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Impacts of low aggregate INDCs ambition

Research commissioned by OXFAM

Technical summary

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1 Climate Action Tracker Global Emission Pathways

The Climate Action Tracker (CAT) assesses emission-reduction pledges and emissions implied by current policy portfolios for the largest emitters and calculates global emissions projections (publicly available on CAT website) and estimates 2100 global mean temperature rise based on these assessments. The three main cases are described below:

Current Policy Projections: The CAT assesses the currently implemented policies of 32 countries, which covered about 80% of global emissions in 2010. The associated emissions are calculated until 2030. A high and a low estimate are given to cover the uncertainty. The pathway presented here is the middle of the high and low case. Countries not covered use the PRIMAP4 baseline (Potsdam Real-time Integrated Model for probabilistic Assessment of emissions Paths (PRIMAP) 2014). Details on the current policy projections are available online at (Climate Action Tracker 2014a).

Unconditional 2020/2030 Pledges: This pathway incorporates the 2020 and 2030 emission-reduction pledges. Where conditional and unconditional pledges exist we use the unconditional pledge. Countries without a pledge use the current policy projection pathway. Details on the pledge pathway methodology are available at www.climateactiontracker.org (Climate Action Tracker 2014b).

Long-Term Targets: This pathway incorporates all pledges including the 2050 long-term targets. If conditional and unconditional targets exist, the unconditional targets are used. Countries without a long term pledge use the 2030 pledge pathway and extension beyond 2030 (Climate Action Tracker 2014b).

The pathways are shown in Figure 1. They are taken from the October 2015 CAT update. For details see Gütschow et al. (2015). The full method is explained on the CAT website[1].

