1 IAL_{i,j,t} + \omega_2 IAT_{i,j,t} + \omega_3 IAP_{i,j,t} + \omega_4 IAGDP_{i,j,t}$$

where $RI_{i,j,t}$ is a three-dimensional matrix (geographical coordinates, time) and, for the simulations in this paper, $\omega_1 = \omega_2 = \omega_3 = \omega_4 = 1$. As such, for a given year, each grid cell $RI_{i,j,t}$ can take the values from 0 to 4. These values can be classified as representing a certain level of risk, for example, medium (1), high (2), very high (3), extreme (4).

It is important to note that other risk measures can be easily incorporated to CLIMRISK depending on the users’ demands. Risk indices in CLIMRISK can be expanded to include other biophysical, socioeconomic, political and sectoral aspects, depending on the particular objectives of the risk assessment that is carried out.

S2. Brief description of the methodology used in Table S19.

Table S19 is adapted from Table 4.1 of the contribution of the Working Group II to the Fourth Assessment Report of the IPCC\textsuperscript{115,116}. Table 4.1 reports the projected impacts of climate change on ecosystems and population systems that were available in the literature and provides the global and regional temperatures changes associated with such impacts. The motivation and method used in for producing Table 4.1 in the IPCC report are briefly described below.

In the literature about the effects of climate change on ecosystems, results are reported for local to global scales, however models are generally run at much finer scales with climate variables at the local scales as input\textsuperscript{117,118}. Some studies include information about global mean temperature increase, but many of them only provide local/regional temperature changes as
reference or information about the climate model used, the time horizon (e.g., 2050) and the emissions scenario used. For review papers and for summarizing the current knowledge on the impacts of climate change it is useful to be able to report global and regional temperatures along with the associated impacts. By means of physical climate models, these global and regional temperatures can be recovered by extracting them from projections from the same climate model, emissions scenario and time horizon. This was originally proposed by Warren\textsuperscript{119} to upscale regional/local temperature change to global annual mean temperature change in order to summarize the available knowledge about the expected impacts of climate change for different levels of global warming. This approach was adapted by the Working Group II of the IPCC to recover global and, in some cases, regional temperatures and to produce uncertainty ranges in temperature change that would have been obtained if other climate models are used. The IPCC authors used this technique to downscale/upscale where necessary temperature change from local to global to make results comparable and more useful: “Projections from the literature were harmonised into a common framework by down/upscaling (where necessary) from local to global temperature rise using multiple GCMs, and by using a common global mean temperature reference point for the year 1990 (after Warren, 2006). Whilst some of the literature relates impacts directly to global mean temperature rises or particular GCM scenarios, many studies give only local temperature rises, \( \Delta T_{\text{reg}} \), and hence require upscaling. The thirteen GCM output data sets used are taken from the IPCC DDC at http://www.ipcc-data.org/”\textsuperscript{116}.

Down/upscaling here refers to recovering local/regional and global temperature change values from climate models’ projections when these values were not directly reported by the original impact studies. The same technique was used to approximate the uncertainty ranges in temperature change that would have been obtained by other climate models. Note that down/upscaling does not refer to impacts, since these are reported at the same spatial scales as in the original papers. Regions in both Table 4.1 and Table S19 are those reported by the original studies. Table S19 reproduces the results of the IPPC’s Table 4.1 for which \( \Delta T_{\text{reg}} \) (regional temperature) increases with respect to the 1990 reference period were reported.

One of the main goals of the integrated assessment framework and modelling is to combine the available knowledge, data and model output to produce information that would not be able otherwise and that could be useful for decision making. Depending on the objective of the analysis and the characteristics of exogenous and endogenous input (e.g., aggregation and detail) the resulting information should be interpreted accordingly. In the case of broad regions, such as those in Table S19, the association between risk measures like those in Figure 2 of the main text and the reported impacts are to be associated to the impacts in a broad manner. In particular, differences in grid cell values within regions provide a measure of spatial variability but the interpretation of any isolated cell is not advised. For instance, our discussion of the impacts of temperature rise on species in the main manuscript refers to impacts we observe based on model results for regions, as is consistent with the regional dimension of Table S19. For other cases in which the objective of the analysis and the external input are more detailed, CLIMRISK’s risk module offers the additional advantage of spatially explicit resolution that allows to integrate exogenous gridded datasets to produce more spatially detailed information.
Discussions of risk measures included in the main paper are based on the characteristics of the datasets used for the different analyses that are presented.

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### Supplementary Tables

**Table S2.** Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP8.5 scenario for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP scenario: SSP5 OECD Env Growth.

| Region | RICE | RICE-P | RICE-U | RICE-P-U |
|--------|------|--------|--------|----------|
| USA    | 45 [5947] (23, 71) [2990, 9382] | 104 [13717] (53, 164) [6904, 21609] | 90 [11844] (52, 133) [6819, 17476] | 208 [27388] (120, 307) [15803, 40339] |
| EU     | 47 [6968] (24, 74) [3501, 10998] | 89 [13198] (45, 140) [6637, 20810] | 77 [2986] (47, 109) [1833, 4248] | 178 [6946] (114, 281) [4273, 9865] |
| JAPAN  | 33 [1267] (16, 51) [641, 1988] | 75 [3549] (38, 118) [1486, 4598] | 70 [1164] (43, 121) [633, 1765] | 178 [3549] (114, 281) [4273, 9865] |
| RUSSIA | 43 [856] (22, 67) [433, 1344] | 176 [3549] (89, 276) [1797, 5550] | 89 [1800] (52, 131) [1041, 2640] | 373 [7519] (217, 545) [4369, 10991] |
| EURASIA| 55 [807] (28, 87) [407, 1270] | 165 [2400] (83, 258) [1211, 3770] | 80 [1164] (43, 121) [633, 1765] | 238 [3476] (110, 253) [4273, 9865] |
| CHINA  | 104 [9825] (57, 156) [538, 14749] | 436 [41207] (240, 653) [22640, 61704] | 218 [20594] (129, 314) [12190, 29666] | 923 [87193] (548, 1326) [51763, 125289] |
| INDIA  | 435 [15901] (260, 624) [9491, 22786] | 1789 [65338] (1072, 2554) [39145, 93311] | 708 [25862] (429, 1009) [15653, 36868] | 2920 [106653] (1774, 4147) [64813, 151506] |
| MEAST  | 149 [3855] (87, 217) [2247, 5602] | 615 [15888] (360, 890) [9298, 23002] | 279 [7202] (169, 397) [4358, 10276] | 1151 [29764] (700, 1363) [18091, 42305] |
| AFRICA | 581 [15988] (330, 862) [9073, 23736] | 3681 [101326] (2106, 5424) [57974, 149313] | 830 [22857] (482, 1219) [13272, 33560] | 5275 [145215] (3091, 7556) [85079, 208015] |
| LAM    | 74 [3275] (39, 113) [1743, 5015] | 193 [8519] (103, 294) [4541, 10326] | 141 [6241] (87, 201) [3847, 8870] | 369 [16318] (228, 523) [10085, 23140] |
| OHI    | 59 [2024] (30, 93) [1016, 3197] | 136 [4667] (68, 215) [2346, 7362] | 124 [4252] (71, 183) [2444, 6281] | 287 [9831] (165, 423) [5663, 14496] |
| OASIA  | 240 [8779] (132, 360) [4852, 13195] | 979 [35877] (543, 1466) [19906, 53734] | 399 [14634] (235, 582) [8601, 21330] | 1637 [59994] (967, 2376) [35437, 87076] |
| MX     | 63 [884] (33, 96) [471, 1354] | 163 [2300] (87, 249) [1227, 3514] | 137 [1933] (85, 194) [1202, 2730] | 358 [5052] (224, 505) [3150, 7119] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S3. Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP8.5 scenario for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP projection: SSP5 IIASA.

| Region | RICE | RICE-P | RICE-U | RICE-P-U |
|--------|------|--------|--------|---------|
| USA    | 43 [5473] | 99 [12614] | 85 [10862] | 197 [25101] |
|        | (22, 68) | (50, 156) | (49, 126) | (114, 291) |
|        | [2747, 8645] | [6340, 19897] | [6237, 16059] | [14445, 37043] |
| EU     | 51 [7609] | 97 [14429] | 111 [16577] | 211 [31490] |
|        | (26, 80) | (49, 152) | (65, 162) | (124, 307) |
|        | [3827, 11998] | [7262, 22731] | [9762, 24168] | [18570, 45857] |
| JAPAN  | 25 [1026] | 59 [2378] | 60 [2458] | 141 [5723] |
|        | (13, 39) | (30, 91) | (37, 86) | (87, 199) |
|        | [520, 1260] | [1208, 3716] | [1522, 3476] | [2978, 7394] |
| RUSSIA | 28 [575] | 116 [2373] | 59 [1220] | 248 [5083] |
|        | (14, 44) | (59, 181) | (35, 87) | (145, 361) |
|        | [291, 900] | [1205, 3708] | [711, 1781] | [2978, 7394] |
| EURASIA| 55 [766] | 162 [2282] | 80 [1125] | 239 [3364] |
|        | (28, 85) | (82, 254) | (44, 120) | (132, 359) |
|        | [388, 1200] | [1157, 3568] | [618, 1692] | [1853, 5051] |
| CHINA  | 83 [7743] | 347 [32490] | 175 [16416] | 742 [69544] |
|        | (46, 124) | (192, 518) | (105, 251) | (444, 1061) |
|        | [4263, 11583] | [17397, 48482] | [9796, 23521] | [41627, 99390] |
| INDIA  | 367 [14263] | 1522 [59149] | 601 [23350] | 2500 [97145] |
|        | (222, 521) | (923, 2152) | (369, 847) | (1542, 3513) |
|        | [8620, 20233] | [35873, 83631] | [14341, 32916] | [59896, 136481] |
| MEAST  | 123 [2575] | 505 [10602] | 229 [4817] | 947 [19893] |
|        | (72, 178) | (296, 729) | (139, 326) | (578, 1342) |
|        | [1505, 3734] | [6224, 15315] | [2956, 6855] | [12141, 28197] |
| AFRICA | 351 [7864] | 2276 [51053] | 502 [11263] | 3267 [73294] |
|        | (201, 516) | (1315, 3327) | (295, 731) | (1935, 4640) |
|        | [4507, 1158] | [29501, 74635] | [6613, 16396] | [43420, 104087] |
| LAM    | 56 [2282] | 145 [5945] | 109 [4449] | 284 [11647] |
|        | (30, 85) | (78, 221) | (68, 153) | (178, 400) |
|        | [1221, 3481] | [3186, 9052] | [2778, 6269] | [72935, 16377] |
| OHI    | 52 [1796] | 121 [4148] | 111 [3784] | 256 [8758] |
|        | (26, 83) | (61, 191) | (64, 163) | (148, 377) |
|        | [903, 2834] | [2087, 6536] | [2180, 5580] | [5056, 12895] |
| OASIA  | 156 [5349] | 643 [21989] | 262 [8972] | 1081 [36994] |
|        | (87, 234) | (360, 957) | (156, 379) | (646, 1557) |
|        | [2981, 7989] | [12300, 32725] | [5335, 12971] | [22110, 53260] |
| MX     | 51 [661] | 133 [1722] | 114 [1475] | 299 [3865] |
|        | (27, 78) | (71, 202) | (72, 160) | (188, 418) |
|        | [354, 1001] | [924, 2619] | [929, 2067] | [2439, 5402] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S4. Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP8.5 scenario for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP projection: SSP5 PIK.

| Region | RICE   | RICE-P  | RICE-U  | RICE-P-U |
|--------|--------|---------|---------|----------|
| USA    | 39 [5033] | 90 [11593] | 78 [10037] | 179 [23183] |
|        | (20, 61)  | (45, 141)  | (45, 115)  | (104, 264)  |
|        | [2530, 7943] | [5835, 1827] | [5783, 14809] | [13387, 34139] |
| EU     | 43 [6518] | 81 [12346] | 93 [14253] | 177 [27050] |
|        | (21, 67)  | (41, 127)  | (55, 136)  | (105, 258)  |
|        | [3279, 10274] | [6217, 19442] | [8413, 20754] | [15992, 39338] |
| JAPAN  | 29 [1170] | 68 [2711] | 70 [2800] | 163 [6519] |
|        | (15, 46)  | (35, 106)  | (43, 99)  | (101, 231)  |
|        | [593, 1830] | [1377, 4236] | [1733, 3962] | [1607, 4461] |
| RUSSIA | 25 [526] | 103 [2170] | 53 [1109] | 220 [4614] |
|        | (13, 39)  | (52, 162)  | (31, 77)  | (128, 321)  |
|        | [266, 826] | [1100, 3396] | [644, 1625] | [2692, 6732] |
| EURASIA| 46 [687] | 136 [2036] | 66 [991] | 196 [2948] |
|        | (23, 72)  | (68, 213)  | (36, 100) | (107, 297)  |
|        | [346, 1082] | [1027, 3199] | [539, 1502] | [1607, 4461] |
| CHINA  | 76 [8104] | 319 [33799] | 159 [16905] | 672 [71283] |
|        | (42, 115) | (175, 477) | (94, 230) | (399, 966)  |
|        | [4437, 12179] | [18564, 50648] | [10010, 24362] | [42357, 102427] |
| INDIA  | 408 [16632] | 1676 [68355] | 664 [27092] | 2740 [111758] |
|        | (244, 583) | (1008, 2386) | (404, 944) | (1673, 3879) |
|        | [9964, 23765] | [41110, 97323] | [16471, 38496] | [68231, 158218] |
| MEAST  | 150 [3616] | 617 [14831] | 280 [6741] | 1153 [27733] |
|        | (87, 219)  | (360, 895) | (169, 401) | (699, 1644)  |
|        | [2102, 5268] | [8655, 21524] | [406, 59646] | [16801, 39523] |
| AFRICA | 447 [10371] | 2800 [64992] | 639 [14826] | 4014 [93164] |
|        | (254, 663) | (1607, 4118) | (372, 937) | (2360, 5770) |
|        | [5896, 15381] | [37293, 95582] | [8628, 21742] | [54766, 133927] |
| LAM    | 67 [2681] | 175 [6964] | 129 [5114] | 336 [13356] |
|        | (36, 103)  | (93, 268)  | (79, 183)  | (208, 476)  |
|        | [1426, 4107] | [3712, 10651] | [3154, 7268] | [8611, 18934] |
| OHI    | 49 [1730] | 112 [3992] | 103 [3654] | 238 [8451] |
|        | (25, 77)  | (57, 177) | (59, 152) | (138, 350)  |
|        | [870, 2729] | [2001, 6287] | [2109, 3583] | [4888, 12427] |
| OASIA  | 182 [6485] | 740 [26330] | 304 [10823] | 1239 [44098] |
|        | (101, 274) | (411, 1107) | (179, 443) | (734, 1796) |
|        | [3589, 9742] | [14636, 39394] | [6375, 15759] | [26126, 63906] |
| MX     | 53 [709] | 137 [1845] | 117 [1569] | 306 [4104] |
|        | (28, 81)  | (74, 209)  | (73, 164)  | (192, 429)  |
|        | [379, 1082] | [988, 2811] | [983, 2206] | [2578, 5756] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S5. Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP8.5 scenario for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP projection: SSP3 OECD.

