National contributions for decarbonizing the world economy in line with the G7 agreement

[1] Australian-German Climate & Energy College, University of Melbourne, Parkville 3010, Victoria, Australia.

[2] Potsdam Institute for Climate Impact Research (PIK), Telegraphenberg, 14412 Potsdam, Germany

[3] School of Geography, University of Melbourne, Parkville 3010, Victoria, Australia.

This Supplementary Information contains a justification for the selection of the IAM scenarios representative of the G7 agreement at Elmau (Annex I), a detailed description of the methodology used to model the five equity approaches (Annex II), a description of the parameters' choice and of the dynamic of the approaches (Annex III). In addition, we provide a supplementary discussion of the limitations of the study framework (Annex IV). Finally we present supplementary figures with results at regional, sub-regional and national level for G20 countries for 2030 and 2050 (Annex V).

Contents

Supplementary Methods

ANNEX I – Additional information on the selected global mitigation scenarios.

The seven selected scenarios result from four models involved in three model inter-comparison exercises (table S1) the Low climate IMpact scenarios and the Implications of required Tight emission control Strategies (LIMITS) (Kriegler *et al* 2014a), and the Energy Model Forum 22 (Clarke *et al* 2009) and 27 (Kriegler *et al* 2014b) (EMF22 and EMF27). Two of the selected scenarios have net negative greenhouse gas (GHG) emissions by 2100 and are therefore consistent with the Paris Agreement commitment to reach “a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century”.

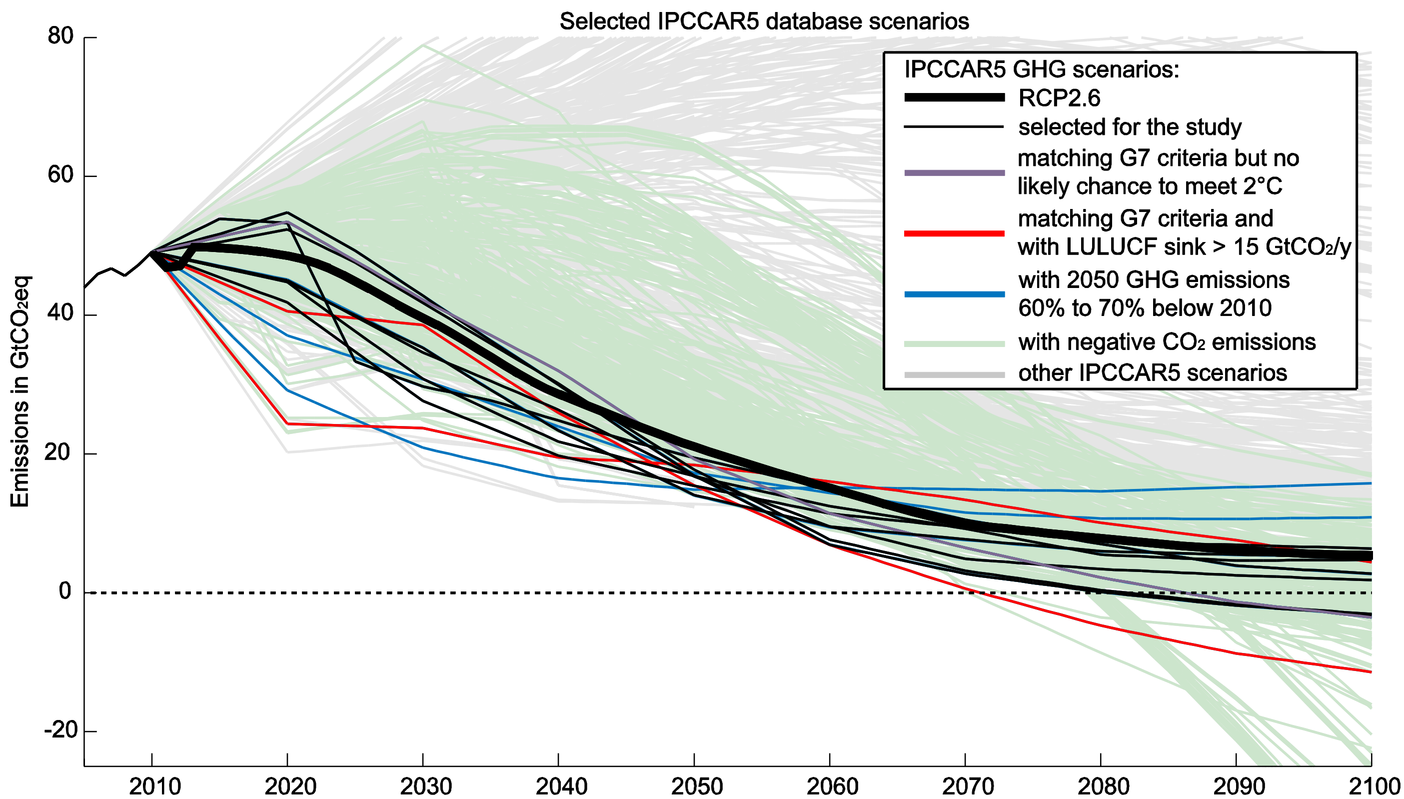

Figure S1 | Selected GHG scenarios from the IPCCAR5 database. We selected scenarios that have net negative CO_2 emissions by 2100 (green), and 60% to 70% reduction compared below their 2010 levels with pre-2020 mitigation actions (blue). We removed scenarios with LULUCF sink greater than 15 $GtCO_2$/y (red). We obtained seven scenarios (black) to which we added RCP2.6 (thick black).

LIMITS

The LIMITS study (Kriegler *et al* 2014a) presents Durban platform scenarios that assume fragmented 2020 emissions reduction levels but comprehensive global reductions beyond 2020. The scenarios StrPol-450 and RefPol-450 both follow fragmented action until policies are implemented in 2020 and achieve 450ppm CO_2eq at the end of the century. The RefPol-450 is a scenario that ensures that the 2°C objective will be met with a probability of 59% to 76%. Under this scenario, atmospheric GHG concentration reaches 450ppm to 480ppm in 2100. This concentration can be overshot before 2100. StrPol-450 includes more stringent near term targets than RefPol-450. Under StrPol-450, GHG concentration is 450ppm to 480ppm in 2100 and the probability of meeting the 2°C target is 60 to 78%.

EMF22

The EMF22 (Clarke *et al* 2009) studies the influence on climate mitigation of choices of long-term target concentrations, of the timing and nature of international participation, and of the importance of the concentration overshoot. The maximum radiative forcing under EMF22 scenario is 2.6 W/m^2 (2.3-2.7 W/m^2 across models in 2100). The GHG concentration stabilizes at 450ppmv (427-460ppmv across models in 2100) and, with medium Climate Sensitivity (CS=3), the warming is 1.9-2.2°C.

EMF27

The EMF27 study (Kriegler *et al* 2014b) investigates the cost and the influence on climate mitigation of options such as energy intensity improvements, Carbon Capture and Storage (CCS), solar and wind power, nuclear power and bioenergy. The EMF27 scenarios aiming at a 450ppmv CO_2eq include a limit on radiative forcing of 2.8 W/m^2 that can be overshot before 2100. This limit was set to ensure the consistency with the global 2 °C (Meinshausen *et al* 2009).

Table S1 | Scenarios' characteristics as from the IPCCAR5 database of the seven selected emissions scenarios. The columns 'Max T(°C)', which shows the maximum expected temperature before 2100, and '<2°C (%)' that gives the likelihood to contain warming below 2°C over the 21st century, are from (Kriegler *et al* 2014b, 2014a, Clarke *et al* 2009). Two scenarios result in net negative emissions by 2100 (highlighted in grey).

