nature climate change

ARTICLES

PUBLISHED ONLINE: 26 OCTOBER 2015 | DOI: 10.1038/NCLIMATE2826

National post-2020 greenhouse gas targets and diversity-aware leadership

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Achieving the collective goal of limiting warming to below 2 °C or 1.5 °C compared to pre-industrial levels requires a transition towards a fully decarbonized world. Annual greenhouse gas emissions on such a path in 2025 or 2030 can be allocated to individual countries using a variety of allocation schemes. We reanalyse the IPCC literature allocation database and provide country-level details for three approaches. At this stage, however, it seems utopian to assume that the international community will agree on a single allocation scheme. Here, we investigate an approach that involves a major-economy country taking the lead. In a bottom-up manner, other countries then determine what they consider a fair comparable target, for example, either a 'per-capita convergence' or 'equal cumulative per-capita' approach. For example, we find that a 2030 target of 67% below 1990 for the EU28, a 2025 target of 54% below 2005 for the USA or a 2030 target of 32% below 2010 for China could secure a likely chance of meeting the 2 °C target in our illustrative default case. Comparing those targets to post-2020 mitigation targets reveals a large gap. No major emitter can at present claim to show the necessary leadership in the concerted effort of avoiding warming of 2 °C in a diverse global context.

The international community agreed to limit warming below 2 °C or even 1.5 °C (ref. 1). Current pledges up to 2020 are not on track for that collective goal[2]. However, new research continues to remind us about the implications of not limiting warming: for example, today's warming of just 0.9 °C already implies 1.2 m global-mean sea-level rise over the coming centuries from ice loss in the West Antarctic Amundsen Sea sector alone[3].

Country-level emission allocations are contentious within the international community, despite the multiple complementary benefits that decarbonization of the energy and transport sectors can have (such as improved local air quality[4] and increased energy security[5]). Mitigation discussions at the United Nations Framework Convention on Climate Change (UNFCCC) are dominated by a 'burden sharing' debate, and disagreement in this so-called 'equity discussion' persists. This reflects fundamental differences regarding the allocation of future emissions following 'common but differentiated responsibilities and respective capabilities'[6] (CBDR&RC). Scientific literature so far provides limited guidance on appropriate quantitative national targets for 2025 or 2030 under different allocation regimes[7–11]. The recent Fifth Assessment Report[12] (AR5) summarizes six distinct allocation categories, and a set of scenario categories that approximate but do not equate to global ambition. Although providing some regional disaggregation, the IPCC and the underlying literature review[11] stopped short of providing country-level detail. Here, we re-analyse the IPCC allocation database and develop country-level allocation pathways to address this information gap. As countries within the UNFCCC have not converged to any particular allocation category or regime, we assume a world with continued differing opinions on what constitutes a fair allocation. Our results give an indication of what might be required for a 'leading' country to guide the world towards a 2 °C-consistent trajectory.

Waypoints for 2025 and 2030

First, we derive 2025 and 2030 waypoints—that is, indicative global aggregate greenhouse gas (GHG) emissions levels consistent with a carbon budget of 1010 $GtCO_2$. This 1010 $GtCO_2$ budget was found by IPCC to be the cumulative CO_2 emissions remaining after 2011 to preserve a likely chance of staying below 2 °C based on multiple lines of evidence[13]. On the basis of our analysis of the IPCC AR5 Scenario Database (see Supplementary Section 3), we choose an illustrative 2025 waypoint of 10% above 1990 emissions (15% below 2010) for world emissions to be in line with the IPCC carbon budget for 2 °C (Fig. 1). For 2030, we define our waypoint as '1990 levels' (or 22% below 2010; see Supplementary Figs 10–31 for variable global waypoints). Our waypoints happen to be in line with RCP3PD, the lowest of the four main IPCC scenarios. These waypoints are more ambitious (that is, imply lower emissions) than some delayed scenarios at the high emissions end suggest (Fig. 2b,c), but less than findings of the least-cost 2010 scenarios assessed by UNEP (ref. 14; see Supplementary Section 3.2) and also less ambitious than the median of IPCC AR5 WG3 scenarios that do not assume subsequent net negative fossil and industrial CO_2 emissions (Supplementary Information). Hence, the global waypoints defined