| Region   | RICE   | RICE-P   | RICE-U   | RICE-P-U |
|----------|--------|----------|----------|----------|
| USA      | 19 [2494] | 44 [5832] | 35 [4636] | 83 [10874] |
|          | (10, 29) | (23, 68) | (21, 51) | (49, 119) |
|          | [1282, 3851] | [3000, 9000] | [2752, 6667] | [6463, 15620] |
| EU       | 20 [2945] | 38 [5626] | 43 [6400] | 82 [12251] |
|          | (10, 31) | (19, 58) | (26, 61) | (50, 116) |
|          | [1512, 4552] | [2891, 8692] | [3904, 9080] | [748, 17366] |
| JAPAN    | 13 [530] | 32 [1244] | 34 [1325] | 80 [3117] |
|          | (7, 21) | (17, 49) | (22, 46) | (52, 109) |
|          | [275, 811] | [646, 1901] | [860, 1808] | [2026, 4251] |
| RUSSIA   | 23 [457] | 94 [1904] | 54 [1078] | 224 [4506] |
|          | (12, 35) | (48, 147) | (32, 77) | (133, 322) |
|          | [233, 710] | [973, 2954] | [637, 1560] | [2675, 6496] |
| EURASIA  | 31 [448] | 91 [1334] | 51 [747] | 153 [2229] |
|          | (16, 48) | (47, 142) | (29, 76) | (86, 227) |
|          | [227, 699] | [679, 2079] | [418, 1113] | [1250, 3316] |
| CHINA    | 49 [4610] | 206 [19458] | 117 [11067] | 496 [46888] |
|          | (27, 72) | (115, 304) | (71, 166) | (303, 701) |
|          | [2569, 6830] | [10871, 28757] | [6728, 15667] | [28589, 66206] |
| INDIA    | 155 [5669] | 647 [23652] | 277 [10128] | 1156 [42233] |
|          | (95, 218) | (397, 907) | (173, 387) | (725, 1607) |
|          | [3464, 7971] | [14501, 33152] | [6325, 14122] | [26473, 58689] |
| MEAST    | 82 [2115] | 341 [8823] | 166 [4279] | 690 [17845] |
|          | (49, 117) | (203, 487) | (103, 232) | (431, 963) |
|          | [1255, 3030] | [5255, 12595] | [2663, 5990] | [11148, 24892] |
| AFRICA   | 185 [5084] | 1217 [33499] | 291 [8009] | 1912 [52624] |
|          | (107, 270) | (712, 1762) | (175, 417) | (1159, 2658) |
|          | [2948, 7421] | [19590, 48519] | [4815, 11489] | [31919, 73180] |
| LAM      | 38 [1700] | 100 [4446] | 82 [3613] | 214 [9481] |
|          | (21, 58) | (54, 152) | (52, 113) | (137, 297) |
|          | [920, 2571] | [2409, 6710] | [2311, 5011] | [6079, 13122] |
| OHI      | 24 [821] | 56 [1918] | 43 [1458] | 100 [3417] |
|          | (12, 37) | (29, 86) | (25, 62) | (58, 145) |
|          | [421, 1270] | [985, 2965] | [851, 2117] | [1996, 4955] |
| OASIA    | 94 [3443] | 389 [14248] | 171 [6253] | 707 [25894] |
|          | (53, 139) | (220, 573) | (105, 242) | (436, 997) |
|          | [1941, 5095] | [8066, 21009] | [3841, 8861] | [15980, 36519] |
| MX       | 38 [537] | 100 [1403] | 93 [1314] | 244 [3444] |
|          | (21, 58) | (54, 150) | (59, 129) | (156, 338) |
|          | [290, 812] | [759, 2120] | [838, 1824] | [2203, 4771] |
|          | [1282, 3851] | [3000, 9000] | [2752, 6667] | [6463, 15620] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S6. Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP3PD scenario for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP projection: SSP3 OECD.

| Region | RICE | RICE-P | RICE-U | RICE-P-U |
|--------|------|--------|--------|----------|
| USA    | 9 [1123] (4, 14) [560, 1778] | 20 [2649] (10, 32) [1321, 4189] | 20 [2610] (12, 28) [1629, 3682] | 47 [6157] (29, 66) [3846, 8682] |
| EU     | 9 [1312] (4, 14) [654, 2077] | 17 [2523] (8, 27) [1258, 3990] | 24 [3638] (16, 34) [2356, 5030] | 47 [6994] (30, 65) [4530, 9668] |
| JAPAN  | 7 [271] (4, 11) [137, 422] | 16 [639] (8, 26) [324, 997] | 23 [885] (16, 30) [608, 1176] | 54 [2089] (37, 71) [1435, 2775] |
| RUSSIA | 9 [186] (5, 15) [92, 298] | 40 [799] (20, 63) [395, 1275] | 27 [539] (17, 38) [337, 762] | 114 [2305] (72, 162) [1445, 3257] |
| EURASIA| 12 [173] (6, 19) [85, 293] | 36 [526] (18, 58) [258, 844] | 23 [338] (13, 34) [197, 499] | 70 [1026] (41, 104) [598, 1512] |
| CHINA  | 24 [2255] (13, 36) [1262, 3359] | 103 [9698] (58, 153) [5434, 1443] | 65 [6130] (41, 90) [3884, 8542] | 279 [26378] (177, 389) [16729, 36720] |
| INDIA  | 77 [2807] (48, 107) [1744, 3918] | 328 [1198] (204, 457) [7454, 1670] | 140 [5132] (91, 192) [339, 7023] | 599 [21879] (390, 818) [14252, 29900] |
| MEAST  | 40 [1026] (24, 56) [620, 1459] | 170 [4383] (103, 241) [2655, 6224] | 85 [2199] (56, 116) [1437, 3009] | 363 [9381] (237, 496) [6139, 1282] |
| AFRICA | 75 [2062] (44, 109) [1220, 2992] | 527 [14509] (313, 761) [8628, 20941] | 124 [3421] (79, 174) [2164, 4802] | 868 [23906] (551, 1214) [15176, 33419] |
| LAM    | 16 [726] (9, 25) [393, 1106] | 43 [1925] (24, 66) [1044, 2929] | 45 [2007] (31, 60) [1393, 2669] | 120 [5322] (84, 160) [3696, 7073] |
| OHI    | 11 [361] (5, 17) [179, 572] | 25 [850] (12, 39) [422, 1348] | 23 [788] (14, 33) [482, 1126] | 54 [1859] (33, 77) [1136, 2655] |
| OASIA  | 40 [1471] (23, 59) [842, 2175] | 171 [6271] (98, 252) [3596, 9250] | 82 [3017] (54, 113) [1979, 4150] | 350 [12824] (230, 481) [8424, 17613] |
| MX     | 16 [226] (9, 24) [122, 345] | 43 [600] (23, 65) [325, 914] | 51 [716] (35, 68) [495, 955] | 135 [1899] (93, 179) [1312, 2529] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
**Table S7.** Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP3PD scenario for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP projection: SSP1 OECD.

| Region | RICE | RICE-P | RICE-U | RICE-P-U |
|--------|------|--------|--------|----------|
| USA    | 11 [1471] (5, 18) [720, 2365] | 26 [3461] (13, 42) [1696, 5559] | 27 [3607] (17, 39) [2239, 5138] | 65 [8491] (40, 92) [5274, 12086] |
| EU     | 12 [1735] (6, 19) [848, 2792] | 22 [3330] (11, 36) [1629, 5357] | 33 [4869] (21, 46) [3115, 6823] | 63 [9348] (40, 88) [5983, 13094] |
| JAPAN  | 9 [364] (5, 15) [180, 580] | 22 [858] (11, 35) [425, 1366] | 31 [1196] (21, 41) [808, 1617] | 72 [2820] (49, 98) [1905, 3809] |
| RUSSIA | 11 [231] (6, 18) [113, 372] | 49 [992] (24, 79) [486, 1594] | 30 [606] (19, 43) [375, 865] | 129 [2606] (80, 184) [1615, 3712] |
| EURASIA| 15 [223] (7, 25) [108, 361] | 46 [677] (22, 75) [328, 1096] | 27 [391] (15, 40) [222, 587] | 81 [1190] (46, 122) [676, 1784] |
| CHINA  | 36 [3369] (20, 54) [1855] | 153 [14471] (84, 231) [7980, 21816] | 89 [8406] (55, 126) [5220, 11866] | 383 [36216] (238, 542) [22512, 51162] |
| INDIA  | 137 [4986] (83, 194) [3037, 7088] | 580 [21176] (354, 822) [12916, 30038] | 232 [8459] (147, 323) [5359, 11816] | 985 [35974] (625, 1373) [22829, 50165] |
| MEAST  | 46 [1185] (28, 66) [711, 1697] | 195 [5055] (118, 279) [3039, 7226] | 91 [2363] (59, 127) [1519, 3271] | 390 [10087] (251, 539) [6493, 13938] |
| AFRICA | 142 [3911] (82, 210) [2261, 5788] | 980 [26966] (570, 1442) [15679, 39691] | 215 [5926] (131, 310) [3614, 8545] | 1483 [40833] (909, 2128) [25025, 58583] |
| LAM    | 22 [967] (12, 34) [516, 1492] | 58 [2560] (31, 89) [1367, 3948] | 57 [2542] (39, 77) [1737, 3427] | 152 [6740] (104, 205) [4608, 9081] |
| OHI    | 14 [468] (7, 22) [228, 754] | 32 [1100] (16, 52) [537, 1772] | 35 [1200] (22, 50) [741, 1716] | 82 [2823] (51, 118) [1744, 4034] |
| OASIA  | 66 [2416] (37, 99) [1355, 3635] | 280 [10255] (157, 420) [5762, 15392] | 125 [4588] (79, 177) [2894, 6491] | 532 [19479] (336, 750) [12315, 27498] |
| MX     | 20 [277] (11, 30) [148, 427] | 52 [734] (28, 80) [392, 1130] | 61 [853] (42, 81) [585, 1145] | 160 [2260] (110, 215) [1552, 3031] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S8. Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP3PD scenario for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP projection: SSP2 OECD.

| Region   | RICE   | RICE-P  | RICE-U  | RICE-P-U |
|----------|--------|---------|---------|----------|
| USA      | 10 [1355] (5, 16) [657, 2136] | 24 [3142] (12, 38) [1548, 5023] | 26 [3428] (16, 37) [2151, 4847] | 61 [8072] (39, 87) [5067, 11405] |
| EU       | 11 [1643] (5, 18) [805, 2640] | 21 [3153] (10, 34) [1545, 5064] | 31 [4688] (20, 44) [3010, 6552] | 60 [8998] (39, 84) [5780, 12571] |
| JAPAN    | 8 [322] (4, 13) [161, 510] | 19 [756] (10, 31) [379, 1200] | 27 [1065] (19, 37) [725, 1429] | 64 [2510] (44, 86) [1710, 3367] |
| RUSSIA   | 11 [215] (5, 17) [105, 346] | 46 [920] (22, 73) [450, 1479] | 29 [576] (18, 41) [358, 821] | 123 [2469] (76, 174) [1534, 3513] |
| EURASIA  | 14 [200] (7, 22) [97, 325] | 42 [608] (20, 67) [295, 984] | 25 [364] (14, 37) [207, 547] | 76 [1106] (43, 113) [630, 1656] |
| CHINA    | 29 [2784] (16, 44) [1540, 4189] | 126 [11945] (70, 190) [6618, 1795] | 76 [7207] (48, 107) [4504, 10151] | 328 [30991] (205, 461) [19390, 43599] |
| INDIA    | 111 [4065] (68, 158) [2484, 5760] | 471 [17217] (289, 666) [10544, 24347] | 197 [7182] (125, 273) [4583, 9989] | 833 [3043] (533, 1156) [19454, 42236] |
| MEAST    | 45 [1161] (27, 64) [697, 1663] | 191 [4941] (115, 273) [2971, 7065] | 93 [2396] (60, 128) [1550, 3305] | 394 [10196] (256, 543) [6609, 14040] |
| AFRICA   | 113 [3108] (66, 167) [1805, 4586] | 775 [21325] (453, 1136) [12461, 31265] | 175 [4827] (108, 251) [2976, 6916] | 1197 [32955] (741, 1706) [2041, 46966] |
| LAM      | 20 [863] (10, 30) [462, 1328] | 52 [2282] (28, 79) [1223, 3509] | 53 [2337] (36, 71) [1609, 3135] | 140 [6192] (96, 187) [4267, 8296] |
| OHI      | 13 [443] (6, 21) [217, 713] | 30 [1042] (15, 49) [510, 1675] | 35 [1193] (22, 49) [745, 1693] | 82 [2806] (51, 116) [1753, 3980] |
| OASIA    | 54 [1986] (31, 81) [1118, 2978] | 229 [8407] (130, 343) [4746, 12572] | 102 [3746] (65, 144) [2388, 5265] | 432 [15845] (276, 606) [10120, 22219] |
| MX       | 19 [263] (10, 29) [141, 406] | 49 [696] (26, 76) [372, 1071] | 58 [819] (40, 78) [562, 1098] | 154 [2166] (106, 206) [1489, 2902] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S9. Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP8.5 scenario for selected regions and a conservative damage function that does (RICE-U) account for urban impacts originating from combined local and global warming, for the central and 95% lower and upper bounds of the UHI effect estimates: SSP5 OECD.