[1] http://climateactiontracker.org/methodology/18/Global-pathways.html

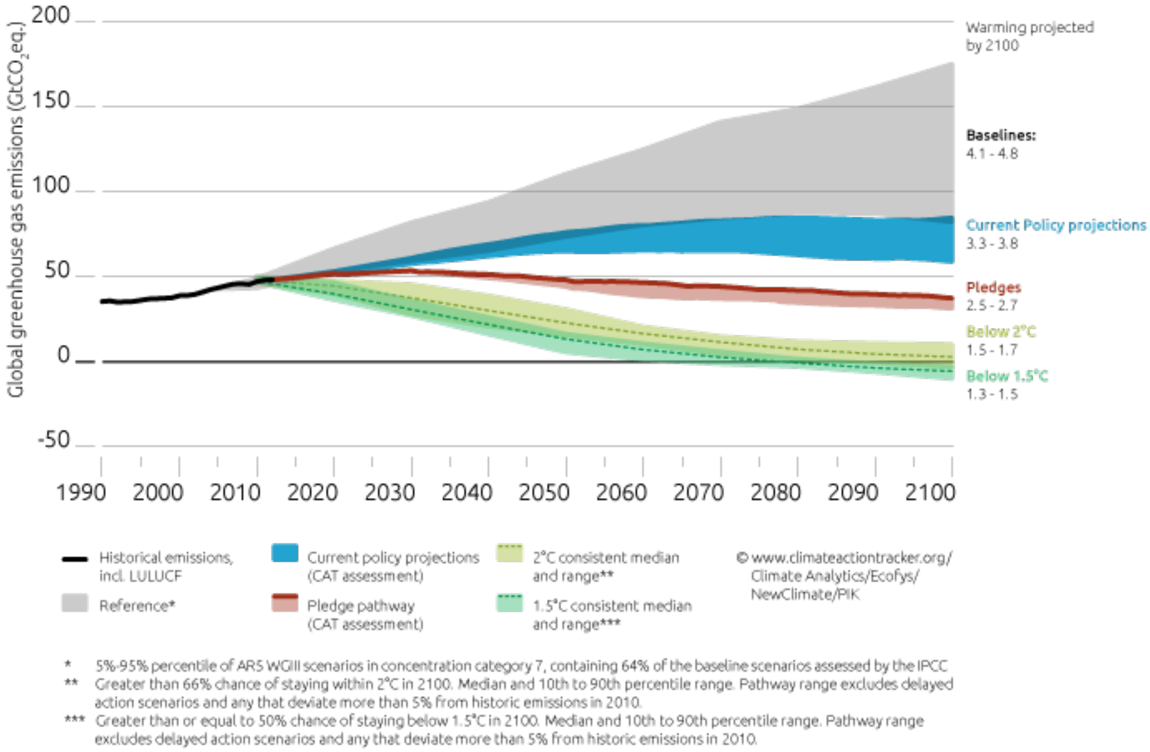

Figure 1: Climate Action Tracker global pathways. All pathways are taken from the Oct 2015 CAT briefing (Gütschow et al. 2015).

2 Sea-Level Rise

2.1 Method and Data

The methodology applied here is consistent with the IPCC AR5 report and based on the same underlying data, except the projections for the Antarctic Ice Sheet. For risks to the Antarctic Ice Sheet the more recent study by Levermann et al. (2014) is used instead, which is based on process-based ice-sheet model simulations (Bindschadler et al. 2013) and allows accounting for ocean melting under the shelf for various warming levels. By contrast, in the IPCCAR5, melting under Antarctica's ice shelves could not be calculated as a function of varying warming levels and was thus taken as constant regardless of the emission scenario, by lack of a better hypothesis.

Projections for thermal expansion and mountain glaciers are based on Perrette et al. (2013), using MAGICC6 surface air temperature (left panel) and ocean heat uptake projections (not shown) as input. The Greenland Ice Sheet follows Fettweis et al. (2013), scaled up by 20% to account for dynamic acceleration of ice streams (as in Hinkel et al. 2014). Note that contribution from land-water is also included (~4 to 9cm in 2100). Calculations are based on 1000 Monte-Carlo samples, (half of) 90% uncertainty range is shown on the figures.

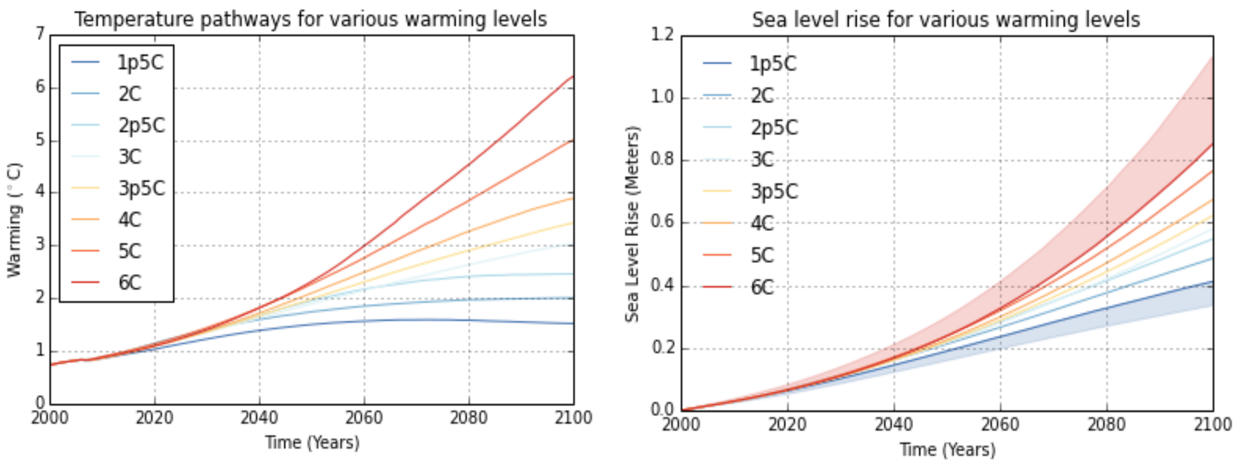

Figure 2: Temperature pathways (left) and sea-level rise above 2000 (right) for global mean temperature pathways reaching between 1.5°C and 6°C by 2100. All lines represent median projections. Shaded areas on the right indicate the distance from median to 5th percentile for lowest scenario (blue), respectively median to 95th percentile for the highest scenario (red).