Study	Model	Scenario	Climate (ppm CO_2eq)	2100 budget ($GtCO_2$eq)	2050 budget ($GtCO_2$eq)	Overshoot (W/m^2)	Neg. emissions ($GtCO_2$/yr)	Policy	Neg. emissions technology	Max T (°C)	<2°C (%)
EMF22	IMAGE 2.4	2.6 OS BECCS	430 - 480	950 - 1500	< 1125	< 0.4	< 20	Immediate	No restriction	N/A	N/A
EMF27	MERGE	450-Conv	430 - 480	350 - 950	< 1125	< 0.4	< 20	Immediate	Restrictions	1.7	78
	REMIND 1.5	450-LimBio	430 - 480	350 - 950	< 825	< 0.4	< 20	Immediate	Restrictions	1.6	83
	REMIND 1.5	450-LimSW	430 - 480	350 - 950	< 1125	> 0.4	< 20	Immediate	Restrictions	1.7	78
LIMITS	REMIND 1.5	RefPol-450	430 - 480	350 - 950	< 1475	> 0.4	< 20	Delay 2020	No restriction	1.7	75
	WITCH	RefPol-450	430 - 480	950 - 1500	< 1125	< 0.4	< 20	Delay 2020	No restriction	N/A	N/A
	REMIND 1.5	StrPol-450	430 - 480	350 - 950	< 1125	> 0.4	< 20	Delay 2020	No restriction	1.7	76

ANNEX II – Detailed allocation methods

The Emissions Allocation Model

Modelling emissions allocation approaches requires historical and projected Business-as-Usual (BaU) national emissions and population data, Gross Domestic Product purchase power parity (GDP) projections and the global multi-gas emissions global scenarios that shall be matched. The emissions module of the Potsdam Real-time Integrated Model for the probabilistic Assessment of emission Paths (PRIMAP) contains such custom built datasets and allows the modelling of emissions allocations approaches (Nabel *et al* 2011). For this study, we implement in the PRIMAP module the new allocation approaches described below. The national populations, GDP and BaU projections are downscaled from RCP2.6 and RCP8.5 using Shared Socioeconomic Pathways framework.

The matched global multi-gas scenarios

In this study, each of the approaches distributes the emissions of a 'Target' global emissions scenario that is either: one the seven scenarios selected to match the G7 agreement or RCP2.6 emissions pathway. Emissions mitigation from Land-Use, Land-Use Change and Forestry (category 5 emissions under the UNFCCC) are not considered unanimously as part of the emissions mitigation scope to be negotiated. Moreover, the choice of methods to account for LULUCF positive or negative emissions remains unsettled. We therefore choose to exclude LULUCF emissions from the international distribution of emissions rights. Consequently, the national emissions allowances calculated here should be added to potential LULUCF emissions credits (or debits) currently under negotiation. Additionally, downscaled BaU RCP8.5 emissions associated with international transport (category 7) are subtracted from country level RCP8.5 total emissions.

We therefore model international distributions of a 'Target' emissions scenario that comprises the harmonized 'Kyoto Annex A' emissions, without emissions from the LULUCF and global international transport sector emissions. The modelling framework developed in this study can be applied similarly to any mitigation pathway, irrespective of the gases or sectors considered (within the limitations of the assumptions described below). As an example, the five modelled international distributions of RCP2.6 emissions are shown in figure S2.

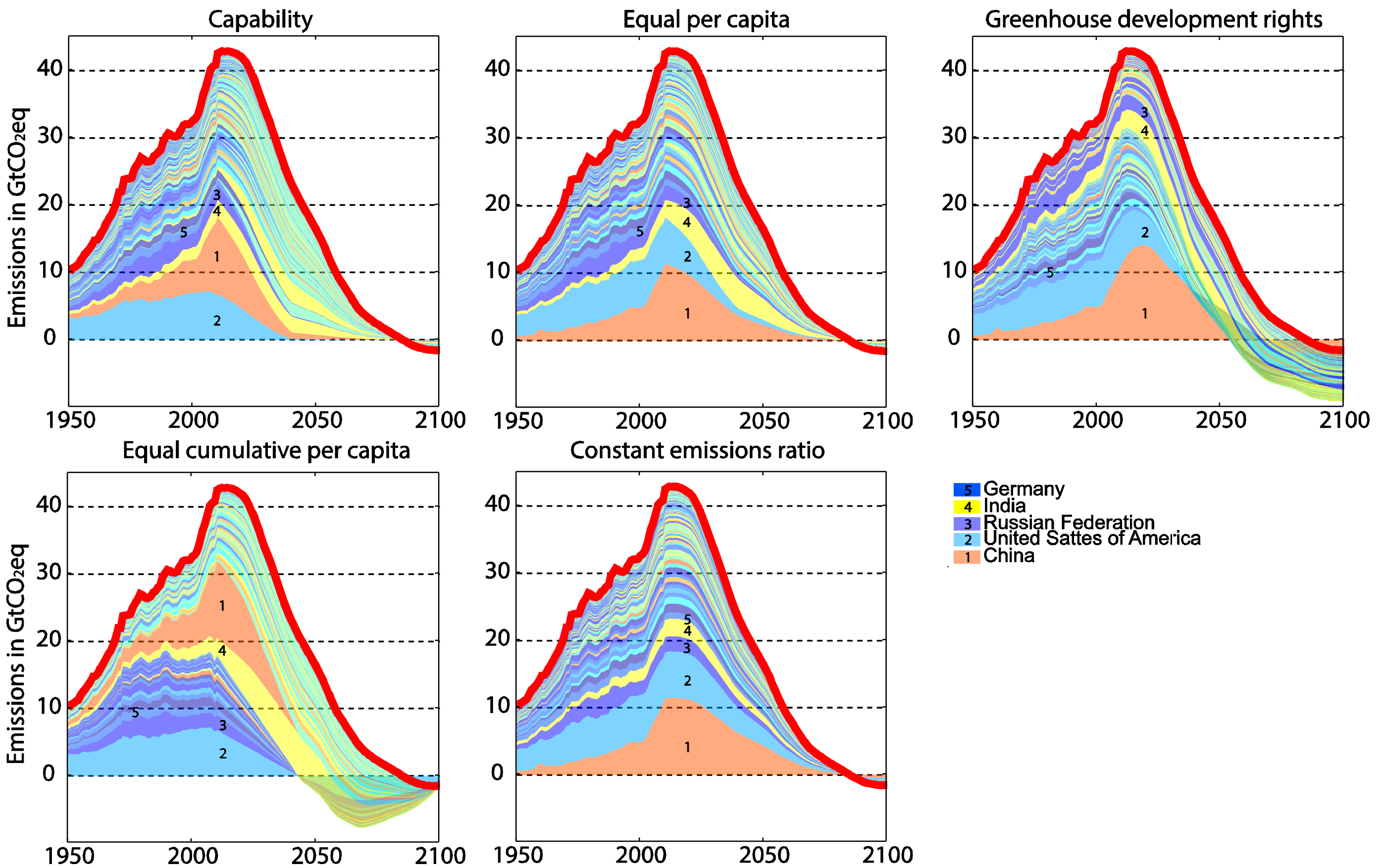

Figure S2 | Stacked national GHG emissions allocations of the RCP2.6 emissions according to five effort sharing approaches. 'Capability', 'Equal cumulative per capita', 'Greenhouse Development Rights', 'Equal per capita' and 'Constant emissions ratio'. The allocation starts in 2011. The red line represent RCP2.6 emissions levels. LULUCF and bunker emissions are excluded.