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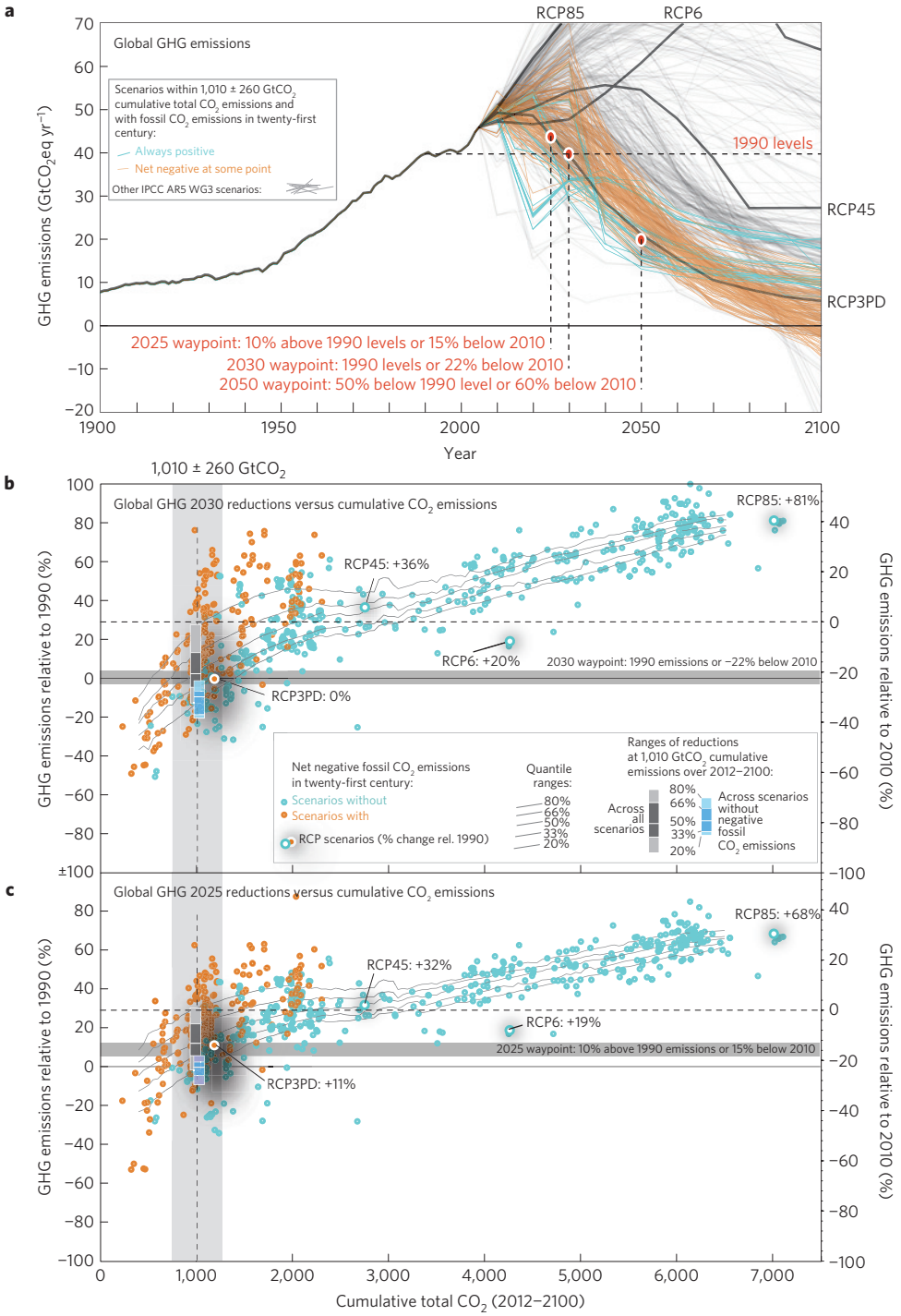