| Region | RICE-U Central UHI | RICE-U Lower bound UHI | RICE-U Upper bound UHI |
|--------|--------------------|------------------------|------------------------|
| USA    | 90 [11844]         | 83 [10919]             | 98 [12860]             |
|        | (52, 133)          | (46,125)               | (58,142)               |
|        | [6819, 17476]      | [6068, 16402]          | [7661, 18642]          |
| EU     | 102 [15164]        | 92 [13781]             | 112 [16695]            |
|        | (60, 148)          | (52,138)               | (68,160)               |
|        | [8921, 22131]      | [7788, 20531]          | [10201, 23878]         |
| JAPAN  | 77 [2986]          | 68 [2650]              | 86 [3363]              |
|        | (47, 109)          | (40,99)                | (55,120)               |
|        | [1833, 4248]       | [1551, 3867]           | [2156, 4671]           |
| RUSSIA | 89 [1800]          | 82 [1659]              | 97 [1955]              |
|        | (52, 131)          | (46,123)               | (58,140)               |
|        | [1041, 2640]       | [927, 2476]            | [1169, 2818]           |
| EURASIA| 80 [1164]          | 76 [1116]              | 83 [1217]              |
|        | (43, 121)          | (41,117)               | (46,125)               |
|        | [633, 1765]        | [594, 1709]            | [676, 1826]            |
| CHINA  | 218 [20594]        | 203 [19149]            | 235 [22156]            |
|        | (129, 314)         | (117,296)              | (142,333)              |
|        | [12190, 29666]     | [11036, 27975]         | [13461, 31474]         |
| INDIA  | 708 [25862]        | 672 [24566]            | 746 [27258]            |
|        | (429, 1009)        | (401,967)              | (459,1054)             |
|        | [15653, 36868]     | [14632, 35334]         | [16775, 38503]         |
| MEAST  | 279 [7202]         | 260 [6733]             | 298 [7710]             |
|        | (169, 397)         | (154,376)              | (185,420)              |
|        | [4358, 10276]      | [3984, 9726]           | [4771, 10866]          |
| AFRICA | 830 [22857]        | 797 [21942]            | 866 [23840]            |
|        | (482, 1219)        | (456,1179)             | (511,1261)             |
|        | [13272, 33560]     | [12557, 32467]         | [14055, 34720]         |
| LAM    | 141 [6241]         | 126 [5616]             | 157 [6953]             |
|        | (87, 201)          | (75,185)               | (101,218)              |
|        | [3847, 8870]       | [3314, 8165]           | [4465, 9661]           |
| OHI    | 124 [4252]         | 114 [3917]             | 135 [4618]             |
|        | (71, 183)          | (63,172)               | (80,195)               |
|        | [2444, 6281]       | [2175, 5889]           | [2745, 6703]           |
| OASIA  | 399 [14634]        | 375 [13746]            | 426 [15609]            |
|        | (235, 582)         | (215,554)              | (257,613)              |
|        | [8601, 21330]      | [7882, 20295]          | [9407, 22454]          |
| MX     | 137 [1933]         | 122 [1723]             | 154 [2170]             |
|        | (85, 194)          | (73,177)               | (100,213)              |
|        | [1202, 2730]       | [1025, 2491]           | [1405, 2996]           |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S10. Median total discounted economic costs of climate change over this century expressed as a percentage of a region’s current GDP under the RCP8.5 scenario for selected regions and a high-impact damage function that does (RICE-P-U) account for urban impacts originating from combined local and global warming, for the central and 95% lower and upper bounds of the UHI effect estimates. GDP scenario: SSP5 OECD.

| Region | RICE-P-U | RICE-P-U | RICE-P-U |
|--------|----------|----------|----------|
|        | Central UHI | Lower bound UHI | Upper bound UHI |
| USA    | 208 [27388] (120, 307) [15803, 40339] | 192 [25230] (107,288) [14048, 37834] | 226 [29759] (135,327) [17770, 43058] |
| EU     | 193 [28776] (114, 281) [16954, 41944] | 175 [26136] (99,261) [14790, 38893] | 212 [31697] (130,303) [19399, 45277] |
| JAPAN  | 178 [6946] (110, 253) [4273, 9865] | 158 [6159] (93,230) [3612, 8972] | 201 [7831] (129,278) [5032, 10857] |
| RUSSIA | 373 [7519] (217, 545) [4369, 10991] | 343 [6917] (193,511) [3880, 10293] | 406 [8178] (244,583) [4915, 11746] |
| EURASIA| 238 [3476] (130, 360) [1894, 5260] | 228 [3329] (122,349) [1776, 5088] | 249 [3637] (139,373) [2025, 5444] |
| CHINA  | 923 [87193] (548, 1326) [51763, 125289] | 857 [80980] (495,1249) [46800, 118022] | 994 [93911] (606,1408) [57231, 133060] |
| INDIA  | 2920 [106653] (1774, 4147) [64813, 151506] | 2770 [101203] (1656,3971) [60509, 145065] | 3080 [112529] (1903,4335) [69544, 158370] |
| MEAST  | 1151 [29764] (700, 1636) [18091, 42305] | 1075 [27794] (639,1547) [16516, 39995] | 1234 [31905] (767,1732) [19836, 44786] |
| AFRICA | 5275 [145215] (3091, 7556) [85079, 208015] | 5056 [139180] (2918,7331) [80343, 201806] | 5511 [151708] (3279,7790) [90275, 214442] |
| LAM    | 369 [16318] (228, 523) [10085, 23140] | 331 [14664] (196,481) [8676, 21277] | 411 [18200] (265,570) [11722, 25231] |
| OHI    | 287 [9831] (165, 423) [5663, 14496] | 264 [9050] (147,396) [5034, 13583] | 312 [10685] (186,451) [6365, 15481] |
| OASIA  | 1637 [59994] (967, 2376) [35437, 87076] | 1536 [56271] (885,2258) [32417, 82748] | 1749 [6409] (1060,2504) [38829, 91764] |
| MX     | 358 [5052] (224, 505) [3150, 7119] | 319 [4497] (190,460) [2683, 6489] | 403 [5677] (262,555) [3688, 7820] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S11. Median total discounted economic benefits of climate change mitigation policy over this century expressed as a percentage of a region’s current GDP under the RCP3PD, NDC with full compliance and without compliance of the USA (NDCnoUSA) and China (NDCnoCHINA) scenarios for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP scenario: SSP5 OECD Env Growth.

| Region | Policy | RICE | RICE-P | RICE-U | RICE-P-U |
|--------|--------|------|--------|--------|----------|
| USA    | RCP3PD | 30 [4002] | 70 [9156] | 52 [6815] | 119 [15601] |
|        |        | (16, 47) | (36, 108) | (28, 78) | (65, 178) |
|        |        | [2056, 6202] | [4712, 14161] | [3717, 10239] | [8527, 23391] |
| NDC    | 13 [1648] | 29 [3767] | 21 [2731] | 48 [6247] |
|        | (7, 21) | (17, 47) | (13, 33) | (30, 76) |
|        | [968, 2713] | [2218, 6192] | [1691, 4393] | [3881, 10032] |
| NDCnoUSA | 10 [1251] | 22 [2856] | 16 [2065] | 36 [4717] |
|        | (5, 16) | (13, 36) | (10, 25) | (22, 57) |
|        | [722, 2053] | [1654, 4680] | [1253, 3313] | [2872, 7556] |
| NDCnoCHINA | 8 [1098] | 19 [2510] | 14 [1814] | 32 [4149] |
|        | (6, 14) | (13, 32) | (10, 23) | (23, 52) |
|        | [746, 1850] | [1712, 4221] | [1302, 2987] | [2990, 6820] |
| EU     | RCP3PD | 32 [4711] | 60 [8874] | 57 [8549] | 108 [16110] |
|        | (16, 49) | (31, 92) | (32, 86) | (60, 161) |
|        | [2418, 7304] | [4561, 13743] | [4708, 12779] | [8885, 24051] |
| NDC    | 13 [1940] | 24 [3653] | 23 [3410] | 43 [6423] |
|        | (8, 21) | (14, 40) | (14, 37) | (27, 69) |
|        | [1138, 3195] | [2147, 6010] | [2126, 5461] | [4014, 10275] |
| NDCnoUSA | 10 [1475] | 19 [2774] | 17 [2580] | 33 [4855] |
|        | (6, 16) | (11, 30) | (11, 28) | (20, 52) |
|        | [850, 2421] | [1603, 4549] | [1577, 4121] | [2974, 7747] |
| NDCnoCHINA | 9 [1293] | 16 [2435] | 15 [2263] | 29 [4262] |
|        | (6, 15) | (11, 27) | (11, 25) | (21, 47) |
|        | [877, 2178] | [1656, 4097] | [1634, 3710] | [3087, 6981] |
| JAPAN  | RCP3PD | 21 [812] | 48 [1865] | 38 [1475] | 87 [3395] |
|        | (11, 32) | (25, 74) | (21, 56) | (49, 129) |
|        | [419, 1251] | [965, 2869] | [823, 2183] | [1898, 5014] |
| NDC    | 9 [333] | 20 [764] | 15 [585] | 34 [1344] |
|        | (5, 14) | (12, 32) | (10, 24) | (22, 55) |
|        | [198, 547] | [456, 1254] | [374, 932] | [862, 2140] |
| NDCnoUSA | 6 [251] | 15 [575] | 11 [437] | 26 [1004] |
|        | (4, 11) | (9, 24) | (7, 18) | (16, 41) |
|        | [147, 411] | [337, 942] | [274, 696] | [630, 1597] |
| NDCnoCHINA | 6 [222] | 13 [509] | 10 [388] | 23 [891] |
|        | (4, 10) | (9, 22) | (7, 16) | (17, 37) |
|        | [154, 373] | [354, 855] | [290, 634] | [670, 1455] |
| RUSSIA | RCP3PD | 28 [556] | 112 [2266] | 49 [984] | 200 [4028] |
|        | (14, 42) | (58, 172) | (27, 73) | (111, 296) |
|        | [288, 854] | [1178, 3469] | [542, 1465] | [2227, 5972] |
| NDC    | 11 [228] | 46 [926] | 19 [393] | 80 [1603] |
|        | (7, 18) | (28, 75) | (12, 31) | (50, 127) |
|        | [135, 373] | [555, 1512] | [247, 628] | [1017, 2556] |
| NDCnoUSA | 9 [171] | 34 [695] | 15 [294] | 59 [1196] |
|        | (5, 14) | (20, 56) | (9, 23) | (37, 94) |
|        | [100, 280] | [409, 1131] | [181, 468] | [743, 1901] |
| NDCnoCHINA | 8 [152] | 31 [617] | 13 [261] | 53 [1065] |
|        | (5, 13) | (21, 51) | (10, 21) | (39, 86) |
| Region   | Scenario | Lower Bound | Upper Bound |
|----------|----------|-------------|-------------|
| EURASIA  | RCP3PD   | 37 [336] (19, 57) | 108 [1577] (56, 166) |
|          |          | 48 [697] (25, 72) | 141 [2058] (75, 213) |
| NDC      |          | 15 [220] (9, 25) | 33 [487] (20, 54) |
|          |          | 19 [282] (9, 23) | 43 [624] (26, 69) |
| NDCnUSA  |          | 11 [166] (7, 19) | 29 [430] (20, 49) |
|          |          | 13 [188] (9, 21) | 38 [554] (27, 63) |
| NDCnCHINA|          | 10 [146] (7, 17) | 29 [430] (20, 49) |
|          |          | 13 [188] (9, 21) | 38 [554] (27, 63) |
| CHINA    | RCP3PD   | 60 [5706] (33, 90) | 249 [23557] (137, 370) |
|          |          | 110 [10433] (63, 161) | 460 [43491] (263, 668) |
| NDC      |          | 24 [2277] (15, 39) | 99 [9382] (63, 158) |
|          |          | 43 [4099] (28, 68) | 181 [17061] (119, 284) |
| NDCnUSA  |          | 18 [1697] (11, 29) | 74 [6975] (46, 117) |
|          |          | 32 [3029] (21, 50) | 133 [12572] (86, 209) |
| NDCnCHINA|          | 16 [1513] (12, 26) | 66 [6233] (49, 108) |
|          |          | 29 [2720] (22, 46) | 120 [11317] (93, 193) |
| INDIA    | RCP3PD   | 258 [9442] (153, 371) | 1042 [38061] (620, 1488) |
|          |          | 409 [14948] (241, 589) | 1655 [60461] (978, 2372) |
| NDC      |          | 100 [3635] (66, 153) | 401 [14635] (266, 615) |
|          |          | 158 [5775] (104, 244) | 639 [23333] (422, 984) |
| NDCnUSA  |          | 75 [2753] (49, 116) | 303 [11055] (197, 464) |
|          |          | 120 [4372] (77, 185) | 482 [17618] (313, 741) |
| NDCnCHINA|          | 66 [2399] (50, 104) | 264 [9655] (202, 416) |
|          |          | 104 [3813] (79, 165) | 422 [15401] (321, 665) |
| MEAST    | RCP3PD   | 87 [2241] (50, 126) | 350 [9041] (202, 507) |
|          |          | 153 [3965] (89, 222) | 620 [16021] (361, 895) |
| NDC      |          | 34 [876] (22, 53) | 136 [3526] (89, 213) |
|          |          | 60 [1543] (39, 93) | 241 [6226] (158, 374) |
| NDCnUSA  |          | 26 [660] (16, 40) | 103 [2651] (66, 160) |
|          |          | 45 [1163] (29, 70) | 181 [4677] (117, 281) |
| NDCnCHINA|          | 22 [579] (17, 36) | 90 [2332] (68, 144) |
|          |          | 39 [1021] (30, 63) | 159 [4116] (122, 254) |
| AFRICA   | RCP3PD   | 390 [10738] (220, 578) | 2384 [65618] (1358, 3501) |
|          |          | 542 [14928] (308, 801) | 3317 [91313] (1900, 4728) |
| NDC      |          | 154 [4235] (96, 243) | 937 [25806] (593, 1471) |
|          |          | 213 [5869] (134, 336) | 1301 [35805] (827, 1906) |
| NDCnUSA  |          | 118 [3251] (72, 186) | 716 [19712] (445, 1119) |
|          |          | 164 [4504] (101, 257) | 993 [27344] (620, 1421) |
| NDCnCHINA|          | 102 [2803] (97, 312) | 620 [17066] (141, 3883) |
| Country | Sub-Region | RCP3PD | NDCnoUSA | NDCnoCHINA | OASIA | MX | NDCnoUSA | NDCnoCHINA | MXnoUSA | MXnoCHINA |
|---------|------------|--------|----------|------------|-------|----|----------|------------|---------|-----------|
|         |            | (72, 165) | (449, 995) | (101, 227) | (625, 1251) | (25, 72) | (25, 67) | (21, 37) | (10, 26) | (10, 26) |
|         |            | [1995, 4531] | [12355, 27388] | [2777, 6260] | [17215, 34436] | [1124, 3190] | [2904, 8208] | [1827, 4790] | [1827, 4790] | [1827, 4790] |
|         | LAM        | 48 [2103] | 123 [5421] | 73 [3248] | 190 [8393] | 19 [851] | 50 [2192] | 29 [1284] | 75 [3314] | 47 [663] |
|         | RCP3PD     | (25, 72) | (66, 186) | (41, 108) | (107, 279) | (12, 31) | (30, 80) | (19, 46) | (48, 118) | (35, 76) |
|         | NDCnoUSA   | 15 [644] | 37 [1658] | 22 [967] | 56 [2492] | 13 [366] | 33 [1457] | 19 [851] | 50 [2196] | 50 [2196] |
|         | NDCnoCHINA | (9, 23) | (22, 60) | (14, 35) | (35, 89) | (9, 21) | (23, 54) | (14, 31) | (37, 80) | (1633, 3556) |
|         | OHI        | 40 [1380] | 92 [3157] | 73 [2499] | 167 [5722] | 17 [568] | 38 [1300] | 29 [1000] | 67 [2289] | (1421, 3667) |
|         | RCP3PD     | (21, 62) | (47, 143) | (40, 109) | (91, 250) | (7, 21) | (23, 54) | (18, 46) | (41, 107) | (3137, 8568) |
|         | NDCnoUSA   | 13 [432] | 29 [987] | 22 [758] | 50 [1731] | 11 [379] | 25 [866] | 19 [664] | 44 [1519] | (1092, 2492) |
|         | NDCnoCHINA | (7, 21) | (17, 42) | (13, 35) | (32, 73) | (7, 19) | (17, 42) | (14, 32) | (32, 73) | (1092, 2492) |
|         | OASIA      | 155 [5694] | 624 [22851] | 241 [8827] | 968 [35453] | 62 [2274] | 249 [9109] | 95 [3487] | 382 [13983] | (242, 600) |
|         | RCP3PD     | (86, 232) | (345, 929) | (136, 356) | (548, 1423) | (1405, 3629) | (155, 395) | (60, 150) | (242, 600) | (8873, 21997) |
|         | NDCnoUSA   | 47 [1731] | 189 [6916] | 72 [2653] | 290 [10609] | 29 [67] | 164 [6040] | 63 [2309] | 253 [9257] | (184, 407) |
|         | NDCnoCHINA | (29, 75) | (115, 299) | (45, 114) | (184, 407) | (29, 67) | (118, 268) | (46, 102) | (184, 407) | (6759, 14899) |
|         | MX         | 40 [564] | 103 [1453] | 70 [986] | 181 [2545] | 16 [228] | 42 [587] | 28 [388] | 71 [1000] | (46, 112) |
|         | RCP3PD     | (21, 61) | (55, 156) | (40, 103) | (646, 1576) | (10, 26) | (25, 67) | (18, 43) | (46, 112) | (646, 1576) |
|         | NDCnoUSA   | 12 [173] | 31 [444] | 21 [292] | 53 [751] | 11 [152] | 28 [390] | 18 [257] | 47 [663] | (35, 76) |
|         | NDCnoCHINA | (7, 20) | (19, 51) | (13, 33) | (47, 118) | (8, 18) | (20, 46) | (14, 29) | (47, 118) | (498, 1069) |
|         |            | (103, 279) | [266, 715] | [184, 459] | [475, 1181] | [107, 251] | [276, 645] | [192, 415] | [475, 1181] | [498, 1069] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S12. Median total discounted economic benefits of climate change mitigation policy over this century expressed as a percentage of a region’s current GDP under the RCP3PD, NDC with full compliance and without compliance of the USA (NDCnoUSA) and China (NDCnoCHINA) scenarios for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP scenario: SSP5 IIASA.