The Emissions Allocation Approaches

The allocation approaches presented below are representative of the 'equality', 'equal cumulative per capita', 'capability', 'responsibility-capability-need' and 'staged' IPCCAR5 categories.

a) The 'equal per capita' approach

The first approach is 'equal per capita' (EPC) and represents the IPCCAR5 'equality' category. This approach allocates the 'Target' pathway's emissions equally amongst the world population at a given point in time. A convergence period can be chosen to allow for a linear transition between initial international emissions ratios and equal per capita emissions ratios. Interpretations that include such a transition period are often referred to as 'per capita convergence' or 'contraction and convergence' (Meyer 2004). After the convergence period, national emissions allocations are defined according to:

$$E_c(y) = E_{global}(y).\frac{Pop_c(y)}{Pop_w(y)},$$

where Pop is the population, $E(y)$ represents the emissions at a year y, $E_{global}(y)$ represents the 'Target' scenario's emissions at a year y to be shared, and the subscripts c and w stand respectively for the considered country and the world.

b) *The 'equal cumulative per capita' approach*

The 'equal cumulative per capita' (CPC) approach allocates to each country total cumulative emissions proportional to its cumulative population over the chosen period. This period can start in the past, present or future. An Autonomous Energy Efficiency Index (AEEI) reflects the effect of technological innovation on emissions efficiency over time (Winkler *et al* 2011). For this study, the AEEI index is set to 1 from the beginning of the allocation onwards. Its value decreases incrementally by a fraction (X) each year back into the past until the starting date of historical emissions accounting. Historical emissions are then multiplied by this dynamic AEEI and therefore contribute less to the cumulative budget of a country than future emissions. A country's total emissions budget is determined by:

$$\sum_{y=y_h}^{y_e} r(y).E_c(y) = \sum_{y=y_h}^{y_e} r(y).E_{global}(y).\frac{\sum_{y=y_h}^{y_e} Pop_c(y)}{\sum_{y=y_h}^{y_e} Pop_w(y)}, with\, r(y) = \begin{cases} 1\, if\ y \geq y_s \\ (1-X)^{(y_s-y)}\, if\ y < y_s \end{cases},$$

where y_h and y_e represent the start and end year of the period over which nations have equal cumulative per capita emissions and $r(y)$ is the AEEI that discounts historical emissions between y_h and y_s, the year when the allocation starts.

The CPC approach modelled in this study distinguishes two country groups. The 'negative countries' that, according to our approach, must undertake net negative emissions at some point, and the 'positive countries' that are allocated positive emissions only. Under this approach, 'negative countries' have emissions allocations that reduce linearly from the start of the allocation on to reach zero at a unique future date, T1, common to all 'negative countries'.

From this same date T1 onwards, ‘positive countries’ linearly reduce their emissions levels to reach zero at the end of the allocation period. Between the start of the allocation and T1, ‘positive countries’ can emit the difference between the ‘Target’ global scenario and the sum of emissions allocated to ‘negative countries’. Conversely, at any time between T1 and the end of the allocation, ‘negative countries’ can emit the difference between the ‘Target’ global scenario and the emissions allocated to ‘positive countries’.

In our approach, T1 is calculated so that ‘negative countries’ and ‘positive countries’ are allocated equal cumulative per capita emissions budgets over the chosen timespan. T1 depends on the parameterization of the approach and may not be realistic, for example it may not be in the projection timeframe (here 2010 to 2100). At any time after T1, national ratios of the total emissions allocated to ‘negative countries’ match the relative importance of their emissions debts at T1. Between the start of the allocation and T1, each ‘positive country’ is allocated a specific dynamic transition ratio of the total ‘positive countries’ emissions allocation. These dynamic national transition ratios are linear interpolations between the national emissions ratios observed at the start of the allocation and the emissions ratios at T1. The emissions allocation of each ‘positive country’ at T1 is determined iteratively to allow equal cumulative per capita emissions.

Some of the identified ‘positive countries’ – countries that have a budget greater than the cumulative emissions of a linear emissions reduction from their emissions level at the start of the allocation to reach 0 at T1 – can have a budget yet lower than the minimal cumulative emissions possible for any ‘positive country’ as defined earlier (this minimum is given by the minimal dynamic national transition ratio applied to global ‘positive countries’ emissions, that ratio is a linear interpolation between the national emissions ratio observed at the start of the allocation and 0 at T1). We modify the trajectories of these ‘positive countries’ (from the ‘positive countries’ trajectories defined earlier) to linearly reduce their emissions from a point in time T0 (between the start of the allocation and T1) to reach 0 at T1. The time T0, specific to each country, is determined iteratively so that each of these countries match their allocated budget.

c) *The ‘capability’ approach*

The ‘capability’ (CAP) approach implemented here follows the approach from Jacoby et al. (2008). This approach allocates to each country a share of the ‘Target’ pathway’s emissions proportional to their population divided by their per capita GDP. When the ‘Target’ pathway’s net emissions are negative, countries are allocated a share proportional to their GDP. A convergence period, similar to that for the equal per capita approach, is implemented. After the convergence period, annual emissions allowances of a country c are:

$$if\ E_{global}(y) > 0, \qquad E_c(y) = E_{global}(y).\frac{{Pop_c(y)^2}\big/{GDP_c(y)}}{\sum_{i=\{countries\}} {Pop_i(y)^2}\big/{GDP_i(y)}},$$

$$if\ E_{global}(y) < 0, \qquad E_c(y) = \ E_{global}(y).\frac{GDP_c(y)}{\sum_{i=\{countries\}} GDP_i(y)},$$

where i is the index of the sum over all countries.

d) The ‘Greenhouse Development Rights’ approach

The ‘Greenhouse Development Rights’ (GDR) approach preserves a ‘right to development’ through the allocation of mitigation requirements (Baer *et al* 2008, Kemp-Benedict 2010, Meinshausen *et al* 2015). The GDR formula distributes across countries the mitigation gap between a global BaU scenario and a ‘Target’ emissions pathway. This approach results in national emissions scenarios that add up to the ‘Target’ scenarios. The GDR approach is in the IPCC ‘Responsibility-Capability-Need’ category. The mitigation burden allocated to a country depends on its historical and projected emissions, population and wealth distribution.

In this study, we used the modelling implemented by one of the authors (LJ) and presented in (Meinshausen *et al* 2015). The GDR approach determines the mitigation burden of a country based on the number of its citizens that earn more than a chosen development threshold, accounted in GDP purchasing power parity. The income distribution within a country is assumed to be a lognormal function of the population and depends on the GINI index. A Capability Index (C) is determined from the cumulated wealth of the members of the population with incomes higher than the threshold. A Responsibility Index (R) is determined from the cumulated emissions of the population that earns more than the threshold. Individual’s emissions are deduced from their income using a hyperbolic function. A Responsibility-

Capability Index (RCI_i) of a country i is calculated as the sum of a responsibility indicator R and a capability indicator C (Kemp-Benedict 2010, p 5, equation 17) according to:

$$RCI_i = a\frac{R_i}{\sum_{j=1}^{N} R_j} + (1-a)\frac{C_i}{\sum_{j=1}^{N} C_j},$$

where j the country index. In this study, we weight both these indicators equally and set the RCI weighting factor $a = 0.5$. The RCI is used to determine the mitigation effort of a country with respect to its business as usual (BaU) projection. We use here the RCP8.5 as the BaU scenario (Riahi *et al* 2011). Scenario RCP8.5 has the highest GHG emissions of the RCP set. This scenario assumes high population and relatively low energy intensity improvements as well as the absence of climate change policies.

e) The 'constant emissions ratio' approach

The 'constant emissions ratios' (CER) approach preserves the GHG emissions ratios across nations from the start of the allocation onwards. This approach, often referred to as the 'grandfathering' or 'inertia' approach, is generally not considered as an equitable option in climate justice (Caney 2009, Peters *et al* 2015). In the IPCCAR5, the 'grandfathering' approach is included in the 'staged approach' category (Höhne *et al* 2013, IPCC WGIII 2014, figure 6.28). A country's annual emissions are calculated as:

$$E_c(y) = E_{global}(y).\frac{E_c(y_s)}{E_w(y_s)}.$$

ANNEX III – Parameterization and dynamics

Parameterization of the allocation approaches.

National emissions scenarios modelled after each equity principle depend on parameters open to political discussions. We present here the set of parameters chosen for this study (table S2). First, the starting date is here set to 2011 as it follows the last year of emissions data available for all countries.

The EPC and GDR approaches start accounting for cumulative GHG emissions at a chosen date. We chose here to start this accounting in 1990. In 1990, the second World Climate Conference and the publication of the first IPCC report informed policy makers of anthropogenic contributions to climate change. The data used in this study is available for most countries since this date. The population data used to calculate per capita emissions is here considered over the same timespan as for historical emissions.

The GDR approach depends on BaU scenarios. We use RCP8.5, discounting bunker and LULUCF emissions, downscaled to the national level using SSP2. This scenario assumes middle socio-economic challenges for both mitigation and adaptation (O'Neill *et al* 2015). The income threshold from which the population of a country qualifies to take on the mitigation efforts is set to $7500 in purchasing power parity. The GDP sources used for the GDR and CAP approaches are from SSP2. The population data is also obtained from SSP2. SSP2 projects middle population and GDP/capita.