- Projected SLR ranges vary from 0.41m (0.33 m to 0.55 m) for the 1.5°C pathway to 0.85m (0.68m to 1.13m) for the 6°C pathway (5th to 95th ranges), which means a doubling in sea-level rise already by 2100

- While the range of sea level rise by 2100 between the different pathways is relatively smaller compared to temperature (2 times higher for SLR vs. 4 for GMT), the multi-centennial commitment differs substantially (not shown on the figure), as hinted by a larger range in the rates of SLR rise in 2100 and the large difference in *rate* of change by 2100, with rate of SLR by 2100 in the 6°C scenario approaching 4 times the rate of SLR in the 1.5°C scenario.
- Based on modelling studies as well as Paleo-evidence, an average of 2.3 m SLR per Degree of warming is estimated on a multi-centennial to millennial time scale (Anders Levermann et al. 2013)
- Finally, note that 21st century estimates do not account for the risk of rapid destabilization of the West Antarctica Ice Sheet, or a more significant contribution from the Greenland Ice Sheet, whose risk cannot be confidently estimated. A panel of experts recently estimated a risk of as much as 1.5m sea level rise by 2100 (Horton et al. 2014), consistent with earlier expert estimates (Bamber and Aspinall 2013)

Note also that while global sea level rise generally provides a good impression of the scale of the related impacts, local oceanographic, Earth's rotational-gravitational and solid Earth processes exist that may redistribute sea level rise differently among world's coastal regions (roughly by 10-15% relatively to global mean). Additionally, the Earth crust may undergo local uplift (e.g. due to tectonic) or subsidence (e.g. due to underground mining or groundwater pumping; lack of sediment transport in delta regions) which together determine the "relative sea level rise" actually felt at the coast. Last, possible changes in storminess will also need to be taken into account to determine how sea level and storm surges will affect people's life and local economy.

For complete consistency, sea-level rise was calculated for the CAT scenarios prepared for Oxfam. Both global warming and associated sea-level rise projections for the CAT scenarios were used for calculations of damages and adaptation costs, as explained in section 4.

3 Agricultural yield analysis

3.1 Assessment of agricultural production losses

The ISI-MIP archive contains data on agricultural yields of the four main crops maize, rice, wheat and soy, based on 7 global agricultural models (AgM), driven by 5 GCMs. Of the 7AgMs, only 6 provide estimates for rice. With regard to the effects of CO_2 fertilization, all models provide calculations with assumptions on the CO_2 effect, while for some AgM noCO_2 runs are limited to one GCM. Finally, the temperature range modelled by the GCMs differs. As a result, between 23 and 12 model combinations were used to assess risks of agricultural production losses.

Global agricultural models provide estimates of current and future yields at a gridded resolution of 0.5°. The models provide estimates of yields for all grid cells, in which production is possible, allowing for a maximum potential expansion of croplands. In order to assess reductions of crop yields from current production patterns, we extract the current production areas, using year 2000 areas for each crop (Portmann, Siebert, and Döll 2010). As we also use these areas for projections of yields, the results are conservative, as they do not allow for potential cropland expansion.

The influence of elevated CO_2 concentrations on plant growth is a topic of debate. While studies suggest an increase in productivity for some crops as a result of CO_2 fertilization, large uncertainties remain, especially with regard to temperature sensitivity as well as nutrient and water limitations. Additionally, the effect of climate extremes such as heat waves (Porter et al. 2014), if fully included in the projections, may counteract the potential gains by CO_2 fertilization. In order to estimate risks to food security in a balanced manner, the present analysis focuses on those model runs not including CO_2 fertilization (noCO_2).

Additional important sources of uncertainty include soil, weather, and management inputs; uncertainties of model parameters; and uncertainties related to model formulation (see e.g.: www.agmip.org for detailed information on global agricultural models). In order to provide regional estimates of changes in agricultural production, we draw on the regional differentiation used in the AD-RICE model. For each crop, mean annual crop yields within the 12 regions are assessed. Changes in crop yields relative to a reference period (1986-2005) are assessed at incremental increases in GMT of 0.5° relative to pre-industrial temperature (1.5°, 2.0°, 3.0° as the closest increment to current INDC projections, 3.5° as closest increment to current policy projections). Probabilities of yield loss refer to the range of modelling results available from model intercomparison efforts and probability numbers refer to the number of models projecting the respective change.