| Region   | Policy      | RICE       | RICE-P      | RICE-U      | RICE-P-U     |
|----------|-------------|------------|-------------|-------------|--------------|
|          |             | (94, 714)  | (94, 714)   | (94, 714)   | (94, 714)    |
| USA      | RCP3PD      | 29 [3726]  | 67 [8520]   | 50 [6343]   | 114 [14512]  |
|          |             | (15, 45)   | (34, 104)   | (27, 75)    | (62, 171)    |
|          |             | [1911, 5782]| [4378, 13196]| [3454, 9544]| [7918, 21792]|
| NDC      |             | 12 [1536]  | 28 [3509]   | 20 [2544]   | 46 [5817]    |
|          |             | (7, 20)    | (16, 45)    | (12, 32)    | (28, 73)     |
|          |             | [899, 2530]| [2060, 5771]| [1570, 4095]| [3600, 9347] |
| NDCnoUSA |             | 9 [1168]   | 21 [2666]   | 15 [1928]   | 35 [4401]    |
|          |             | (5, 15)    | (12, 34)    | (9, 24)     | (21, 55)     |
|          |             | [672, 1918]| [1539, 4370]| [1166, 3095]| [2671, 7054] |
| NDCnoCHINA|             | 8 [1024]   | 18 [2338]   | 13 [1690]   | 30 [3863]    |
|          |             | (5, 14)    | (12, 31)    | (9, 22)     | (22, 50)     |
|          |             | [692, 1724]| [1588, 3933]| [1206, 2784]| [2770, 6353] |
| EU       | RCP3PD      | 34 [5114]  | 65 [9649]   | 62 [9825]   | 117 [17523]  |
|          |             | (18, 53)   | (33, 100)   | (34, 93)    | (65, 175)    |
|          |             | [2630, 7916]| [4968, 14916]| [5123, 13855]| [9682, 26114]|
| NDC      |             | 14 [2104]  | 27 [3968]   | 25 [3700]   | 47 [6980]    |
|          |             | (8, 23)    | (16, 44)    | (16, 40)    | (29, 75)     |
|          |             | [1237, 3460]| [2337, 6519]| [2314, 5917]| [4374, 11150]|
| NDCnoUSA |             | 11 [1597]  | 20 [3008]   | 19 [2795]   | 35 [5267]    |
|          |             | (6, 18)    | (12, 33)    | (11, 30)    | (22, 56)     |
|          |             | [923, 2617]| [1742, 4926]| [1713, 4458]| [3236, 8394] |
| NDCnoCHINA|             | 9 [1402]   | 18 [2644]   | 16 [2456]   | 31 [4632]    |
|          |             | (5, 14)    | (12, 30)    | (12, 27)    | (23, 51)     |
|          |             | [692, 1724]| [1804, 4444]| [1779, 4020]| [3366, 7575] |
| JAPAN    | RCP3PD      | 16 [640]   | 36 [1472]   | 29 [1165]   | 66 [2682]    |
|          |             | (8, 24)    | (19, 56)    | (16, 42)    | (37, 97)     |
|          |             | [331, 984]| [763, 2259] | [652, 1720] | [1503, 3952] |
| NDC      |             | 6 [262]    | 15 [602]    | 11 [461]    | 26 [1060]    |
|          |             | (4, 11)    | (9, 24)     | (7, 18)     | (17, 42)     |
|          |             | [157, 430]| [361, 988]  | [297, 734]  | [685, 1687]  |
| NDCnoUSA |             | 5 [197]    | 11 [452]    | 8 [343]     | 19 [789]     |
|          |             | (3, 8)     | (7, 18)     | (5, 13)     | (12, 31)     |
|          |             | [116, 323]| [266, 739]  | [216, 547]  | [498, 1255]  |
| NDCnoCHINA|             | 4 [174]    | 10 [401]    | 8 [305]     | 17 [703]     |
|          |             | (3, 7)     | (7, 17)     | (6, 12)     | (13, 28)     |
|          |             | [122, 294]| [282, 674]  | [231, 499]  | [534, 1147]  |
| RUSSIA   | RCP3PD      | 18 [364]   | 72 [1475]   | 31 [643]    | 128 [2615]   |
|          |             | (9, 27)    | (37, 110)   | (17, 47)    | (70, 189)    |
|          |             | [188, 560]| [766, 2260] | [353, 958]  | [1445, 3881] |
| NDC      |             | 7 [149]    | 29 [603]    | 13 [256]    | 51 [1041]    |
|          |             | (4, 12)    | (18, 48)    | (8, 20)     | (32, 81)     |
|          |             | [89, 245]| [362, 987]  | [162, 411]  | [664, 1665]  |
| NDCnoUSA |             | 5 [112]    | 22 [452]    | 9 [192]     | 38 [775]     |
|          |             | (3, 9)     | (13, 36)    | (6, 15)     | (24, 60)     |
|          |             | [66, 184]| [267, 738]  | [119, 307]  | [483, 1237]  |
| NDCnoCHINA|             | 5 [99]     | 20 [402]    | 8 [170]     | 34 [691]     |
|          |             | (3, 8)     | (14, 33)    | (6, 14)     | (25, 55)     |
| Region     | Scenario | Values |
|------------|----------|--------|
| EURASIA    | RCP3PD   | [69, 167] [282, 673] [126, 280] [517, 1133] |
|            | NDC      | [14 [198] [8, 23] [119, 325]] |
|            | NDCnoUSA | [11 [149] [8, 17] [88, 243]] |
|            | NDCnoCHINA | [9 [132] [7, 16] [92, 222]] |
| CHINA      | RCP3PD   | [46 [4344] [25, 69] [2388, 6458]] |
|            | NDC      | [18 [1732] [12, 30] [1098, 2772]] |
|            | NDCnoUSA | [14 [1288] [9, 22] [800, 2057]] |
|            | NDCnoCHINA | [12 [1151] [9, 20] [855, 1888]] |
| INDIA      | RCP3PD   | [200 [7785] [120, 285] [4649, 11084]] |
|            | NDC      | [77 [2986] [52, 118] [2012, 4590]] |
|            | NDCnoUSA | [58 [2238] [38, 88] [1475, 3435]] |
|            | NDCnoCHINA | [51 [1972] [40, 80] [1541, 3106]] |
| MEAST      | RCP3PD   | [70 [1467] [40, 102] [845, 2137]] |
|            | NDC      | [27 [573] [18, 43] [373, 898]] |
|            | NDCnoUSA | [21 [431] [13, 32] [275, 675]] |
|            | NDCnoCHINA | [18 [379] [14, 29] [286, 609]] |
| AFRICA     | RCP3PD   | [223 [5009] [127, 329] [2848, 7377]] |
|            | NDC      | [88 [1969] [56, 138] [1246, 3102]] |
|            | NDCnoUSA | [67 [1502] [42, 105] [933, 2360]] |
|            | NDCnoCHINA | [58 [1303] [361, 8097] [80 [1805]] |
Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S13. Median total discounted economic benefits of climate change mitigation policy over this century expressed as a percentage of a region’s current GDP under the RCP3PD, NDC with full compliance and without compliance of the USA (NDCnoUSA) and China (NDCnoCHINA) scenarios for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-P-U) account for urban impacts originating from combined local and global warming. GDP scenario: SSP5 PIK.