Figure 1 | Global 2025/2030 GHG emission waypoints implied by the IPCC 2 °C carbon budget of 1,010 $GtCO_2$. **a**, Historical GHG emissions and harmonized future scenarios from the IPCC AR5 scenario database (thin lines) and RCP scenarios (thick grey lines). Our default waypoints are indicated as well as a 50% reduction compared to 1990 by 2050 (60% reduction compared to 2010). **b**, 2030 GHG emission waypoints derived by quantile regression of GHG emissions in 2030 versus the scenarios cumulative emissions from 2012–2100—distinguishing between scenarios that imply negative fossil CO_2 emissions (orange circles) or not (blue circles). **c**, Same as **b**, but for 2025 GHG emissions.

here roughly reflect upper limits for 'middle-of-the-road' indicators. Consequently, this same interpretation applies for the national targets that we discuss below—that is, that national targets might err on the side of too small reductions, for the reason of how we derive global waypoints, not necessarily for other reasons. Furthermore, our results should be considered conservative in two other respects: remaining within a 2 °C target with a higher level of confidence than likely (>66%), or limiting warming to 1.5 °C, imply global emissions lower than these waypoints in 2025 and 2030 (see discussion of the waypoints with regard to earlier studies and recent emission trends in the Supplementary Information).

The binary equity debate

Much of the equity debate within the UNFCCC centres on the operationalization of the CBDR&RC principle instated in the 1992 Framework Convention. At the time, CBDR&RC was primarily