Analysis
The analysis is conducted for the 12 regions that have been defined for the purpose of the RICE/AD-RICE models, see table below for an overview, details can be found at http://www.econ.yale.edu/~nordhaus/homepage/documents/RICE_042510.xlsm. For each region, all available impact-model climate-model combinations are used to show the potential range of change, depicting the percent chance in yields between

a. Ref and 1.5°C temperature increase
b. Ref and 2.0°C temperature increase
c. Ref and INDC projections
d. Ref and policy projections

Additionally, data to assess the gaps between the respective levels are provided

a. 1.5°C temperature limit versus current INDC pledges
b. 2°C temperature limit versus current INDC pledges
c. 1.5°C temperature limit versus current policy pledges
d. 2°C temperature limit versus current policy pledges

Output and data provided:

- csv tables with the ending 'lower_likely_range' provide the lower end of the likely range, as defined by the IPCC (66%). Maps show the corresponding values for each region.
- csv tables with the ending 'all_likely values' provide the values for the 90-percentile (5-95% range) likely range (17-83% range) and the median. Annex plots provide an overview of these values (bars: likely range, whiskers 90-percentile)

Overview of AD-RICE regions

Region Code	**Region Name**
1	US
2	EU
3	Japan
4	Russia
5	Eurasia
6	China
7	India
8	Middle East
9	Africa
10	Latin America
11	Other High Income
12	OthAs

4 Adaptation costs and macroeconomic damage

4.1 Summary of results

Table 1. Summary of adaptation costs and macroeconomic damage in the RCP2.6, CAT INDC2.7°C, INDC3.0°C and CAT. (Current Policy Projections scenarios using AD-RICE model)

		Global				Developing countries			
		RCP2.6	INDC 2.7°C	INDC 3°C*	CPP	RCP2.6	INDC	INDC 3°C*	CPP
Adaptation costs (in US$ 2012 billion[2])	2030	$271,91	$327,07	$333,93	$343,94	$204,96	$239,29	$243,14	$248,75
	2050	$659,64	$982,00	$1.056,55	$1.165,19	$520,56	$745,90	$794,90	$866,29
Macroeconomic damage (in % of GDP)	2030	0,45%	0,48%	0,48%	0,49%	0,57%	0,61%	0,61%	0,61%
	2050	0,69%	1,02%	1,10%	1,22%	0,84%	1,22%	1,31%	1,45%
Macroeconomic damage (in US$ 2012 billion)	2030	$640,16	$686,56	$690,10	$695,27	$399,92	$426,33	$428,42	$431,46
	2050	$1.581,76	$2.326,72	$2.512,29	$2.782,71	$1.069,22	$1.552,29	$1.673,06	$1.849,04

* INDC 3°C (RCP6.0 interpolated)

The interpolation consisted in estimating the adaptation and damage costs in the INDC 3°C scenario from the adaptation and damage costs in the INDC 2.7°C and Current Policy Projections scenarios. The estimation is derived from the temperature deviation between these three scenarios at the end of the 21st century, i.e. 2.7°C, 3.1°C and 3.6°C respectively in the INDC 2.7°C, INDC 3.0°C proxy and Current Policy Projections scenarios, respectively.