| Region    | Policy      | RICE   | RICE-P | RICE-U | RICE-P-U |
|-----------|-------------|--------|--------|--------|----------|
| USA       | RCP3PD      | 26 [3388] (13, 41) [1739, 5257] | 60 [7738] (31, 93) [3978, 11980] | 45 [5768] (24, 67) [3143, 8676] | 102 [13181] (56, 153) [7196, 19784] |
|           | NDC         | 11 [1396] (6, 18) [819, 2301] | 25 [3185] (15, 41) [1874, 5241] | 18 [2313] (11, 29) [1430, 3724] | 41 [5281] (25, 66) [3277, 8489] |
|           | NDCnoUSA    | 8 [1061] (5, 13) [612, 1743] | 19 [2417] (11, 31) [1389, 3965] | 14 [1750] (8, 22) [1061, 2811] | 31 [3990] (19, 50) [2427, 6399] |
|           | NDCnoCHINA  | 7 [931] (5, 12) [632, 1569] | 16 [2123] (11, 28) [1447, 3573] | 12 [1536] (9, 20) [1101, 2532] | 27 [3507] (20, 45) [2525, 5772] |
| EU        | RCP3PD      | 29 [4351] (15, 44) [2236, 6741] | 54 [8196] (28, 83) [4217, 12680] | 52 [7897] (29, 77) [4354, 11795] | 98 [14880] (54, 145) [8215, 22194] |
|           | NDC         | 12 [1791] (7, 19) [1053, 2950] | 22 [3371] (13, 36) [1987, 5547] | 21 [3148] (13, 33) [1969, 5042] | 39 [5929] (24, 62) [3717, 9484] |
|           | NDCnoUSA    | 9 [1359] (5, 15) [785, 2231] | 17 [2556] (10, 27) [1480, 4192] | 16 [2378] (10, 25) [1457, 3799] | 29 [4473] (18, 47) [2748, 7140] |
|           | NDCnoCHINA  | 8 [1194] (5, 13) [813, 2011] | 15 [2247] (10, 25) [1535, 3782] | 14 [2089] (10, 22) [1516, 3426] | 26 [3934] (19, 42) [2864, 6445] |
| JAPAN     | RCP3PD      | 18 [728] (9, 28) [377, 1120] | 42 [1674] (22, 64) [869, 2571] | 33 [1326] (19, 49) [742, 1957] | 77 [3052] (43, 113) [1711, 4496] |
|           | NDC         | 7 [298] (4, 12) [179, 490] | 17 [685] (10, 28) [411, 1124] | 13 [524] (8, 21) [338, 836] | 30 [1206] (20, 48) [780, 1920] |
|           | NDCnoUSA    | 6 [224] (3, 9) [132, 367] | 13 [514] (8, 21) [303, 841] | 10 [391] (6, 16) [246, 623] | 23 [897] (14, 36) [567, 1427] |
|           | NDCnoCHINA  | 5 [199] (3, 8) [139, 334] | 11 [456] (8, 19) [321, 767] | 9 [348] (7, 14) [263, 569] | 20 [800] (15, 33) [609, 1306] |
| RUSSIA    | RCP3PD      | 16 [340] (8, 25) [176, 524] | 65 [1375] (34, 101) [713, 2110] | 29 [600] (16, 43) [329, 895] | 116 [2437] (64, 172) [1343, 3621] |
|           | NDC         | 7 [139] (4, 11) [83, 229] | 27 [562] (16, 44) [337, 921] | 11 [239] (7, 18) [151, 384] | 46 [971] (29, 74) [615, 1552] |
|           | NDCnoUSA    | 5 [105] (3, 8) [61, 172] | 20 [423] (12, 33) [249, 690] | 9 [179] (5, 14) [110, 287] | 35 [725] (21, 55) [450, 1157] |
|           | NDCnoCHINA  | 4 [93] (3, 7) | 18 [375] (12, 30) | 8 [159] (6, 12) | 31 [645] (23, 50) |
| Region     | RCP3PD | NDC  |
|------------|--------|------|
| EURASIA    |        |      |
|            | [64, 156] | [261, 628] | [117, 261] | [478, 1056] |
| NDC        |        |      |
|            | [13] [188] | [7] [21] | [111, 308] | [37] [549] | [22, 60] | [326, 900] | [16] [240] | [10, 26] | [146, 390] | [47] [706] | [29, 76] | [432, 1143] |
| NDCnOUSA   |        |      |
|            | [9] [142] | [5] [15] | [83, 233] | [28] [415] | [16, 45] | [242, 678] | [12] [181] | [7] [20] | [108, 293] | [35] [530] | [21, 57] | [318, 857] |
| NDCnOCHINA |        |      |
|            | [8] [125] | [6] [14] | [86, 210] | [24] [366] | [17, 41] | [252, 614] | [11] [160] | [8] [18] | [113, 266] | [31] [469] | [22, 52] | [335, 778] |
| CHINA      | RCP3PD | NDC  |
|            | [45] [4728] | [24, 67] | [2586, 7060] | [183] [19362] | [100, 271] | [10633, 28794] | [81] [8564] | [46, 118] | [4848, 12523] | [334] [35457] | [190, 487] | [20154, 51644] |
| NDC        |        |      |
|            | [18] [1890] | [11, 29] | [1186, 3031] | [73] [7726] | [46, 116] | [4879, 12350] | [32] [3372] | [21, 50] | [2200, 5327] | [131] [13934] | [86, 207] | [9153, 21952] |
| NDCnOUSA   |        |      |
|            | [13] [1414] | [8, 21] | [869, 2261] | [54] [5759] | [34, 87] | [3565, 9184] | [24] [2498] | [15, 37] | [1594, 3941] | [97] [10292] | [62, 153] | [6612, 16186] |
| NDCnOCHINA |        |      |
|            | [12] [1256] | [9, 19] | [919, 2063] | [48] [5133] | [36, 79] | [3790, 8404] | [21] [2237] | [16, 34] | [1714, 3623] | [87] [9242] | [67, 141] | [7143, 14926] |
| INDIA      | RCP3PD | NDC  |
|            | [236] [9633] | [140, 338] | [5713, 13796] | [950] [38767] | [566, 1355] | [23101, 55268] | [374] [15251] | [220, 537] | [8988, 21918] | [1510] [61594] | [894, 2161] | [36465, 88128] |
| NDC        |        |      |
|            | [91] [3705] | [60, 140] | [2459, 5711] | [365] [14891] | [244, 561] | [9959, 22864] | [144] [5887] | [95, 223] | [3887, 9101] | [582] [23744] | [387, 897] | [15793, 36572] |
| NDCnOUSA   |        |      |
|            | [69] [2798] | [45, 106] | [1819, 4304] | [275] [11214] | [180, 421] | [7344, 17177] | [109] [4444] | [70, 168] | [2874, 6855] | [438] [17874] | [286, 673] | [11645, 27462] |
| NDCnOCHINA |        |      |
|            | [60] [2446] | [46, 95] | [1871, 3860] | [241] [9826] | [186, 379] | [7592, 15451] | [95] [3888] | [73, 151] | [2961, 6155] | [384] [15676] | [295, 606] | [12050, 24726] |
| MEAST      | RCP3PD | NDC  |
|            | [89] [2142] | [51, 130] | [1229, 3129] | [357] [8591] | [206, 519] | [4955, 12492] | [157] [3785] | [91, 229] | [2188, 5505] | [633] [15214] | [368, 916] | [8838, 22025] |
| NDC        |        |      |
|            | [35] [838] | [22, 55] | [540, 1314] | [140] [3355] | [91, 218] | [2181, 5244] | [61] [1475] | [40, 96] | [958, 2306] | [246] [5921] | [161, 383] | [3875, 9220] |
| NDCnOUSA   |        |      |
|            | [26] [634] | [17, 41] | [400, 992] | [105] [2530] | [67, 164] | [1611, 3945] | [46] [1115] | [29, 72] | [709, 1739] | [185] [4460] | [119, 288] | [2859, 6930] |
| NDCnOCHINA |        |      |
|            | [23] [554] | [17, 37] | [413, 891] | [92] [2219] | [69, 148] | [1670, 3552] | [41] [976] | [30, 65] | [732, 1562] | [163] [3914] | [123, 260] | [2966, 6242] |
| AFRICA     | RCP3PD | NDC  |
|            | [296] [6879] | [167, 439] | [3882, 10199] | [1780] [41310] | [1014, 2614] | [23538, 60678] | [412] [9560] | [234, 609] | [5425, 14126] | [2476] [57471] | [1419, 3560] | [32931, 82631] |
| NDC        |        |      |
|            | [117] [2712] | [73, 185] | [1695, 4294] | [700] [16239] | [444, 1099] | [10303, 25503] | [162] [3758] | [102, 256] | [2360, 5932] | [971] [22525] | [619, 1455] | [14361, 33767] |
| NDCnOUSA   |        |      |
|            | [90] [2080] | [55, 142] | [1277, 3284] | [534] [12383] | [332, 835] | [7713, 19391] | [124] [2881] | [77, 195] | [1777, 4537] | [740] [17175] | [463, 1091] | [10748, 25310] |
| NDCnOCHINA |        |      |
|            | [77] [1796] |            | [463] [10743] | [107] [2487] |            | [642] [14895] |
| Region  | RCP3PD | LAM | NDC | NDCnoUSA | NDCnoCHINA | OHI | OASIA | MX | NDC | NDCnoUSA | NDCnoCHINA |
|---------|--------|-----|-----|----------|------------|-----|-------|----|-----|----------|-------------|
|         | 43 [1723] | [23, 66] | [920, 2617] | 111 [4433] | [60, 169] | [2373, 6718] | 67 [2659] | [38, 99] | [1494, 3926] | 172 [6857] | [97, 254] | [3863, 10100] |
| NDC     | 18 [697] | [11, 28] | [423, 1130] | 45 [1793] | [27, 73] | [1091, 2899] | 26 [1051] | [17, 42] | [670, 1667] | 68 [2709] | [44, 108] | [1732, 4286] |
| NDCnoUSA| 13 [529] | [8, 21] | [315, 854] | 34 [1357] | [20, 55] | [811, 2187] | 20 [792] | [12, 32] | [494, 1253] | 51 [2038] | [32, 81] | [1276, 3218] |
| NDCnoCHINA | 12 [464] | [8, 19] | [325, 768] | 30 [1192] | [21, 50] | [839, 1972] | 18 [697] | [13, 28] | [515, 1131] | 45 [1795] | [34, 73] | [1333, 2909] |
| OHI     | 33 [1162] | [17, 51] | [597, 1800] | 75 [2658] | [39, 116] | [1368, 4110] | 59 [2104] | [32, 89] | [1153, 3154] | 136 [4817] | [74, 203] | [2644, 7206] |
| OASIA   | 13 [478] | [8, 22] | [281, 787] | 31 [1093] | [18, 51] | [644, 1979] | 24 [841] | [15, 38] | [523, 1351] | 54 [1925] | [34, 87] | [1200, 3085] |
| OASIA   | 13 [478] | [8, 22] | [281, 787] | 31 [1093] | [18, 51] | [644, 1979] | 24 [841] | [15, 38] | [523, 1351] | 54 [1925] | [34, 87] | [1200, 3085] |
| NDC     | 10 [363] | [6, 17] | [210, 596] | 23 [829] | [14, 43] | [840, 1358] | 18 [662] | [11, 29] | [384, 1019] | 41 [1454] | [25, 65] | [888, 2324] |
| NDCnoUSA| 9 [319] | [6, 15] | [217, 537] | 21 [729] | [14, 35] | [497, 1225] | 16 [559] | [11, 26] | [402, 918] | 36 [1278] | [26, 59] | [924, 2097] |
| NDCnoCHINA | 42 [1716] | [8, 19] | [325, 768] | 30 [1192] | [21, 50] | [839, 1972] | 18 [697] | [13, 28] | [515, 1131] | 45 [1795] | [34, 73] | [1333, 2909] |
| OASIA   | 117 [4166] | [64, 175] | [2293, 6241] | 465 [16559] | [257, 694] | [9160, 24686] | 181 [6456] | [102, 269] | [3633, 9553] | 722 [25684] | [408, 1063] | [14530, 37816] |
| NDC     | 47 [1664] | [29, 75] | [1028, 2661] | 186 [6602] | [116, 296] | [4111, 10517] | 72 [2551] | [45, 114] | [1607, 4039] | 285 [10132] | [181, 449] | [6434, 15973] |
| NDCnoUSA| 36 [1267] | [22, 57] | [768, 2020] | 141 [5010] | [86, 224] | [3062, 7957] | 55 [1940] | [34, 86] | [1199, 3065] | 216 [7683] | [134, 339] | [4784, 12079] |
| NDCnoCHINA | 31 [1104] | [22, 51] | [785, 1807] | 123 [4379] | [88, 201] | [3143, 7138] | 48 [1690] | [34, 77] | [1224, 2739] | 189 [6710] | [138, 304] | [4909, 10825] |
| MX      | 33 [442] | [18, 50] | [237, 670] | 85 [1140] | [46, 128] | [612, 1723] | 58 [774] | [33, 84] | [441, 1134] | 149 [1999] | [85, 218] | [1140, 2922] |
| NDC     | 13 [179] | [8, 22] | [109, 289] | 34 [460] | [21, 55] | [282, 743] | 23 [304] | [15, 36] | [197, 480] | 58 [785] | [38, 92] | [510, 1236] |
| NDCnoUSA| 10 [135] | [6, 16] | [81, 218] | 26 [347] | [16, 42] | [209, 559] | 17 [228] | [11, 27] | [144, 359] | 44 [588] | [28, 69] | [374, 924] |
| NDCnoCHINA | 9 [119] | [6, 15] | [84, 197] | 23 [306] | [16, 38] | [218, 506] | 15 [202] | [11, 24] | [152, 326] | 39 [520] | [29, 62] | [394, 839] |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S14. Total discounted costs over this century expressed as a percentage of a region’s current GDP of key participants (the USA or China) dropping out of the NDC mitigation effort for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-U-P) account for urban impacts originating from combined local and global warming. GDP scenario: SSP5 OECD Env Growth.