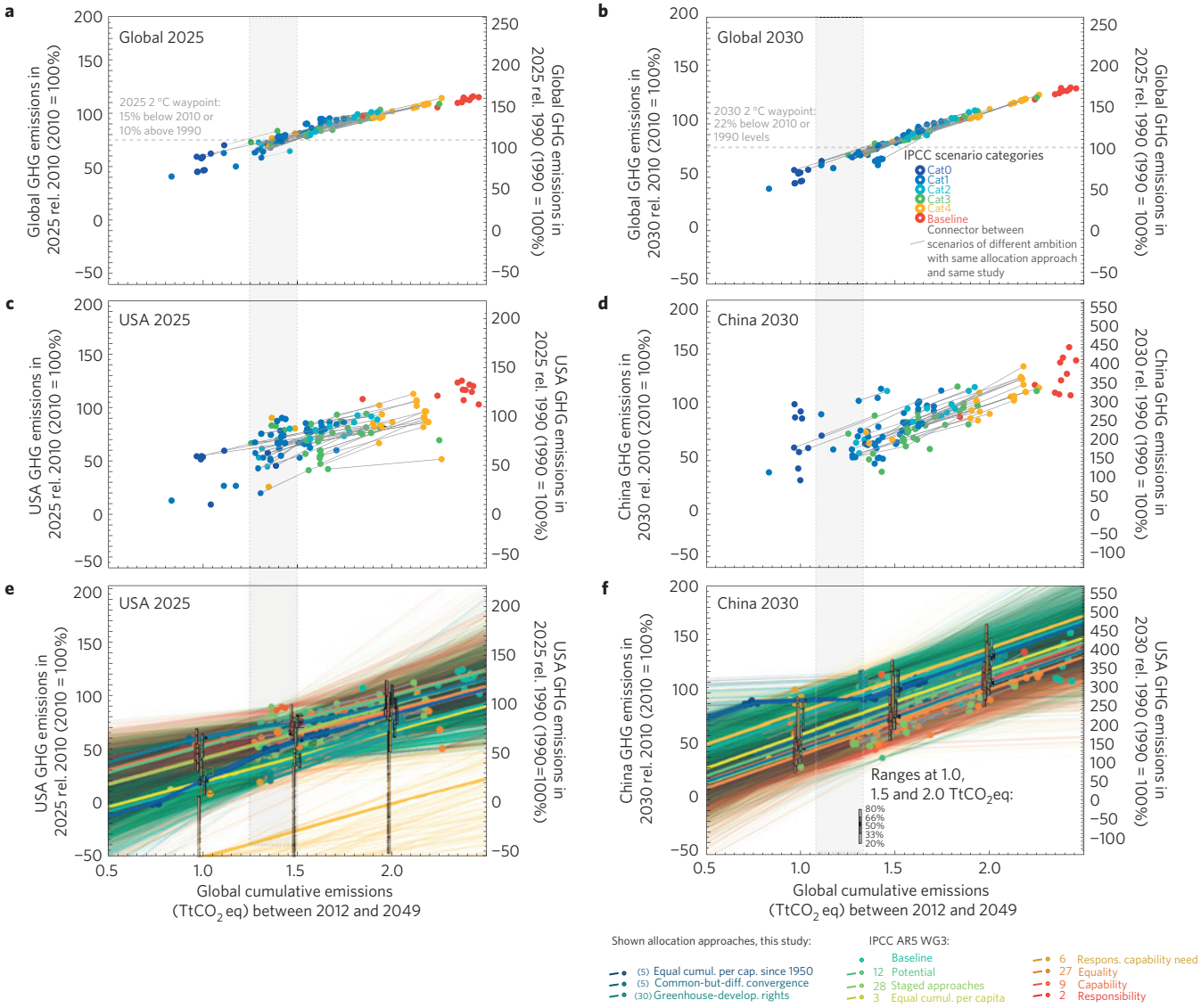

Figure 2 | Re-analysis of the IPCC allocation database and our country-level allocations in comparison for USA and China. a, Global 2025 GHG emissions relative to 2010 levels (left axis) and 1990 levels (right axis) in the IPCC allocation regime database collected in ref. 11, distinguished by their respective IPCC WG3 stabilization categories Cat0 to Cat4 (colour codes as in **b**). Studies that explored multiple stabilization levels are connected (grey lines). The horizontal axis shows cumulative GHG emissions between 2012 and 2049, with the range between 1.34 and 1.50 $TtCO_2eq$ (trillion tonnes CO_2 eq) highlighted (grey vertical band) as the range between medians of a quantile regression at the 1,010 $GtCO_2$ budget across the IPCC AR5 scenario database without and with negative fossil CO_2 emissions, respectively. **b**, Same as **a**, but for 2030. **c**,**d**, Same as **a** and **b**, respectively, but for GHG emissions of USA and China on the *y*-axis (derived as ~90% fractions of the North American and East Asian regions, Supplementary Information). Colour codes as in **b**. **e**,**f**, Same as **c** and **d**, but complemented by extrapolation of single-stabilization level studies, and three of our country-level allocation regimes (Supplementary Information). Colour codes reflect different allocation regimes in **e** and **f** (see legend in **f**).

addressed by creating the dichotomy between industrialized Annex I and developing Non-Annex I countries[15] as the main indicator for mitigation responsibilities. With only 22% of the global population[16], Annex I countries emitted approximately 46% of global GHG emissions (incl. land use) in 1992 (Supplementary Fig. 3). This binary differentiation remains strongly influential on the negotiations[17]. However, given a decreasing global share of Annex I countries' direct GHG emissions (~31% in 2014, Supplementary Section 6) and given that China's territorial emissions share has risen to almost the same level as all Annex I emissions together (~26% in 2014, Supplementary Section 6), negotiations are moving towards a more complex self-differentiation within an agreement that shall be 'applicable to all'[18]. Hence, the more than decade old effort-sharing debate[19–22] for a more gradual differentiation gained momentum again: How much should individual countries contribute to the collective mitigation effort in the coming decades? In the academic literature, a host of effort-sharing approaches has been developed on this question, and the answer is fundamentally dependent on a series of value judgements[6,11,12,20,21,23–31].

For our study, a simplification of the political debate is useful. In essence, countries' positions predominantly follow a logic of either distributive or corrective justice[32]. Thus, an almost binary view has surfaced about what type of gradual differentiation can be considered fair. We capture the range of proposals with two illustrative allocation approaches: 'Common but differentiated convergence'[24] (CDC), which is a modified per-capita convergence approach, and the 'equal cumulative per-capita' approach (ECPC) (compare Fig. 2c and Supplementary Sections 8.1 and 8.2). The CDC approach essentially postulates that it is fair to converge to equal per-capita emission allocations (distributive justice). The