In order avoid steep emissions reductions, we implement in the CAP and EPC approaches a convergence period of 30 years that we estimate of political relevance. The Responsibility and Capability Indicator (RCI) was set here to account equally for responsibility and capability.

Table S2 | Parameters used for each allocation approach.

	Allocation start	Convergence period (y)	Cumulative emissions period (y)	AEEI (%)	Income thresholds ($)	Population & GDP	BaU reference	RCI weighting factor
CER	2011					SSP2		
CAP	2011	30				SSP2		
EPC	2011	30				SSP2		
CPC	2011		1990-2100	1.5		SSP2		
GDR	2011		1990-2100		7500	SSP2	SSP2	0.5

Dynamics of the approaches

Under the CER approach, the relative change in emissions is the same for all countries, and all national emissions allocations follow the same trend as the global emissions pathway. The national shares remains unchanged relatively to global emissions throughout the allocation period.

The EPC approach shows an inflexion point at the end of the convergence period. After this period, emissions allocations respect a pure per capita allocation.

The CAP approach also displays an inflexion point at the end of the convergence period. However, under this approach the change of slope can be greater than under the EPC approach because current high per capita emitting countries tend to have high projected per capita GDP in 2040. After the inflexion point, emissions are proportional to countries' populations and inversely proportional to their GDP per capita. Countries with relatively low populations and high GDP per capita, such as the USA and the EU, will be allowed very low emissions until global net emissions become negative. Once global net emissions are negative, all countries should have a share of global negative emissions proportional to their GDP. The significant difference in allocations between China and India arises from the difference between their GDPs per capita.

The CPC approach shows positive emissions allocations between the allocation starting date and a later date that depends on the parametrization. Beyond the date, the net emissions allocations of these high historical per capita emitters are negative. The importance of their net negative emissions depends on their historical per capita emissions as well as their emissions levels at the beginning of the allocation.

The GDR approach accounts for historical responsibility and capacity to fund mitigation and therefore results in strong net negative emissions for rich high-historical emitters (e.g. G7 countries). Conversely, countries with low per capita GDP and low historical emissions (e.g. India) are allowed to increase their emissions for some time before slowly mitigating while preserving positive emissions throughout the century. High historical per capita emitters with low GDP per capita (e.g. Russia) are required significantly less mitigation efforts than countries with higher GDP. Under the parameterization chosen in this study, Russia has strictly positive allocations. The BaU scenario used for each country plays an important role for future emissions allocations. More details on the implementation of the GDR approach are available in the SI of (Meinshausen *et al* 2015).

Comparison with the IPCC results

Our study follows the categorization adopted in IPCCAR5 figure 6.28 from Höhne et al. (2013) study. In this section we compare our results presented in figure 3 (of the main article) to the figure 6.28 of the IPCCAR5 (IPCC WGIII 2014). The original study from Höhne et al. groups over forty studies into the five categories we adopted here. The forty studies present the distribution of emissions from diverse global scenarios that show diverse global emissions levels in 2030. As a consequence, the variability of targets in IPCC figure 6.28 results not only from both the distribution methods but also from the global emissions scenarios to be matched. In this study, we apply all five approaches developed here to each of the eight selected scenarios. We can then observe, down to the national level, the effect of using different allocation approaches applied to a unique global emissions scenario. In our study, the variability of results observed across approaches (figure 3 in the main article) reflects only the effect of the distribution methodology and its parameterization.

Compared with figure 6.28, our capability (CAP approach) based results are more stringent for developed countries and less stringent for developing countries (especially in Middle East and Africa). Our CAP approach does not use reference scenarios and directly reflects the magnitude of international disparities in GDP per capita. A country's emissions allocation is inversely proportional to its GDP per capita and the variability in emissions allocations is greater for countries with low GDP per capita. For example, Middle East and Africa has a much higher allocation under CAP for 2030, between +140% and +275% above 2010 levels. Another feature of our CAP approach is that all countries have either positive or net negative emissions allocations at a given point in time irrespectively of their GDP per capita.

A limit to the modelling of approaches that rely on GDP projections (CAP and GDR) is that these do not account for the impact of the allocated mitigation efforts on GDP projections. The implementation of a capability approach is expected to reduce international GDP per capita differences, compared to reference projections, through the allocation of mitigation efforts. A dynamic implementation, with regularly updated allocations following GDP projections updates, is expected to reduce disparities across countries' mitigation targets over time compared to the results presented here.

The formulation of the EPC approach leaves little possibility for diverging modelling methodology and our results are similar to previous findings of the 'equality' category.

Our modelling of the CPC approach ensures strict equal cumulative per capita emissions over the 1990-2100 period. The period to account for historical emissions and the AEEI rate are the most influent parameters to define future emissions allocations. Our CPC approach allocates net negative emissions to high historical emitters. To the contrary, some approaches included in the IPCCCAR5 figure do not have net negative emissions allocations (IPCC WGIII 2014, figure 6.28, Nabel *et al* 2011) and require high historical emitters to mitigate more rapidly. Compared to the IPCCAR5 figure, our allocations for 2030 are less stringent for high historical emitters and more stringent to low historical emitters.

Our CER approach strictly preserves national emissions ratios measured at the start of the allocation. The CER approach is in the 'staged approaches' category of the IPCCAR5 figure. This category includes multiple approaches that follow diverse concepts of equity resulting in 2030 mitigation targets that do not match our results. Overall, our results are less stringent than IPCCAR5 figure 6.28 for OECD and EIT and more stringent for ASIA, MAF and LAM.

Our modelling of the GDR approach follows the methodology of earlier studies (2008, Kemp-Benedict 2010, Meinshausen *et al* 2015). Our results for 2030 are less stringent for OECD and EIT regions than the 'Responsibility, Capability, Need' category results of the IPCCAR5 figure. The 2030 targets calculated here for ASIA, MAF and LAM are similar to the IPCCAR5 figure.

Supplementary discussion

ANNEX IV – Limitations

The scope of this study leaves out the emissions from the land-use sector that many countries include in their pledges or INDCs. The accounting of avoided LULUCF emissions and added 'carbon sinks' strongly relies both on unsettled accounting rules and contentious business as usual projections.

Finally, the study is based on data projections in order to show emissions scenarios throughout the 21st century. However, it is possible to implement the approaches presented here in a dynamic manner whereby scenarios are updated regularly with new available data projections.

Supplementary Tables

ANNEX V – Additional results.

G7 aggregated allocations compared to existing G7 goals.

At the meeting of L'Aquila in 2009, the G8 (G7 plus Russia) declared support for "a goal of developed countries reducing emissions of greenhouse gases in aggregate by 80% or more by 2050 compared to 1990 or more recent years" (G8 2009). We show in figure S3 the emissions allocations for the G7 group (with non-G7 EU countries) following the allocation approaches developed in this study. We derive the G7 aspiration as formulated at L'Aquila, and calculate an 80% mitigation target for 2050 compared to both the maximum and minimum emissions levels of the 1990-2010 period (respectively 79 and 81% reduction compared to 2010). Compared to the allocations derived from the Elmau Agreement (main article), the L'Aquila goal is more ambitious only than the CER approach and falls short of meeting the aggregate allocations corresponding to any vision of climate justice (Caney 2009). The G7, including all EU countries, would make a 'fair' (excluding the CER results) contribution towards the realization of the global goal set at Elmau by reducing its aggregate emissions by: 44% to 92% in 2030 and 84% to 144% in 2050 depending on the approach compared to 2010 levels.