| Region  | Country dropping out | RICE | RICE-P | RICE-U | RICE-P-U |
|---------|----------------------|------|--------|--------|----------|
| USA     | USA                  | 3 [397] (2, 5) [245, 659] | 7 [911] (4, 11) [565, 1512] | 5 [666] (3, 8) [438, 1079] | 12 [1531] (8, 19) [1009, 2476] |
|         |                      |     |        |        |          |
| CHINA   | 4 [549] (2, 7) [221, 863] | 10 [1256] (4, 15) [506, 1970] | 7 [917] (3, 11) [389, 1406] | 16 [2099] (7, 24) [891, 3211] |
|         |                      |     |        |        |          |
| EU      | USA                  | 3 [466] (2, 5) [288, 775] | 6 [880] (4, 10) [544, 1461] | 6 [830] (4, 9) [550, 1339] | 11 [1568] (7, 17) [1040, 2528] |
|         |                      |     |        |        |          |
| CHINA   | 4 [647] (2, 7) [261, 1017] | 8 [1219] (3, 13) [491, 1913] | 8 [1147] (3, 12) [492, 1750] | 14 [2161] (6, 22) [928, 3294] |
|         |                      |     |        |        |          |
| JAPAN   | USA                  | 2 [82] (1, 3) [51, 136] | 5 [189] (3, 8) [119, 312] | 4 [147] (3, 6) [100, 236] | 9 [340] (6, 14) [232, 543] |
|         |                      |     |        |        |          |
| CHINA   | 3 [111] (1, 4) [44, 174] | 7 [255] (3, 10) [102, 399] | 5 [197] (2, 8) [84, 298] | 12 [453] (5, 18) [193, 685] |
|         |                      |     |        |        |          |
| RUSSIA  | USA                  | 3 [56] (2, 5) [35, 93] | 11 [231] (7, 19) [145, 380] | 5 [99] (3, 8) [66, 159] | 20 [408] (14, 32) [274, 654] |
|         |                      |     |        |        |          |
| CHINA   | 4 [76] (2, 6) [31, 119] | 15 [309] (6, 24) [124, 481] | 7 [132] (3, 10) [56, 201] | 27 [539] (11, 41) [228, 817] |
|         |                      |     |        |        |          |
| EURASIA | USA                  | 4 [54] (2, 6) [33, 89] | 11 [159] (7, 18) [99, 262] | 5 [70] (3, 8) [45, 114] | 14 [208] (9, 23) [135, 339] |
|         |                      |     |        |        |          |
| CHINA   | 5 [73] (2, 8) [30, 115] | 15 [216] (6, 23) [87, 337] | 7 [94] (3, 10) [39, 146] | 19 [279] (8, 29) [115, 429] |
|         |                      |     |        |        |          |
| CHINA   | USA                  | 6 [579] (4, 10) [386, 932] | 25 [2407] (17, 41) [1611, 3865] | 11 [1071] (8, 18) [744, 1694] | 48 [4489] (33, 75) [3135, 7087] |
|         |                      |     |        |        |          |
| CHINA   | 8 [764] (3, 12) [322, 1162] | 33 [3149] (14, 51) [1327, 4778] | 15 [1380] (6, 22) [594, 2065] | 61 [5744] (26, 91) [2473, 8574] |
|         |                      |     |        |        |          |
| INDIA   | USA                  | 24 [882] (17, 38) [618, 1370] | 98 [3581] (69, 152) [2528, 5544] | 38 [1403] (27, 60) [978, 2187] | 156 [5715] (110, 243) [4010, 8877] |
|         |                      |     |        |        |          |
| CHINA   | 34 [1236] (16, 50) [579, 1817] | 136 [4981] (64, 200) [2336, 7294] | 54 [1962] (25, 79) [912, 2893] | 217 [7932] (101, 319) [3693, 11655] |
|         |                      |     |        |        |          |
| MEAST   | USA                  | 8 [215] (6, 13) [148, 339] | 34 [875] (24, 53) [608, 1375] | 15 [380] (10, 23) [264, 597] | 60 [1549] (42, 94) [1084, 2425] |
|         |                      |     |        |        |          |
| CHINA   | 11 [296] (5, 17) | 46 [1194] (21, 69) | 20 [523] (9, 30) | 82 [2110] (37, 121) |
| Region | USA | China | LAM | OHI | OASIA | MX | CHINA |
|--------|-----|-------|-----|-----|-------|----|--------|
|        | [133, 442] | [537, 1775] | [236, 777] | [956, 3125] | [24, 57] | [1432, 4372] | [24, 79] |
| AFRICA | 36 [984] (24, 57) 650, 1570 | 221 [6094] (148, 351) 4077, 9660 | 50 [1365] (33, 79) 906, 2172 | 307 [8461] (207, 485) 3690, 13344 | 52 [1432] (24, 79) 648, 2161 | 317 [8739] (144, 476) 3975, 13096 | 72 [1986] (33, 109) 905, 2989 | 441 [12136] (202, 655) 5553, 18029 |
| CHINA  | 5 [206] (3, 8) 132, 337 | 12 [534] (8, 20) 343, 871 | 7 [317] (5, 11) 215, 505 | 19 [822] (13, 30) 559, 1309 | 6 [285] (3, 10) 119, 440 | 17 [735] (7, 26) 308, 1132 | 10 [433] (4, 15) 189, 653 | 25 [1118] (11, 38) 489, 1683 |
| LAM    | 4 [136] (2, 7) 84, 226 | 9 [313] (6, 15) 193, 519 | 7 [243] (5, 11) 159, 392 | 16 [557] (11, 26) 367, 900 | 6 [190] (2, 9) 77, 298 | 13 [434] (5, 20) 175, 680 | 10 [336] (4, 15) 144, 514 | 22 [769] (10, 34) 329, 1175 |
| OHI    | 15 [543] (10, 24) 354, 874 | 60 [2193] (39, 96) 1442, 3522 | 23 [834] (15, 36) 557, 1330 | 92 [3374] (62, 146) 2267, 5360 | 21 [765] (9, 32) 334, 1166 | 84 [3069] (37, 127) 1342, 4658 | 32 [1177] (14, 48) 526, 1775 | 129 [4726] (58, 194) 2114, 7098 |
| OASIA  | 4 [55] (3, 6) 36, 91 | 10 [143] (7, 17) 92, 234 | 7 [96] (5, 11) 66, 153 | 18 [249] (12, 28) 171, 395 | 5 [76] (2, 8) 32, 118 | 14 [197] (6, 22) 82, 303 | 9 [131] (4, 14) 58, 197 | 24 [338] (11, 36) 149, 507 |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S15. Total discounted costs over this century expressed as a percentage of a region’s current GDP of key participants (the USA or China) dropping out of the NDC mitigation effort for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-U-P) account for urban impacts originating from combined local and global warming. GDP scenario: SSP5 IIASA.

| Region | Country dropping out | RICE | RICE-P | RICE-U | RICE-P-U |
|--------|----------------------|------|--------|--------|----------|
| USA    | USA                  | 3 [368] (2, 5) [226, 611] | 7 [843] (4, 11) [521, 1401] | 5 [617] (3, 8) [404, 1000] | 11 [1416] (7, 18) [929, 2293] |
|        | CHINA                | 4 [512] (2, 6) [207, 805] | 9 [1170] (4, 14) [472, 1837] | 7 [855] (3, 10) [363, 1311] | 15 [1954] (7, 24) [831, 2993] |
| EU     | USA                  | 3 [508] (2, 6) [314, 843] | 6 [960] (4, 11) [595, 1593] | 6 [905] (4, 10) [601, 1458] | 11 [1713] (8, 18) [1138, 2756] |
|        | CHINA                | 5 [702] (2, 7) [283, 1101] | 9 [1323] (4, 14) [534, 2075] | 8 [1245] (4, 13) [535, 1897] | 16 [2348] (7, 24) [1009, 3575] |
| JAPAN  | USA                  | 2 [65] (1, 3) [41, 108] | 4 [150] (2, 6) [95, 248] | 3 [117] (2, 5) [81, 187] | 7 [271] (5, 11) [187, 433] |
|        | CHINA                | 2 [87] (1, 3) [35, 137] | 5 [201] (2, 8) [80, 314] | 4 [155] (2, 6) [66, 235] | 9 [357] (4, 13) [151, 540] |
| RUSSIA | USA                  | 2 [37] (1, 3) [23, 61] | 7 [151] (5, 12) [96, 249] | 3 [65] (2, 5) [44, 105] | 13 [266] (9, 21) [180, 428] |
|        | CHINA                | 2 [50] (1, 4) [20, 78] | 10 [201] (4, 15) [80, 314] | 4 [86] (2, 6) [36, 131] | 17 [350] (7, 26) [146, 532] |
| EURASIA| USA                  | 4 [49] (2, 6) [31, 82] | 10 [146] (7, 17) [93, 241] | 5 [65] (3, 8) [43, 106] | 14 [193] (9, 22) [127, 313] |
|        | CHINA                | 5 [66] (2, 7) [26, 101] | 14 [195] (6, 22) [78, 303] | 6 [85] (2, 9) [35, 132] | 18 [252] (7, 28) [103, 388] |
| CHINA  | USA                  | 5 [444] (3, 8) [299, 715] | 20 [1846] (13, 32) [1247, 2965] | 9 [822] (6, 14) [578, 1301] | 37 [3446] (26, 58) [2435, 5443] |
|        | CHINA                | 6 [581] (3, 9) [243, 885] | 26 [2393] (11, 39) [999, 3633] | 11 [1048] (5, 17) [446, 1570] | 47 [4360] (20, 70) [1856, 6513] |
| INDIA  | USA                  | 19 [748] (14, 30) [537, 1156] | 79 [3060] (57, 121) [2212, 4715] | 31 [1192] (22, 48) [851, 1849] | 126 [4895] (91, 195) [3517, 7567] |
|        | CHINA                | 26 [1014] (12, 38) [471, 1485] | 106 [4115] (49, 154) [1911, 6001] | 42 [1613] (19, 61) [743, 2369] | 169 [6567] (78, 247) [3028, 9608] |
| MEAST  | USA                  | 7 [141] (5, 11) [98, 223] | 27 [574] (19, 43) [401, 902] | 12 [250] (8, 19) [175, 393] | 48 [1016] (34, 76) [715, 1591] |
|        | CHINA                | 9 [194] (4, 14) [87, 289] | 37 [779] (17, 55) [349, 1158] | 16 [342] (7, 24) [154, 508] | 66 [1376] (30, 97) [620, 2039] |
| Region   | Country | 2005  | (2005, 2008) | (2008, 2012) | (2012, 2016) | (2016, 2020) | (2020, 2025) | (2025, 2030) | (2030, 2035) | (2035, 2040) | (2040, 2045) | (2045, 2050) |
|----------|---------|-------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| AFRICA   | USA     | 21 [467] | (14, 33)    | 132 [2957]  | 29 [648]    | 183 [4104]  |                |                |                |                |                |
|          |         | [313, 742] | [90, 208]   | [2012, 4667] | [19, 46]    | [437, 1026] | [2805, 6438] |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 30 [666] | (13, 45)    | 185 [4147]  | 41 [924]    | 257 [5759]  |                |                |                |                |                |
|          |         | [301, 1001] | [84, 276]   | [1879, 6189] | [19, 62]    | [420, 1385] | [2626, 8503] |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 3 [140]  | (2, 6)      | 9 [363]     | 5 [216]     | 14 [561]    |                |                |                |                |                |
|          |         | [91, 229] | [6, 14]     | [236, 591]  | [4, 8]      | [148, 344]  | [386, 892]    |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 5 [191]  | (2, 7)      | 12 [493]    | 7 [291]     | 18 [752]    |                |                |                |                |                |
|          |         | [80, 295] | [5, 19]     | [205, 759]  | [3, 11]     | [126, 438]  | [326, 1131]   |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 4 [120]  | (2, 6)      | 8 [277]     | 6 [214]     | 14 [493]    |                |                |                |                |                |
|          |         | [74, 200] | [5, 13]     | [171, 459]  | [4, 10]     | [141, 346]  | [325, 796]    |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 5 [167]  | (2, 8)      | 11 [382]    | 9 [296]     | 20 [678]    |                |                |                |                |                |
|          |         | [67, 262] | [5, 18]     | [154, 599]  | [4, 13]     | [127, 453]  | [325, 796]    |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 9 [320]  | (6, 15)     | 38 [1299]   | 14 [491]    | 58 [1996]   |                |                |                |                |                |
|          |         | [212, 514] | [25, 61]    | [866, 2080] | [10, 23]    | [332, 781]  | [1360, 3163]  |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 13 [443] | (6, 20)     | 52 [1784]   | 20 [681]    | 80 [2746]   |                |                |                |                |                |
|          |         | [192, 674] | [23, 79]    | [775, 2702] | [9, 30]     | [302, 1025] | [1220, 4115]  |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 3 [40]   | (2, 5)      | 8 [105]     | 5 [70]      | 14 [183]    |                |                |                |                |                |
|          |         | [26, 66] | [5, 13]     | [68, 170]   | [4, 9]      | [49, 111]   | [127, 289]    |                |                |                |                |
|          |         |        |             |             |             |             |                |                |                |                |                |
|          |         | 4 [55]   | (2, 7)      | 11 [141]    | 7 [94]      | 19 [243]    |                |                |                |                |                |
|          |         | [23, 84] | [5, 17]     | [59, 217]   | [3, 11]     | [41, 141]   | [106, 364]    |                |                |                |                |

Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer.
Table S16. Total discounted costs over this century expressed as a percentage of a region’s current GDP of key participants (the USA or China) dropping out of the NDC mitigation effort for selected regions and a conservative damage function that does not (RICE) or does (RICE-U) account for urban impacts originating from combined local and global warming and for a high-impact damage function that does not (RICE-P) or does (RICE-U-P) account for urban impacts originating from combined local and global warming. GDP scenario: SSP5 PIK.