4.2 Does AD-RICE over or under-estimate macroeconomic damage and adaptation costs

4.2.1 Scenarios used

The assessments of adaptation and macroeconomic costs are based on the IPCC RCP2.6 (referred to in as "below 2°C degree scenario") and the IPCC RCP6.0 temperature pathways. The IPCC RCP2.6 scenario was assessed by IPCC in AR5 as holding warming "likely" below 2°C and also in our carbon-cycle-climate model leads warming 'likely' below 2°C, with a central estimate of about 1.7°C degrees global mean temperature increase by 2100. The RCP6.0 scenario is projected to lead to about 3.1°C degree increase by 2100 (central estimate). The RCP6.0 scenario was used as a proxy for the aggregate INDCs scenario selected by Oxfam. Macroeconomic and adaptation costs in the INDC 3°C degrees proxy scenario were

[2] All dollar values are expressed in 2012 dollars. AD-RICE outputs, in US$2005 dollars, were converted using dollar deflator values from the OECD database.

interpolated to fit RCP6.0 temperature deviation for 2030 and 2050 between these scenarios using cost estimates from the CAT INDC scenario (leading to 2.7°C degrees by the end of the century) and the CAT Current Policy Projections scenario (about 3.5°C degrees by 2100). The cost estimates in the CAT INDC scenario and CAT Policy Projections scenario were calculated using the AD-RICE2012 model (see specification in section below). **Table** 1 summarizes results for CAT INDC 2.7°C degrees (INDC), CAT Current Policy Projections (CPP) and INDC 3°C degrees.

4.2.2 Adaptation costs

With respect to adaptation costs, the estimates from the AD-RICE model for developing countries are in line with United Nations Environment Programme 2014 Adaptation Gap report (Anne Olhoff et al. 2014), including the bottom-up estimates in the latter. UNEP estimates adaptation costs between US$280 and 500 billion dollars by 2050 (in 2005 dollar value – or about US$570 billion in 2012 dollar value) for developing countries, for a temperature scenario of about 2°C degrees. In the current publication, using the AD-RICE model, adaptation costs for developing countries in a scenario leading to below 2°C degrees (IPCC RCP2.6) by 2100 are estimate at about US$520 billion in 2050 (in 2012 dollar value), in the same but upper range as UNEP's bottom-up assessment.

4.2.3 Macroeconomic damage

There exists a wide range of methodologies to estimate macroeconomic damage, while estimating adaptation costs at the regional level relies on mostly two approaches: integrated assessment models (IAMs) and a bottom-up assessment of country and sectoral studies (next section). According to a recent publication in Nature (Burke, Hsiang, and Miguel 2015), existing Integrated Assessment Models (DICE2010, PAGE09 and FUND3.8) largely under-estimate future climate-change induced macroeconomic costs. While IAM estimate a global decrease in GDP per capita between 0 and 10 percent when global mean temperature increase reaches 5°C degrees above pre-industrial levels, the new approach developed by Burke, Hsiang, and Miguel (2015) estimates decrease ranging from 25 to 75 percent at the same temperature level. The value and significance of these new estimates are to be interpreted with care as they still to be tested and proven by additional research and publications. The Figure 3 below, extracted from the above mentioned publication summarizes these estimates. Owing to these new results, the DICE macroeconomic damage estimates on which the AD-RICE model is based are possibly very conservative. Hitherto, no IAMs have integrated these new damage functions in their specifications. As a consequence, it is not possible yet to relate these new estimates to future adaptation costs.

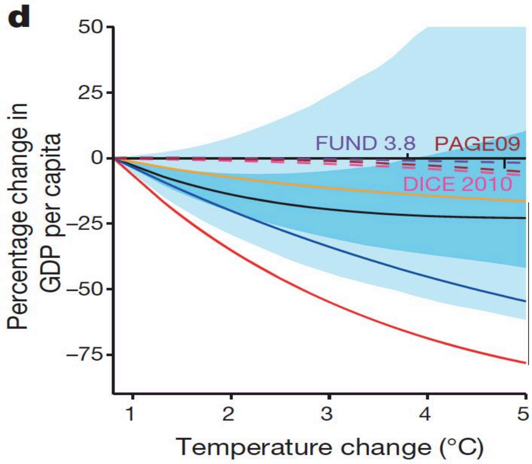

Figure 3 Comparison in percentage change in GDP per capita as a function of temperature change using estimates from the FUND3.8, PAGE09 and DICE2010 models and new estimates from Burke, Hsiang, and Miguel (2015). Graphic extracted from Burke, Hsiang, and Miguel (2015).