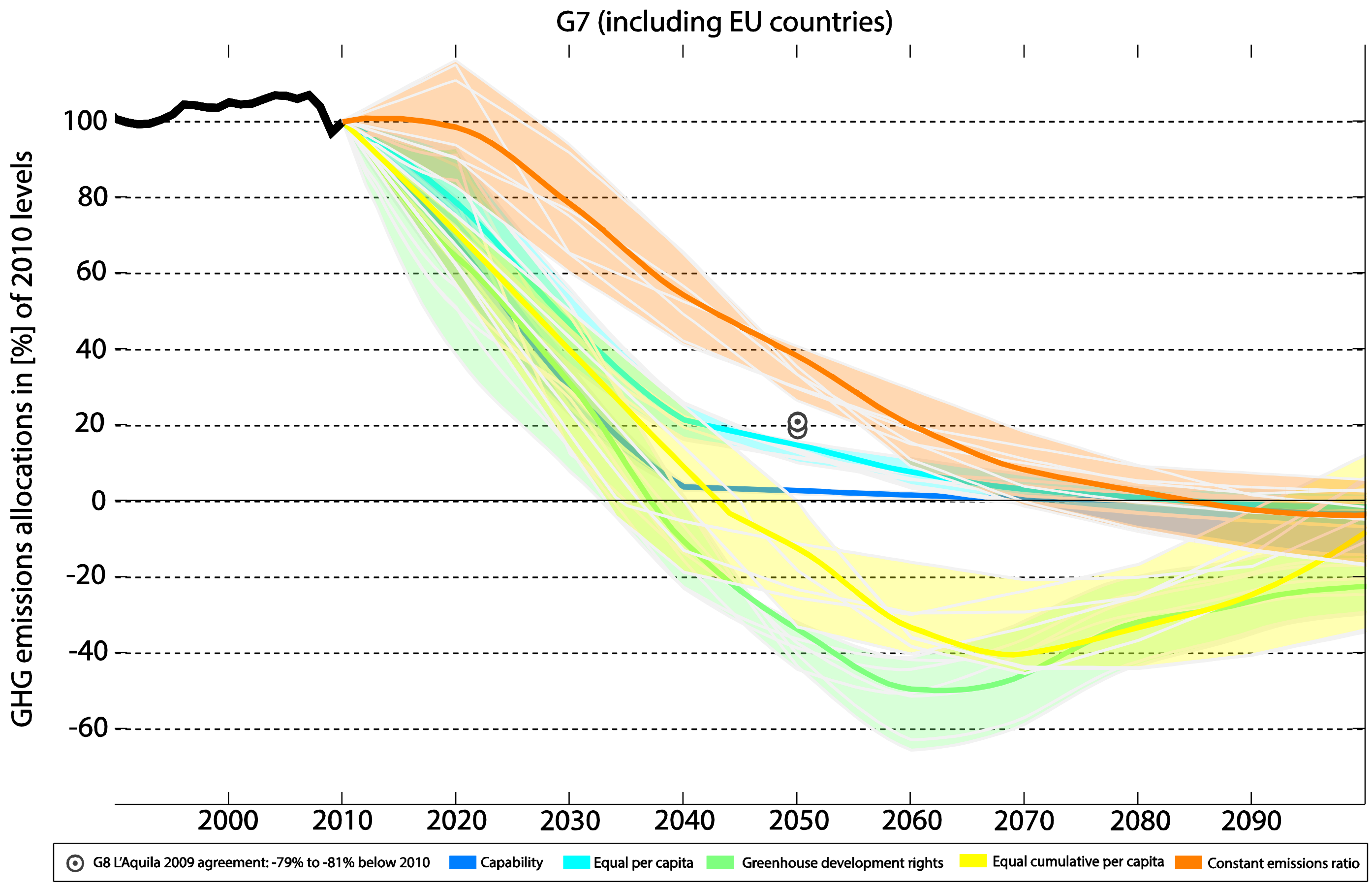

Figure S3 | Emissions allocations for the G7 group – including EU countries not part of the G7 – coherent with the Elmau agreement according to the five effort sharing approaches compared with 2009 L'Aquila target. National emissions scenarios (white lines in coloured patches) coherent with selected global scenarios are shown for five approaches: capability (dark blue), equal per capita (turquoise), Greenhouse Development Rights (green), equal cumulative per capita (yellow) and constant emissions ratio (orange). The target of 80% reduction is shown compared to the maximum and minimum emissions of the 1990-2010 period (black circles). Results are shown in percentage of their respective 2010 levels. LULUCF emissions are excluded.

Regional, Sub-regional and national results

We present additional results at the regional, sub-regional and national levels, derived following the allocation framework developed in this study.

We derive emissions allocations for 2050 consistent with the G7 agreement expressed as percentage of 2010 emissions in five world sub-regions according to five equity approaches (figure S4). Allocations are lower in 2050 than in 2030 (figure 3 in the main article) in each region and each approach respectively. Net negative emissions are allocated to OECD under the CPC and GDR approaches, and to EIT under the CPC approach only. Asia and Latin-America are allocated reductions mostly contained in the +40% to +80% range compared to 2010 across all approaches. Middle East and Africa is allocated emissions greater than their 2010 levels under the CAP, GDR and CPC approaches.

We further present mitigation targets for 2030 and 2050 for a set of ten sub-regions: ‘North-America’, ‘Western Europe’, ‘Economies in Transition’, ‘Japan, Australia, New Zealand’, ‘Latin America’, ‘Sub-Saharan Africa’, ‘Middle East, North Africa’, ‘South Asia’, ‘East Asia’ and ‘ Pacific Asia’ (figure S5 and figure S6). Allocations for both 2030 and 2050, compared to 2010 levels, are rather similar across the ‘North America’, ‘Western Europe’, ‘Economies in Transition’, ‘Japan Australia New-Zealand’ and ‘East Asia’ regions and across all approaches except for the GDR. Amongst these five sub-regions, the ‘Economies in Transition’ and ‘East Asia’ regions have a substantially greater allocation under the GDR than other sub-regions. Compared to these five sub-regions, ‘Pacific Asia’ and ‘Middle East, North Africa’ regions have less stringent targets, with little or no mitigation required in 2030, and allocation up to 80% below 2010 levels in 2050. Only two regions – ‘Sub-Saharan Africa’ and ‘South Asia’ – show allocations in 2030 and 2050 greater than 2010 levels and have the least stringent targets of all sub-regions.

Finally, we derive emissions allocations consistent with the G7 agreement for G20 countries not addressed elsewhere in this study according to five equity approaches for 2030 (figure S7) and 2050 (figure S8). We also provide for these countries the means and ranges of allocations for 2025, 2030 and 2050 across all approaches (table S3). The INDC of Australia appears consistent with only the CER and the GDR approaches (figure S7). The GDR approach depends strongly on BaU emissions – here downscaled from RCP8.5 global scenario using GDP projections – that are here very high for Australia. The INDC of the Republic of Korea, appears consistent only with the higher end of the CER approach and is far above allocations of any other approach. The INDC of Mexico is consistent with all approaches except for the CAP. Under the GDR approach, France and Germany can be allocated net negative emissions in 2030 depending on the selected global pathway. In 2050, net negative emissions are also allocated to Australia, Italy, the UK, Korea, South Africa and Saudi Arabia under GDR and/or CPC (figure S8). Only Indonesia has higher allocations in 2050 than its 2010 levels, following the higher end of the CPC range. The 2050 pledge of Mexico is consistent with all approaches but the CAP and the CER.

Table S3 | Emissions reductions consistent with the G7 agreement in 2025, 2030 and 2050 according the five allocation approaches. The INDCs and pledges, the average mitigation target over the eight selected scenarios and the complete range are given in percentage change compared to 2010 levels. The original INDC/pledge is in brackets.