| Region | Country dropping out | RICE | RICE-P | RICE-U | RICE-P-U |
|--------|----------------------|------|--------|--------|----------|
| USA    | USA                  | 3 [335] (2, 4) [207, 558] | 6 [768] (4, 10) [476, 1277] | 4 [563] (3, 7) [370, 913] | 10 [1291] (7, 16) [851, 2090] |
|        | CHINA                | 4 [465] (1, 6) [187, 732] | 8 [1062] (3, 13) [427, 1668] | 6 [777] (3, 9) [329, 1192] | 14 [1774] (6, 21) [752, 2717] |
|        | EU                   | 3 [432] (2, 5) [268, 718] | 5 [816] (3, 9) [506, 1355] | 5 [770] (3, 8) [512, 1242] | 10 [1455] (6, 15) [969, 2344] |
|        | CHINA                | 4 [597] (2, 6) [240, 938] | 7 [1124] (3, 12) [452, 1765] | 7 [1059] (3, 11) [453, 1615] | 13 [1994] (6, 20) [854, 3039] |
| JAPAN  | USA                  | 2 [74] (1, 3) [47, 123] | 4 [171] (3, 7) [109, 283] | 3 [134] (2, 5) [92, 214] | 8 [309] (5, 12) [213, 493] |
|        | CHINA                | 2 [99] (1, 4) [40, 156] | 6 [228] (2, 9) [91, 357] | 4 [176] (2, 7) [75, 267] | 10 [406] (4, 15) [172, 614] |
| RUSSIA | USA                  | 2 [34] (1, 3) [21, 57] | 7 [140] (4, 11) [88, 231] | 3 [60] (2, 5) [40, 97] | 12 [246] (8, 19) [166, 396] |
|        | CHINA                | 2 [47] (1, 3) [19, 73] | 9 [188] (4, 14) [75, 293] | 4 [80] (2, 6) [34, 123] | 16 [326] (7, 24) [137, 496] |
| EURASIA| USA                  | 3 [46] (2, 5) [28, 76] | 9 [134] (6, 15) [84, 222] | 4 [59] (3, 6) [38, 97] | 12 [175] (8, 19) [114, 286] |
|        | CHINA                | 4 [63] (2, 7) [25, 98] | 12 [183] (5, 19) [74, 287] | 5 [80] (2, 8) [33, 124] | 16 [236] (7, 24) [97, 365] |
| CHINA  | USA                  | 4 [477] (3, 7) [317, 770] | 19 [1967] (12, 30) [1315, 3167] | 8 [874] (6, 13) [606, 1387] | 34 [3642] (24, 54) [2542, 5766] |
|        | CHINA                | 6 [634] (3, 9) [266, 968] | 24 [2593] (10, 37) [1089, 3946] | 11 [1135] (5, 16) [486, 1704] | 44 [4692] (19, 66) [2011, 7025] |
| INDIA  | USA                  | 22 [907] (16, 34) [640, 1407] | 90 [3677] (64, 139) [2614, 5687] | 35 [1442] (25, 55) [1012, 2246] | 144 [5870] (102, 223) [4148, 9109] |
| CHINA  | USA                  | 41 [8757] (45, 170) [3871, 15892] | 124 [5065] (58, 182) [2367, 7413] | 49 [1999] (23, 72) [926, 2946] | 198 [8068] (92, 290) [3743, 11845] |
| MEAST  | USA                  | 8 [204] (6, 13) [140, 322] | 34 [825] (24, 54) [570, 1299] | 15 [360] (10, 24) [249, 567] | 61 [1460] (42, 95) [1016, 2290] |
| CHINA  | USA                  | 12 [283] (5, 18) [127, 424] | 47 [1136] (21, 70) [311, 1692] | 21 [500] (9, 31) [226, 744] | 83 [2006] (38, 124) [910, 2978] |
| Region   | USA | AFRICA  | CHINA | LAM | OHI | OASIA | MX | CHINA | Note: Figures in brackets are in billions US$2005. 95% confidence intervals based on uncertainty in global warming projections are shown in between parenthesis for the percentage of a region’s current GDP and in brackets for billions US$2005. Figures are rounded to the nearest integer. |
|----------|-----|---------|-------|-----|-----|-------|----|--------|-------------------------------------------------|
|          |     | 27 [632] | 39 [916] | 4 [169] | 3 [115] | 11 [397] | 3 [44] | 4 [60] |                                                                 |
|          |     | (18, 44) | (18, 60) | (3, 7) | (2, 5) | (7, 18) | (2, 5) | (2, 7) |                                                                 |
|          |     | [418, 1010] | [414, 1385] | [108, 276] | [71, 192] | [260, 641] | [28, 71] | [25, 92] |                                                                 |
|          |     | 166 [3855] | 237 [5496] | 11 [436] | 7 [265] | 45 [1593] | 8 [113] | 11 [154] |                                                                 |
|          |     | (112, 263) | (107, 355) | (7, 18) | (5, 14) | (30, 72) | (5, 14) | (5, 18) |                                                                 |
|          |     | [2591, 6112] | [2490, 8240] | [280, 711] | [73, 184] | [1049, 2560] | [73, 184] | [64, 238] |                                                                 |
|          |     | 38 [876] | 55 [1271] | 7 [259] | 6 [205] | 17 [611] | 6 [76] | 8 [103] |                                                                 |
|          |     | (25, 60) | (25, 83) | (4, 10) | (4, 9) | (11, 27) | (4, 9) | (4, 11) |                                                                 |
|          |     | [538, 1396] | [577, 1915] | [176, 413] | [135, 332] | [408, 975] | [53, 121] | [45, 154] |                                                                 |
|          |     | 230 [5350] | 329 [7630] | 17 [671] | 13 [471] | 69 [2449] | 15 [197] | 20 [265] |                                                                 |
|          |     | (156, 364) | (150, 491) | (11, 27) | (9, 21) | (46, 109) | (10, 23) | (9, 30) |                                                                 |
|          |     | [3614, 8457] | [3478, 11397] | (456, 1069) | (312, 761) | [1649, 3894] | (137, 312) | [116, 397] |                                                                 |
|          |     | 38 [55] | 237 [5496] | 55 [1271] | 9 [354] | 18 [647] | 18 [647] | 46 [109] |                                                                 |
|          |     | (25, 60) | (25, 83) | (4, 13) | (155, 535) | (8, 28) | (8, 28) | (46, 109) |                                                                 |
|          |     | [538, 1396] | [577, 1915] | [176, 413] | [135, 332] | [408, 975] | [135, 332] | [1649, 3894] |                                                                 |
|          |     | 13 [471] | 223 [861] | 18 [647] | 13 [471] | 15 [197] | 15 [197] | 15 [197] |                                                                 |
|          |     | (9, 35) | (155, 535) | (8, 28) | (9, 21) | (10, 23) | (10, 23) | (10, 23) |                                                                 |
|          |     | [399, 1377] | [3478, 11397] | (456, 1069) | (312, 761) | [1649, 3894] | (137, 312) | [116, 397] |                                                                 |
Table S17. Relation between world regions and countries included in CLIMRISK.

| Region    | Countries                                                                 |
|-----------|---------------------------------------------------------------------------|
| USA       | USA, Puerto Rico                                                          |
| EU        | Austria, Belgium, Channel Islands, Cyprus, Czech Republic, Denmark, Estonia, Faeroe Islands, Finland, France, Germany, Greece, Greenland, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom |
| JAPAN     | Japan                                                                     |
| RUSSIA    | Russia                                                                    |
| EURASIA   | Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Romania, TFYR Macedonia, Yugoslavia, Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Republic of Moldova, Tajikistan, Turkmenistan, Ukraine, Uzbekistan |
| CHINA     | China, Hong Kong SAR                                                     |
| INDIA     | India                                                                     |
| MEAST     | Bahrain, Occupied Palestinian Terr., Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen |
| AFRICA    | Angola, Botswana, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Dem. Rep. of the Congo, Benin, Equatorial Guinea, Ethiopia, Eritrea, Djibouti, Gabon, Gambia, Ghana, Guinea, Cote d’Ivoire, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Guinea-Bissau, Reunion, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Zimbabwe, Swaziland, Togo, Uganda, United Republic of Tanzania, Burkina Faso, Zambia, Algeria, Libyan Arab Jamahiriya, Morocco, Western Sahara, Sudan, Tunisia, Egypt |
| LAM       | Argentina, Bahamas, Barbados, Bolivia, Brazil, Belize, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Saint Vincent and the ... |
| Code | Description |
|------|-------------|
| Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela |
| OHI | Australia, Canada, New Zealand, Republic of Korea, Taiwan |
| OTHASIA | Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Dem. People's Rep. of Korea, East Timor, Fiji, French Polynesia, Indonesia, Lao People's Dem. Republic, Malaysia, Mongolia, Myanmar, New Caledonia, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Vanuatu, Viet Nam |
| MX | Mexico |
| Model name       | Modeling center                                                                 |
|------------------|----------------------------------------------------------------------------------|
| ACCESS1-0        | Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia |
| ACCESS1-3        | Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia |
| BNU-ESM          | College of Global Change and Earth System Science, Beijing Normal University      |
| CCSM4            | University of Miami - RSMAS                                                      |
| CESM1-BGC        | Community Earth System Model Contributors                                       |
| CESM1-CAM5       | Community Earth System Model Contributors                                       |
| CESM1-WACCM      | Community Earth System Model Contributors                                       |
| CMCC-CESM        | Centro Euro-Mediterraneo per I Cambiamenti Climatici                              |
| CMCC-CMS         | Centro Euro-Mediterraneo per I Cambiamenti Climatici                              |
| CMCC-CM          | Centro Euro-Mediterraneo per I Cambiamenti Climatici                              |
| CNRM-CM5         | Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique |
| CSIRO-MK3-6-0    | Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique |
| CANESM2          | Canadian Centre for Climate Modelling and Analysis                                |
| EC-EARTH         | EC-EARTH consortium                                                              |
| FGOALS-G2        | LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences               |
| FIO-ESM          | The First Institute of Oceanography, SOA, China                                   |
| GFDL-CM3         | NOAA Geophysical Fluid Dynamics Laboratory                                        |
| GFDL-ESM2G       | NOAA Geophysical Fluid Dynamics Laboratory                                        |
| GFDL-ESM2M       | NOAA Geophysical Fluid Dynamics Laboratory                                        |
| GISS-E2-H-CC     | NASA Goddard Institute for Space Studies                                          |
| GISS-E2-H        | NASA Goddard Institute for Space Studies                                          |
| GISS-E2-R-CC     | NASA Goddard Institute for Space Studies                                          |
| GISS-E2-R        | NASA Goddard Institute for Space Studies                                          |
| Model               | Institution                                                                 |
|---------------------|------------------------------------------------------------------------------|
| HADGEM2-AO          | Met Office Hadley Centre                                                     |
| HADGEM2-CC          | Met Office Hadley Centre                                                     |
| HADGEM2-ES          | Met Office Hadley Centre                                                     |
| IPSL-CM5A-LR        | Institut Pierre-Simon Laplace                                                |
| IPSL-CM5A-MR        | Institut Pierre-Simon Laplace                                                |
| IPSL-CM5B-LR        | Institut Pierre-Simon Laplace                                                |
| MIROC-ESM-CHEM      | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean   |
|                     | Research Institute (The University of Tokyo), and National Institute for      |
|                     | Environmental Studies                                                        |
| MIROC-ESM           | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean   |
|                     | Research Institute (The University of Tokyo), and National Institute for      |
|                     | Environmental Studies                                                        |
| MIROC5              | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean   |
|                     | Research Institute (The University of Tokyo), and National Institute for      |
|                     | Environmental Studies                                                        |
| MPI-ESM-LR          | Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)  |
| MPI-ESM-MR          | Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)  |
| MRI-CGCM3           | Meteorological Research Institute                                            |
| MRI-ESM1            | Meteorological Research Institute                                            |
| NORESM1-ME          | Norwegian Climate Centre                                                    |
| NORESM1-M           | Norwegian Climate Centre                                                    |
| BCC-CSM1-1-M        | Beijing Climate Center, China Meteorological Administration                 |
| BCC-CSM1-1          | Beijing Climate Center, China Meteorological Administration                 |
| INMCM4              | Institute for Numerical Mathematics                                         |
Table S19. Expected impacts to ecosystems as a function of regional temperature increase