4.3 Specifications and description of the AD-RICE model

In this annex a short description of the AD-RICE2012 model and its calibration are given. AD-RICE is a Ramsey-type growth model with explicit representation of adaptation to climate change (K. C. de Bruin, Dellink, and Tol 2009; K. de Bruin, Dellink, and Agrawala 2009). The AD-RICE2012 model (Kelly de Bruin 2014) has been developed based on the RICE2010 (W. Nordhaus 2011) model. The AD-RICE model extends the RICE model to include adaptation policy variables.

The AD-RICE2012 model is an Integrated Assessment Model (IAM), where economic production leads to GHG emissions. In this model, industrial CO_2 is the only endogenous GHG. The amount of industrial CO_2 emissions per unit of output is assumed to decrease over time due to technological development. In turn CO_2 emissions increase the stock of CO_2 in the atmosphere, resulting in climate change. Though climate change includes a multitude of phenomena (such as changes in precipitation, changes in weather variability, increased extreme weather), it is represented by changes in atmospheric temperature in this model. Overall climate change negatively affects society and the economy through various different impacts. GDP impacts due to climate change are modelled as a percentage decrease in production as a function of mean atmospheric temperature change compared to 1900. Investments in mitigation will reduce CO_2 emissions per unit of output at a cost, which decreases over time due to technological change. By adjustments to the economy (i.e. adaptation) initial climate change damages (gross damages) can be reduced to residual damages at a cost.

The model comprises 12 regions, which together represent the globe. The regions included in the model are as follows: USA, EU, Japan, Other High Income regions (OHI), India, China, Africa, Russia, European Asia (EUASIA), Asia, Latin America (LATAM) and the Middle East (ME).

AD-RICE2012 is a forward-looking Ramsey growth model, where regional utility is maximized (given regional endowments) over the model horizon. The model has time periods of 10 years and has a time horizon of 300 years. Utility is a function of consumption per capita discounted over time and over income per capita (richer generation's consumption creates less utility than poorer generation). The model finds the optimal balance of capital investments, mitigation investments, adaptation investments, adaptation costs and consumption to maximize utility.

The climate change damage estimates in the AD-RICE2012 model replicate the net damages of the RICE2010 model. The damages of the RICE2010 model have been calibrated based on (W. D. Nordhaus 2007; Tol 2009; IPCC 2007). The impacts generally considered in IAM and here as well are: health impacts, agricultural impacts, effects on leisure activities, water resources, energy and sea level rise. Given the obvious data restrictions, this list is not comprehensive and many impacts of climate change remain un-quantified. The AD-RICE model uses a stylized damage function where temperature increases lead to direct decreases in production. A more detailed description of damages would include a production function approach, which includes the effects on production inputs and direct utility effects. There remains a large degree of uncertainty regarding the damages associated with climate change, where particularly many impacts have not yet been identified or quantified. The quantified damages in this model could be seen as a lower bound to expected climate change damages, but damages could be significantly higher than projected. Table 2 shows the climate change damages for the different regions in percentage of GDP for 2010, 2050 and 2100 in the BAU scenario. As can be seen in the table damages estimates vary considerably between regions in the model.

Table 2 Climate change damages as percentage of GDP for regions of the AD-RICE2012 model for 2010, 2050 and 2100 for the BAU scenario

Region	Japan	USA	EU	OHI	ME	LATAM	Russia	Asia	EuAsia	China	India	Africa
2010	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.2	0.1	0.1	0.4	0.5
2050	0.8	0.6	0.7	0.7	1.3	0.7	0.5	1.22	0.5	0.7	1.6	1.5
2100	2.3	2.0	1.8	1.9	3.0	2.0	1.3	2.8	1.9	1.9	4.6	4.3

The AD-RICE2012 model includes 2 forms of adaptation namely proactive adaptation, reactive adaptation. This distinction has been made to enable a more accurate description of the costs and benefits of different forms of adaptation and hence the total adaptation costs. Reactive adaptation describes adaptation measures that can be taken in reaction to climate change or climate change stimuli. This form of adaptation comes at a relatively low cost and is generally undertaken by individuals. Examples of this form of adaptation are the use of air-conditioning or the changing of crop planting times. Proactive adaptation on the other hand refers to adaptation measures that require investments long before the effects of climate change are felt. This form of adaptation usually requires large scale investments made by governments. Examples of this form of adaptation are research and development into new crop types or the construction of a dam for irrigation purposes.