	INDCs and pledges		2025		2030		2050	
Argentina		CAP	-45	[-35 to -56]	-63	[-54 to -70]	-92	[-90 to -94]
		EPC	-22	[-7 to -37]	-36	[-21 to -49]	-75	[-69 to -80]
		GDR	-10	[8 to -28]	-21	[-2 to -38]	-60	[-51 to -68]
		CPC	-40	[-32 to -54]	-59	[-50 to -72]	-94	[-85 to -100]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
Australia	2030 | -28%	CAP	-54	[-45 to -63]	-73	[-66 to -78]	-98	[-98 to -99]
	2030 | -30% conditional	EPC	-43	[-32 to -53]	-59	[-50 to -68]	-89	[-87 to -92]
	(26 to 28% below 2005)	GDR	-9	[15 to -32]	-23	[2 to -45]	-111	[-102 to -119]
		CPC	-50	[-38 to -65]	-66	[-50 to -87]	-117	[-100 to -136]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
France		CAP	-51	[-42 to -61]	-69	[-62 to -76]	-96	[-96 to -97]
		EPC	-25	[-10 to -39]	-39	[-25 to -52]	-77	[-71 to -81]
		GDR	-58	[-25 to -89]	-79	[-47 to -105]	-168	[-159 to -180]
		CPC	-45	[-36 to -61]	-64	[-50 to -81]	-98	[-93 to -102]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
Germany		CAP	-52	[-42 to -61]	-70	[-62 to -76]	-97	[-96 to -97]
		EPC	-37	[-25 to -49]	-53	[-42 to -63]	-87	[-84 to -89]
		GDR	-77	[-54 to -99]	-97	[-76 to -115]	-151	[-147 to -156]
		CPC	-50	[-38 to -65]	-66	[-50 to -87]	-116	[-100 to -134]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
Indonesia		CAP	-7	[11 to -24]	-18	[1 to -35]	-65	[-57 to -72]
		EPC	38	[65 to 12]	33	[65 to 6]	-31	[-16 to -46]
		GDR	2	[12 to -8]	-6	[8 to -18]	-31	[-22 to -39]
		CPC	62	[118 to 34]	56	[95 to 37]	4	[23 to -31]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
Italy		CAP	-52	[-43 to -61]	-70	[-63 to -76]	-97	[-96 to -98]
		EPC	-29	[-15 to -42]	-44	[-30 to -55]	-80	[-76 to -85]
		GDR	-49	[-17 to -79]	-67	[-36 to -93]	-158	[-149 to -168]
		CPC	-49	[-37 to -65]	-66	[-50 to -87]	-105	[-100 to -111]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
Republic of Korea	2030 | -19% (81% above 1990)	CAP	-51	[-42 to -60]	-69	[-62 to -76]	-96	[-96 to -97]
		EPC	-39	[-28 to -51]	-56	[-45 to -65]	-88	[-86 to -91]
		GDR	-95	[-80 to -109]	-111	[-98 to -122]	-130	[-128 to -134]
		CPC	-50	[-38 to -65]	-66	[-50 to -87]	-112	[-100 to -126]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
Mexico	2030 | -31%	CAP	-34	[-21 to -46]	-49	[-37 to -60]	-83	[-80 to -87]
	2030 | -45% conditional	EPC	3	[23 to -16]	-7	[15 to -26]	-56	[-46 to -65]
	(25 to 40% below 2013)	GDR	-17	[2 to -36]	-24	[-3 to -42]	-39	[-29 to -48]
	2050 | -59% (50%	CPC	18	[81 to -15]	1	[45 to -22]	-58	[-37 to -98]
	below 2000)	CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
Saudi Arabia		CAP	-48	[-38 to -57]	-65	[-57 to -72]	-93	[-91 to -94]
		EPC	-33	[-21 to -46]	-49	[-37 to -59]	-82	[-78 to -85]
		GDR	-21	[-6 to -36]	-35	[-19 to -49]	-66	[-59 to -73]
		CPC	-48	[-38 to -65]	-66	[-50 to -86]	-101	[-99 to -105]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
South Africa		CAP	-44	[-33 to -54]	-60	[-51 to -69]	-91	[-89 to -93]
		EPC	-26	[-11 to -39]	-40	[-25 to -52]	-77	[-72 to -82]
		GDR	18	[31 to 5]	15	[30 to 1]	-11	[-3 to -21]
		CPC	-44	[-36 to -59]	-63	[-50 to -79]	-98	[-91 to -101]
		CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
Turkey		CAP	-36	[-23 to -48]	-52	[-40 to -62]	-84	[-81 to -88]

	EPC	-6	[12 to -24]	-18	[2 to -35]	-63	[-54 to -70]
	GDR	-15	[1 to -30]	-22	[-5 to -38]	-88	[-80 to -95]
	CPC	1	[35 to -25]	-17	[8 to -36]	-69	[-51 to -100]
	CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]
United Kingdom	CAP	-53	[-43 to -61]	-71	[-64 to -77]	-97	[-97 to -98]
	EPC	-30	[-16 to -43]	-45	[-31 to -56]	-80	[-76 to -84]
	GDR	-54	[-20 to -85]	-73	[-40 to -100]	-164	[-154 to -175]
	CPC	-50	[-38 to -65]	-66	[-50 to -87]	-105	[-100 to -114]
	CER	-12	[5 to -28]	-24	[-6 to -40]	-67	[-59 to -74]

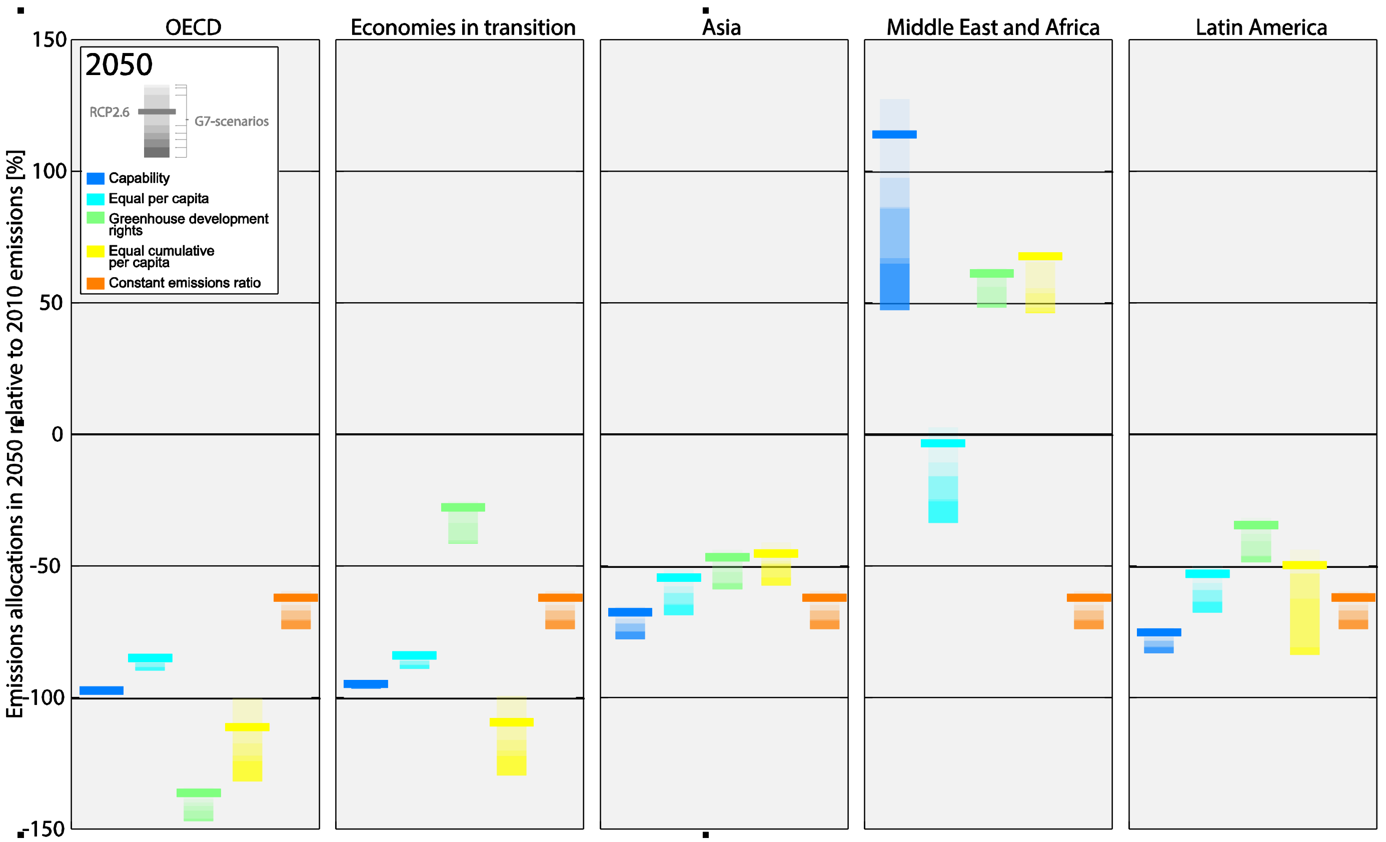

Figure S4 | Emissions allocations in 2050 consistent with the G7 agreement expressed as percentage of 2010 emissions in five world regions according to five equity approaches: Capability, Equal Per Capita, Greenhouse Development Rights, Equal Cumulative Per Capita, Constant Emissions Ratio. The shading of the colour patch is darker below the allocation of each G7 scenario. The wider line shows results when considering RCP2.6.