| ΔTreg above 1990 (ºC) | Impacts to unique or widespread ecosystems or population systems | Region |
|-----------------------|---------------------------------------------------------------|--------|
| 1                     | Range loss begins for golden bowerbird                       | Australia |
| 2                     | 9-31% (mean 18%) of species committed to extinction          | Globe |
| 3                     | 8% loss freshwater fish habitat, 15% loss in Rocky Mountains, 9% loss of salmon | N. America |
| 4                     | 7-14% of reptiles, 8-18% of frogs, 7-10% of birds and 10-15% of mammals committed to extinction as 47% of appropriate habitat in Queensland lost | Australia |
| 5                     | Suitable climates for 25% of eucalypts exceeded               | Australia |
| 6                     | Range loss of 40-60% for golden bowerbird                    | Australia |
| 7                     | 1°C SST All coral reefs bleached                              | Great Barrier Reef, S.E. Asia, Caribbean |
| 8                     | 1-2 Alpine systems in Alps can tolerate local temperature rise of 1-2°C, tolerance likely to be negated by land-use change | Europe |
| 9                     | 1-3 Extensive loss/conversion of habitat in Kakadu wetland due to sea-level rise and saltwater intrusion | Australia |
| 10                    | 1.4-2.6 13-23% of butterflies committed to extinction        | Australia |
| 11                    | 1.6-1.8 15-37% (mean 24%) of species committed to extinction | Globe |
| 12                    | 2 16% freshwater fish habitat loss, 28% loss in Rocky Mountains, 18% loss of salmon | N. America |
| 13                    | 2 High risk of extinction of golden bowerbird as habitat reduced by 90% | Australia |
| 14                    | 2 Risk of extinction of Hawaiian honeycreepers as suitable habitat reduced by 62-89% | Hawaii |
| 15                    | 2°C SST Loss of Antarctic bivalves and limpets                | Southern Ocean |
| 16                    | 2°C SST Extinction of coral reef ecosystems (overgrown by algae) | Indian Ocean |
| 17                    | 2°C SST Extinction of remaining coral reef ecosystems (overgrown by algae) | Globe |
| 18                    | 2.1-2.5 Cloud-forest regions lose hundreds of meters of elevational extent, potential extinctions ΔTreg 2.1°C for C. America and ΔTreg 2.5°C for Africa | C. America, Tropical Africa, Indonesia |
| 19                    | 2.1-2.8 21-52% (mean 35%) of species committed to extinction | Globe |
| 20                    | 2.1-3.9 21-36% of butterflies committed to extinction; >50% range loss for 83% of 24 latitudinally-restricted species | Australia |
| 21                    | 2.5-3.0 Extinctions (100% potential range loss) of 10% endemics; 51-65% loss of Fynbos; including 21-40% of Proteaceae committed to extinction; Succulent Karoo area reduced by 80%, threatening 2,800 plant species with extinction; 5 parks lose >40% of plant species | S. Africa |
| 22                    | 2.5-3.0 24-59% of mammals, 28-40% of birds, 13-70% of butterflies, 18-80% of other invertebrates, 21-45% of reptiles committed to extinction; 66% of animal species potentially lost from Kruger National Park | S. Africa |
| 23                    | 2.5-3.5 Loss of temperate forest wintering habitat of monarch butterfly | Mexico |
| 24                    | 2.6-2.9 Substantial loss of alpine zone, and its associated flora and fauna (e.g., alpine sky lily and mountain pygmy possum) | Australia |
| 25                    | 3 24% loss freshwater fish habitat, 40% loss in Rocky Mountains, 27% loss of salmon | N. America |
| 26                    | 3 Eventual loss of 9-62% of the mammal species from Great Basin montane areas | USA |
| 27                    | 3 38-54% loss of waterfowl habitat in Prairie Pothole region | USA |
| 28                    | 3-4 Alpine systems in Alps degraded | Europe |
| 29                    | 3-4 Risk of extinction of alpine species | Europe |
| 30                    | 3 Bioclimatic limits of 50% of eucalypts exceeded | Australia |
| 31                    | 3 Likely extinctions of 200-300 species (32-63%) of alpine flora | New Zealand |
| 32 | 3.2-6.6 | 50% loss existing tundra offset by only 5% eventual gain; millions of Arctic nesting shorebird species variously lose up to 5-57% of breeding area; high-Arctic species most at risk; geese species variously lose 5-56% of breeding area | Arctic |
| 33 | 3.5 | 38-67% of frogs, 48-80% of mammals, 43-64% of reptiles and 49-72% of birds committed to extinction in Queensland as 85-90% of suitable habitat lost | Australia |
| 34 | 3.7 | 4-38% of birds committed to extinction | Europe |

Note: ΔTreg refers to regional temperature change with respect to 1990. Colors denote impacts that occur for ranges in changes in regional temperature that include 1.5°C or less (light yellow), 2.5°C (yellow) and 3.5°C. Source: Table 4.1 of chapter 4 Ecosystems, their properties, goods and services of the contribution of the Working Group II to the Fourth Assessment Report of the IPCC (see S2).
Table S20. Parameter values for the regional damage functions in CLIMRISK

|     | USA  | EU   | JAPAN | RUSSIA | EURASIA | CHINA  | INDIA  | MEAST  | AFRICA | LAM   | OHI   | OTHASIA | MX    |
|-----|------|------|-------|--------|---------|--------|--------|--------|--------|-------|-------|---------|-------|
| a_{1,r} | 0    | 0    | 0     | 0      | 0       | 0.0785 | 0.4385 | 0.2780 | 0.3410 | 0.0609 | 0     | 0.1755  | 0.0609 |
| a_{2,r} | 0.1414 | 0.1591 | 0.1617 | 0.1151 | 0.1305  | 0.1259 | 0.1689 | 0.1586 | 0.1983 | 0.1345 | 0.1564 | 0.1734  | 0.1345 |
Table S21. Persistence parameter values for the regions in CLIMRISK

| Region    | $\alpha_r$ | Region    | $\alpha_r$ |
|-----------|------------|-----------|------------|
| USA       | 0.60       | MEAST     | 0.80       |
| EU        | 0.50       | AFRICA    | 0.90       |
| JAPAN     | 0.60       | LAM       | 0.65       |
| RUSSIA    | 0.80       | OHI       | 0.60       |
| EURASIA   | 0.70       | OTHASIA   | 0.80       |
| CHINA     | 0.80       | MX        | 0.65       |
| INDIA     | 0.80       |           |            |
### Table S22. Brief description of the SSP narratives.

| Scenario          | Main characteristics of the narrative                                                                                                                                                                                                 |
|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SSP1              | **Sustainability – Taking the green road.**  
|                   | - Low challenges to mitigation and adaptation.  
|                   | - Gradual but pervasive shift towards a more sustainable path.  
|                   | - Rapid technological development.  
|                   | - Inclusive development that respects environmental boundaries.  
|                   | - Accelerated demographic transition, emphasis on wellbeing, health, and education.  
|                   | - Lower resource and energy intensity.  
|                   | - Consistent baseline: SSP1-RCP2.6                                                                                                                                  |
| SSP2              | **Middle of the road.**  
|                   | - Medium challenges to mitigation and adaptation.  
|                   | - Technological, social, economic trends are similar to the historic period.  
|                   | - Uneven economic and income growth among regions.  
|                   | - Slow progress towards sustainability goals.  
|                   | - Resource and energy intensity decrease at a slow pace.  
|                   | - Moderate global population growth.  
|                   | - Income inequality persists or improves slowly.  
|                   | - Consistent baseline: SSP2-RCP4.5                                                                                                                                  |
| SSP3              | **Regional rivalry – A rocky road**  
|                   | - High challenges to mitigation and adaptation.  
|                   | - Resurgent nationalism, focus on domestic or, at most, regional issues.  
|                   | - Education and technology decline.  
|                   | - Low international priority for environmental issues, strong environmental degradation in some regions.  
|                   | - Low economic growth, inequalities persist or worsen.  
|                   | - Material-intensive consumption.  
|                   | - Consistent baseline: SSP3-RCP6, SSP3-RCP7                                                                                                                           |
| SSP4              | **Inequality – A road divided.**  
|                   | - Low challenges to mitigation, high challenges to adaptation.  
|                   | - Increasing stratification and inequalities across and within countries.  
|                   | - Increasing disparities in human capital, economic opportunity, and political power.  
|                   | - Environmental policies focus on local issues around middle- and high-income areas.  
|                   | - Consistent baseline: SSP4-RCP6                                                                                                                                  |
| SSP5              | **Fossil-fueled development – Taking the highway**  
|                   | - High challenges to mitigation, low challenges to adaptation.  
|                   | - Technological progress and human capital as the path for sustainable development.  
|                   | - Global integration, competitive markets, innovation and participatory societies.  
|                   | - Economic and social development based on fossil fuels.  
|                   | - Resource and energy intensive lifestyles.  
|                   | - Rapid economic growth with peak and decline population in the 21st century.  
|                   | - Local environmental problems are successfully managed.  
|                   | - Consistent baseline: SSP5-RCP8.5                                                                                                                                  |
Supplementary Figures

Note: Figures S8, S9, S12, S13, S17, S18, S21, S22, S26, S27, S29-S32 are animated files contained in the Power Point document Supplementary Figures Estrada_Botzen.pptx.

Figure S8. Animation of the spatially explicit economic impacts of climate change for the RICE-U damage function. Median economic impacts of climate change expressed in US$ per grid cell under the RCP8.5 and SSP5 scenarios. See Supplementary file.
Figure S9. Animation of the spatially explicit economic impacts of climate change for the RICE-P-U damage function. Median economic impacts of climate change expressed in US$ per grid cell under the RCP8.5 and SSP5 scenarios. See Supplementary file.
Figure S10. Dates for exceeding the threshold of economic impacts exceeding 5% of GDP per year using the RICE-P-U damage function. Panels a) and b) show the estimated dates under the RCP8.5 and the NDC scenarios, using the damage function RICE-U. Panels c) and d) show the estimated dates under the RCP8.5 and the NDC scenarios, using the damage function RICE-P-U. Socioeconomic scenario SSP5.
Figure S11. Dates for exceeding the threshold of economic impacts exceeding 1 billion US$ per year. Panels a) and b) show the estimated dates under the RCP8.5 and the NDC scenarios, using the damage function RICE-U. Panels c) and d) show the estimated dates under the RCP8.5 and the NDC scenarios, using the damage function RICE-P-U. Socioeconomic scenario SSP5.
Figure S12. Animation of the probability of exceeding 2.5°C of warming (w.r.t 1990) per grid cell, during this century under the RCP8.5 scenario. See Supplementary file.
Figure S13. Animation of the probability of exceeding 2.5°C of warming (w.r.t 1990) per grid cell during this century under the NDC scenario. See Supplementary file.
Figure S14. Dates for exceeding levels of warming of 3.5°C in annual temperature. Panels a), b) and c) show the estimated dates for exceeding levels of warming per grid cell of 3.5°C (w.r.t. 1990) under the scenarios NDC, NDC without the US and the NDC without China, respectively.
Figure S15. Dates for exceeding levels of warming of 2.5°C in annual temperature. Panels a), b) and c) show the estimated dates for exceeding levels of warming per grid cell of 2.5°C (w.r.t. 1990) under the scenarios NDC, NDC without the US and the NDC without China, respectively.
Figure S16. Dates for exceeding the threshold of a 10% decline in precipitation (w.r.t 1990) per grid cell during this century. Panel a) shows the estimated dates under the RCP8.5 scenario and panel b) shows the estimated dates for the NDC mitigation scenario.
Figure S17. Animation of the probability of exceeding -10% decrease in precipitation (w.r.t 1990) per grid cell during this century under the RCP8.5 scenario. See Supplementary file.
Figure S18. Animation of the probability of exceeding -10% decrease in precipitation (w.r.t 1990) per grid cell during this century under the NDC scenario. See Supplementary file.
Figure S19. Dates for exceeding 2.5°C of warming and -10% decrease in precipitation (w.r.t 1990) per grid cell during this century. Panel a) shows the estimated dates under the RCP8.5 scenario and panel b) shows the estimated dates for the NDC mitigation scenario.
Figure S20. Dates for exceeding 1.5°C of warming and -10% decrease in precipitation (w.r.t 1990) per grid cell during this century. Panel a) shows the estimated dates under the RCP8.5 scenario and panel b) shows the estimated dates for the NDC mitigation scenario.
Figure S21. Animation of the joint probability of exceeding 2.5°C of warming and -10% decrease in precipitation (w.r.t 1990) per grid cell during this century under the RCP8.5 scenario. See Supplementary file.
Figure S22. Animation of the joint probability of exceeding 2.5°C of warming and -10% decrease in precipitation (w.r.t 1990) per grid cell during this century under the NDC scenario. See Supplementary file.
Figure S23. Dates for reaching a high score in the multivariate risk index. Panels a) and b) show the estimated dates under the RCP8.5 and the NDC scenarios, respectively, using the damage function RICE-P-U damage function. Socioeconomic scenario SSP5.
Figure S24. Dates for reaching a moderate score in the multivariate risk index. Panels a) and b) show the estimated dates under the RCP8.5 and the NDC scenarios, respectively, using the damage function RICE-U. Panels c) and d) show the estimated dates under the RCP8.5 and the NDC scenarios, respectively, using the damage function RICE-P-U. Socioeconomic scenario SSP5.
Figure S25. Dates for reaching a very high score in the multivariate risk index. Panels a) and b) show the estimated dates under the RCP8.5 and the NDC scenarios, respectively, using the damage function RICE-U. Panels c) and d) show the estimated dates under the RCP8.5 and the NDC scenarios, respectively, using the damage function RICE-P-U. Socioeconomic scenario SSP5.
Figure S26. Animation of the evolution of the multivariate risk index during this century per grid cell under the RCP8.5 scenario and the RICE-U damage function. Socioeconomic scenario SSP5. See Supplementary file.
Figure S27. Animation of the evolution of the multivariate risk index during this century per grid cell under the NDC scenario and the RICE-U damage function. Socioeconomic scenario SSP5. See Supplementary file.
Figure S28. Dates for reaching moderate, high and very high scores in the multivariate risk index under the RCP3PD scenario. Panels a), c) and e) show the estimated dates using the damage function RICE-U. Panels b), d) and f) show the estimated dates using the damage function RICE-P-U. Socioeconomic scenario SSP5.
Figure S29. Animation of the evolution of the multivariate risk index during this century per grid cell under the RCP3PD scenario and the RICE-U damage function. Socioeconomic scenario SSP5. See Supplementary file.
Figure S30. Animation of the evolution of the multivariate risk index during this century per grid cell under the RCP8.5 scenario and the RICE-P-U damage function. Socioeconomic scenario SSP5. See Supplementary file.
Figure S31. Animation of the evolution of the multivariate risk index during this century per grid cell under the NDC scenario and the RICE-P-U damage function. Socioeconomic scenario SSP5. See Supplementary file.
Figure S32. Animation of the evolution of the multivariate risk index during this century per grid cell under the RCP3PD scenario and the RICE-P-U damage function. Socioeconomic scenario SSP5. See Supplementary file.
Figure S33. Emissions of fossil CO2, CH4 and N2O for the RCP8.5, NDC, NDCnoUSA, NDCnoCHINA and RCP3PD scenarios. Panel a) shows the emissions trajectories for CO2, while panels b) and c) show those for CH4 and N2O, respectively.
Figure S34. Global annual temperature change for a reference, three policy scenarios based on the Intended Nationally Determined Contributions and a policy scenario consistent with the objective of the Paris Climate Agreement. Panel a) shows the simulations of annual temperature change for the RCP8.5 scenarios (reference), while panels b), c) and d) show those corresponding to the NDC, NDCnoUSA and NDCnoCHINA policy scenarios. Panel e) shows the simulated global temperature change for the RCP3PD policy scenarios, which is consistent with the objective of the Paris Climate Agreement.