The net damages of the RICE2010 models are separated into adaptation costs and residual damages. Firstly the gross damages (damages before/without adaptation) are defined as follows:

$$GD_{j,t} = \alpha_{1,j} \cdot T_t + \alpha_{2,j} \cdot T_t^{\alpha_{3,j}} .$$

where $\alpha_{1,j}$ and $\alpha_{2,j}$ are positive damage parameters and $\alpha_{3,j}$ ranges between 1-4 and T the level of atmospheric temperature increase compared to 1900.

These are the damages that occur if no adaptation takes place, and are thus higher than the net damages. These damages can be reduced through the use of adaptation, assuming the following relationship:

$$RD_{j,t} = \frac{GD_{j,t}}{1 + P_{j,t}},$$

where $P_{j,t}$ is the total level of protection (stock and flow) and $RD_{j,t}$ are the residual damages. This functional form is chosen because it limits the fraction by which the gross damages can be reduced to the interval of 0 to 1. When total protection reaches infinity, all gross damages are reduced (the residual damages are zero) and when no protection is undertaken no gross damages are reduced (residual damages equal gross damages). This functional form also ensures decreasing marginal damage reduction of protection, that is the more protection is used the less effective additional protection will be. This is assumed as more effective, efficient measures of adaptation will first be applied whereas less effective measures after that.

1. Two forms of adaptation (stock and flow) together create total adaptation. The two forms of adaptation are aggregated together using a Constant Elasticity of Substitution (CES) function. Here the elasticity of substitution can be calibrated to reflect the observed relationship between the two forms. This function is given as follows:

$$P_{j,t} = \gamma_j \cdot (\nu_{1,j} SAD_{j,t}{}^{\rho A} + \nu_{2,j} FAD_{j,t}^{\rho_A})^{\nu_{3,j}/\rho_A},$$

where $SAD_{j,t}$ is the total amount of adaptation capital stock. $FAD_{j,t}$ is the amount spent on reactive adaptation in that period. Furthermore, $\rho_A = \frac{\sigma - 1}{\sigma}$, where σ is the elasticity of substitution.

Adaptation capital stock is built up as follows:

$$SAD_{j,t+1} = (1 - \delta_k) SAD_{j,t} + IAD_{j,t},$$

where δ_k is the depreciation rate and $IAD_{j,t}$ are the investments in stock adaptation (SAD_t).

The adaptation module of AD-RICE2012 is calibrated based on estimates of adaptation costs and benefits from the impact literature. More precisely for each climate impact sector the adaptation costs and benefits for each region were estimated based on available impact studies and expert judgment. For a full description of this process, please refer to de Bruin (2014).

Climate change is global environmental problem, affecting all regions of the world both now and in centuries to come. Both the causes of climate change (different sources of GHG emissions) and the effects of climate change are innumerable, diverse, and vary is scope and scale. Attempting to include all causes and effects of climate change in a single model is a difficult task. Especially estimating the effects of climate change in the long run is a complex process, which involves many uncertainties. IAMs are tools created to assess the effects of the economy on climate change and vice versa in the long run. Due to the many mechanisms involved and the long time frame, these models need to make (simplifying) assumptions. IAMs are hence highly aggregated top-down models, which do not include all sectoral and regional impacts in detail. Though these assumptions and simplifications are necessary due to both lack of data (it is hard to predict future effects) and computational limitations, they do form a significant drawback of IAMs. Given these drawbacks applying a model such as AD-RICE can still give important insights into the magnitude and development of both the economy and the climate. Given that climate change is both a global problem and will have the greatest affects in the long term, an analysis of climate change is incomplete without a global long-term perspective. The strength of IAMs such as AD-RICE is that they can shed some light on the long-term climate consequences of our actions now.

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