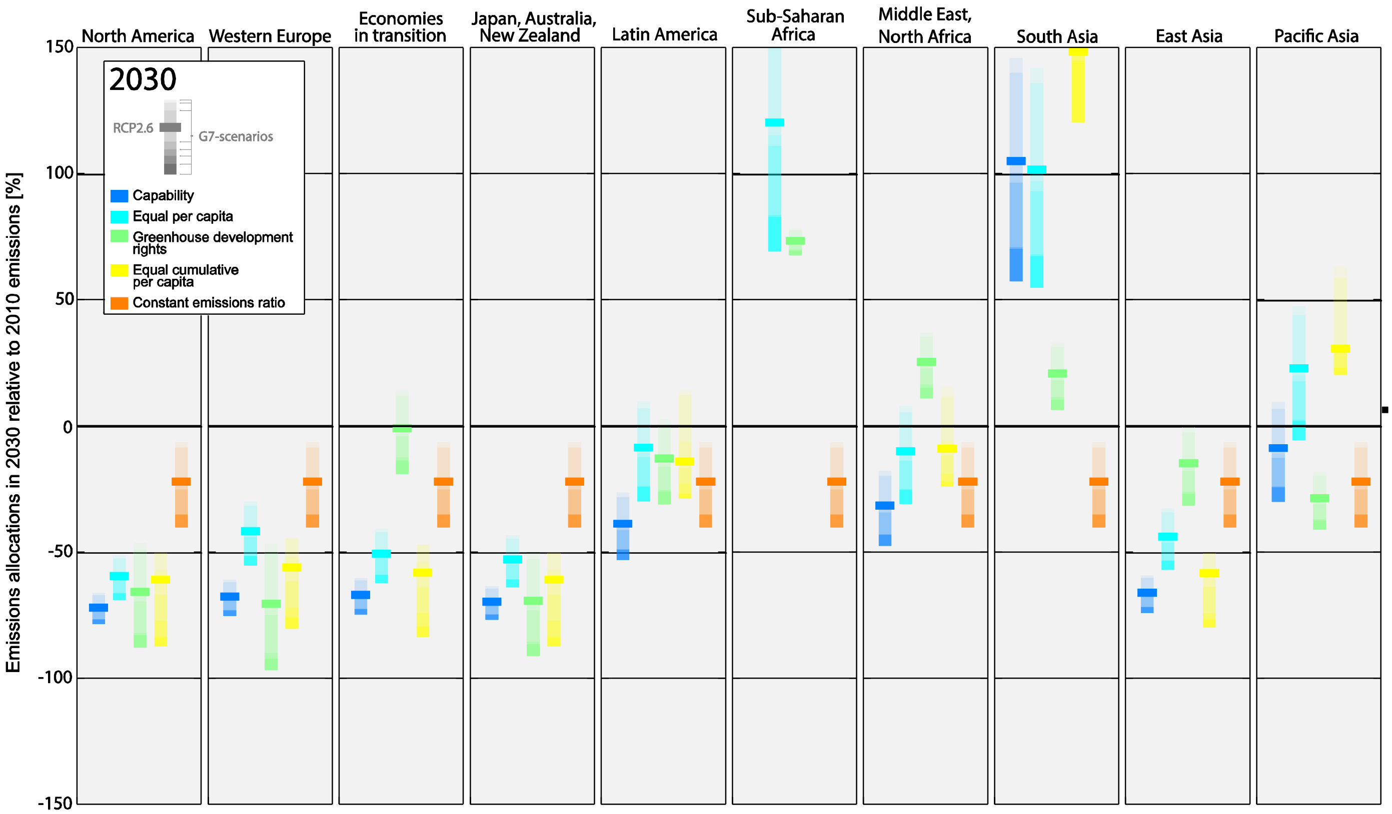

Figure S5 | Emissions allocations in 2030 consistent with the G7 agreement expressed as percentage of 2010 emissions in 10 world sub-regions according to five equity approaches: Capability, Equal Per Capita, Greenhouse Development Rights, Equal Cumulative Per Capita, Grandfathering. The shading of the colour patch is darker below the allocation of each G7 scenario. The wider line shows results when considering RCP2.6.

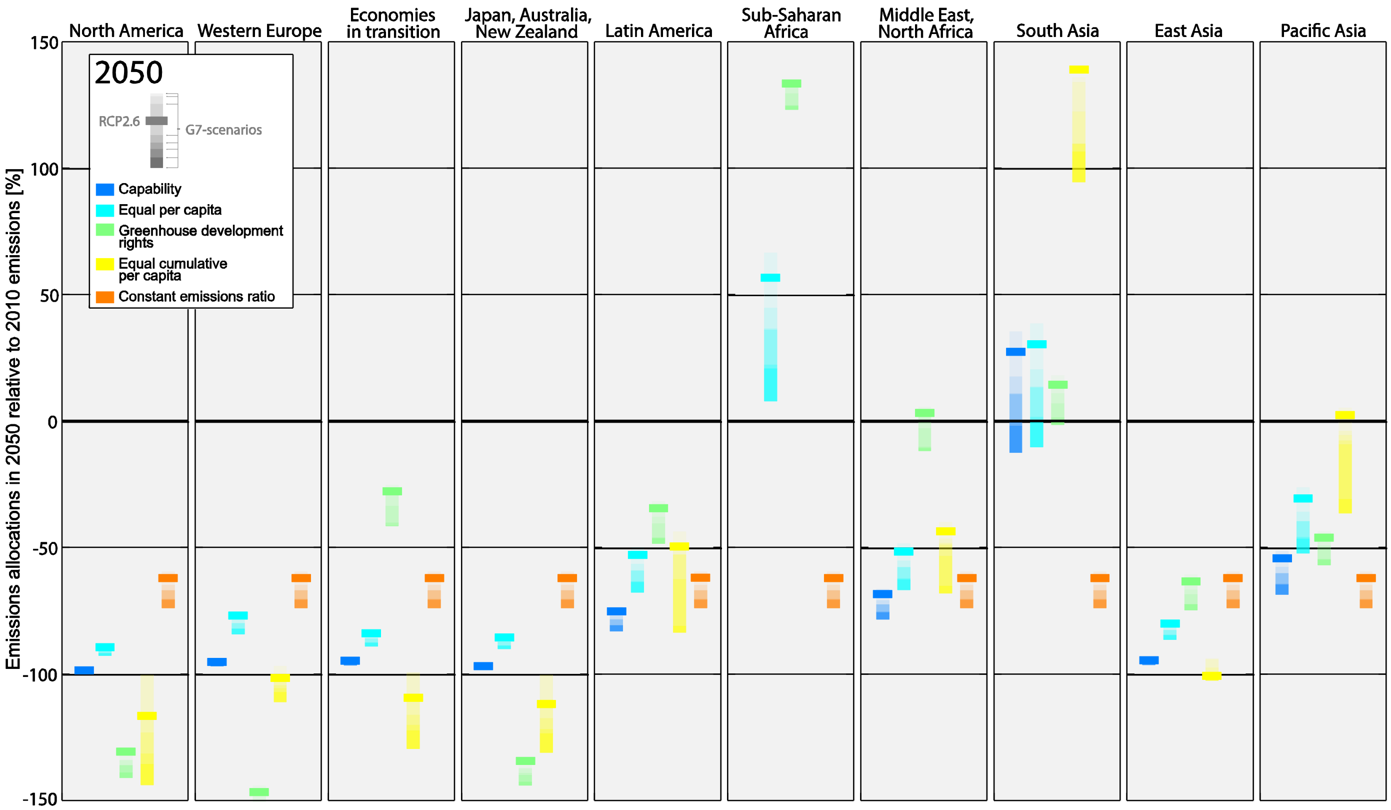

Figure S6 | Emissions allocations in 2050 consistent with the G7 agreement expressed as percentage of 2010 emissions in ten world sub-regions according to five equity approaches: Capability, Equal Per Capita, Greenhouse Development Rights, Equal Cumulative Per Capita, Grandfathering. The shading of the colour patch is darker below the allocation of each G7 scenario. The wider line shows results when considering RCP2.6.

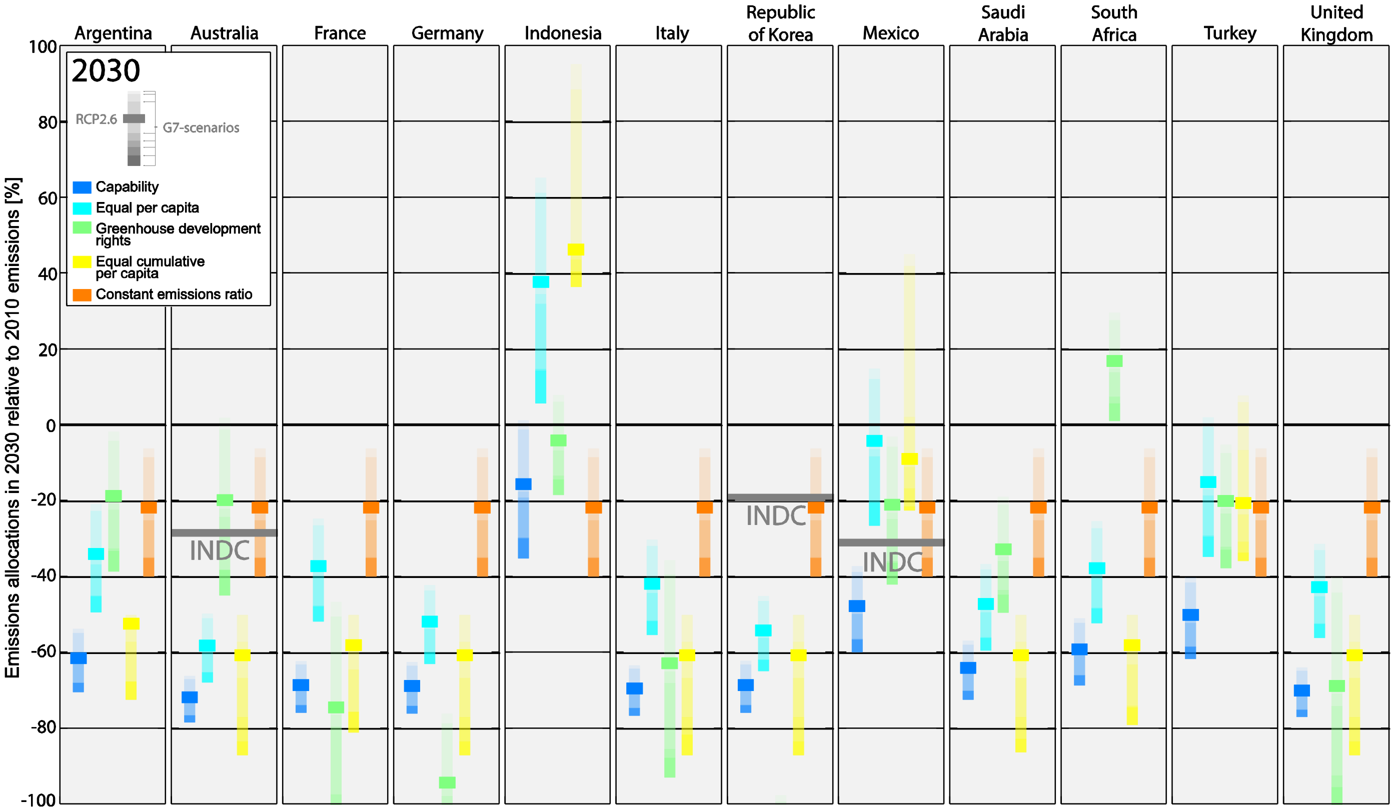

Figure S7 | Emissions allocations in 2030 consistent with the G7 agreement as a percentage of 2010 levels for G20 members according to five equity approaches: Capability, Equal Per Capita, Greenhouse Development Rights, Equal Cumulative Per Capita, Grandfathering. The shading of the colour patch is darker below the allocation of each G7 scenario. The wider line shows results when considering RCP2.6. The grey lines show INDC mitigation targets applied to 'Kyoto Annex A' emissions.

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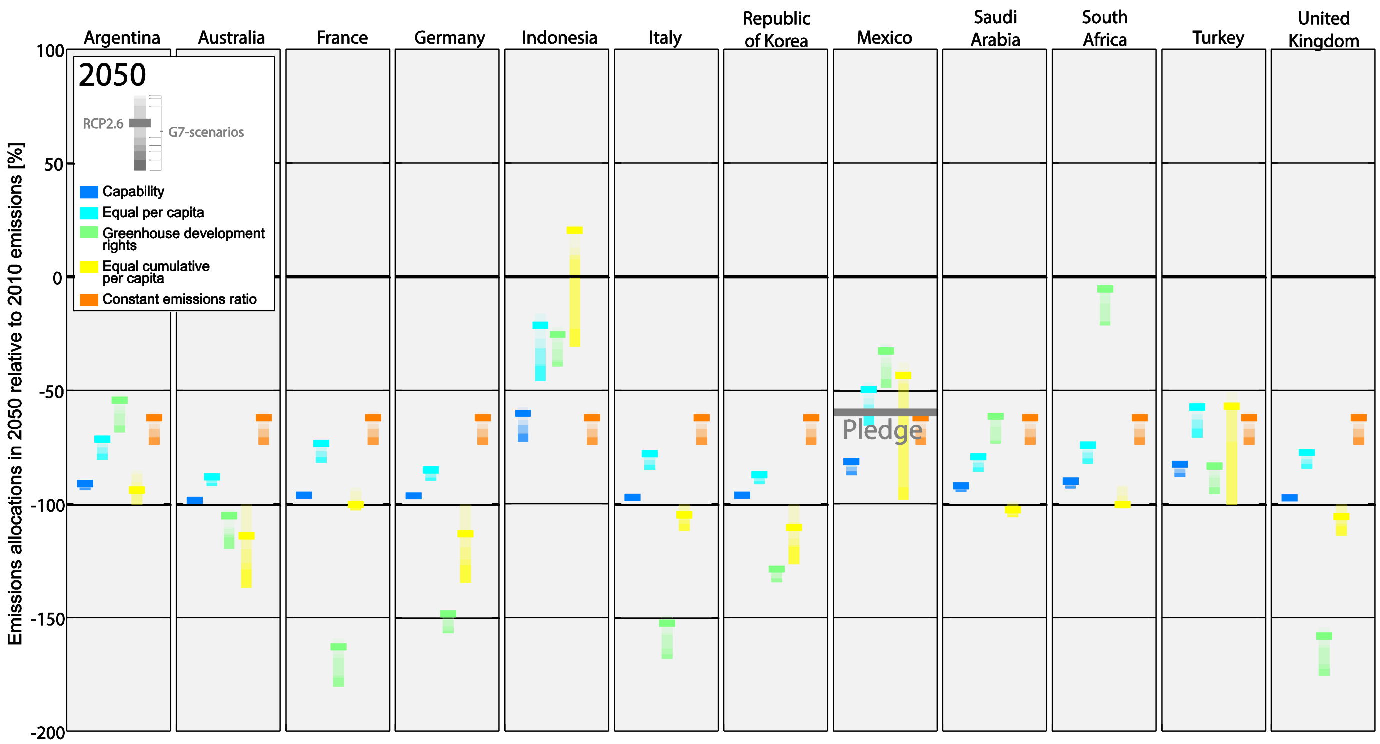

372 **Figure S8 | Emissions allocations in 2050 consistent with the G7 agreement as a percentage of 2010 levels for G20 members according to**
373 **five equity approaches:** Capability, Equal Per Capita, Greenhouse Development Rights, Equal Cumulative Per Capita, Grandfathering. The
374 shading of the colour patch is darker below the allocation of each G7 scenario. The wider line shows results when considering RCP2.6. The grey
375 line shows Mexico's pledge mitigation targets applied to 'Kyoto Annex A' emissions.

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