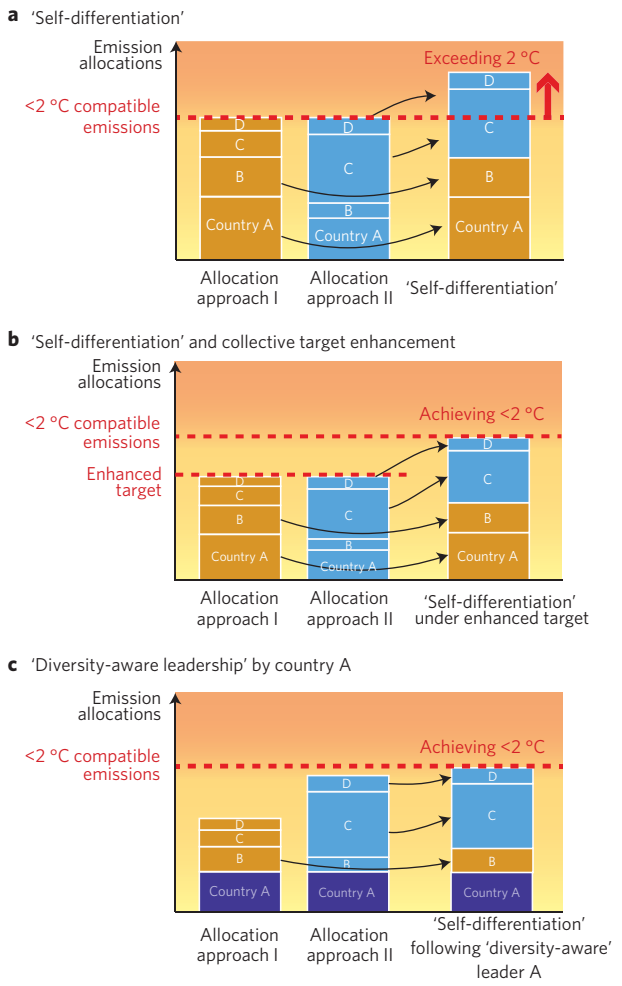

Figure 3 | Illustration of the 'diversity-aware leadership' concept in contrast with self-differentiation. a, Self-differentiation under a joint target C leads to the collective target C being exceeded. **b**, A collective target enhancement could ensure the self-differentiation still achieving the collective target C. **c**, A 'diversity-aware' leadership country A could set a target so that with self-differentiation of 'follower' countries (committing to a 'comparable' level of effort under their chosen allocation approach) would still ensure achieving the collective target C. Mathematical formulation in Supplementary Information.

ECPC approach implies that a country A with higher per-capita emissions than country B in the past will have lower per-capita emission allocations in the future (corrective justice)[28,29]. We model two variants with different starting years from when per-capita emissions are counted, either 1950 (ECPC50) or 1990 (ECPC90) (Supplementary Information). Per-capita convergence is implied in some government's submissions. For example, the indicative previous US 2050 goal of −83% below 2005 (ref. 33), confirmed recently[34] with a tentative '−80% or more' goal by 2050, is only somewhat short (4 to 7%) of an equal per-capita allocation by 2050. Similarly, the EU's 'intended nationally determined contribution' (INDC; ref. 35) is presented in the context of a per-capita convergence approach (Supplementary Information). On the other hand, 'cumulative equal per-capita emissions' are mentioned as an equity principle in presentations by China[15,36]. Although India proposed a regime similar to the CDC (ref. 24) in 2007 by stating its 'per-capita emissions will remain lower than those of the developed countries'[37], recent Indian negotiator and expert positions seem to favour approaches closer to China's cumulative per-capita proposal[38].

'Incompletely principled' agreements

Countries' preferences in international negotiations can often be understood as primarily motivated by self-interest: 'general principles of fairness are invoked only to promote or defend one's own interests'[20]. This narrow self-interest is the underlying cause for the 'tragedy of the commons'[39]. The existence of an international regime to address climate change, however, is evidence of a limited extent of cooperative behaviour, when 'rational choice, prisoner's dilemma, collective goods and global commons theories would predict non-cooperation with a worse outcome overall'[40]. By its very nature, a regime can provide soft boundaries and incentives for acceptable behavioural norms or principles that guide the development of country positions. Within those soft boundaries of a regime, countries are guided by their interests, and engage in a deliberative discourse, positioning themselves with sometimes fluid moral justifications to match their interests[41]. Within the soft boundaries of a climate change regime, self-interest of a country serves as a first-order explanation of why the least-ambitious emission allocation seems preferable. Indeed, in the UNFCCC negotiations and countries' submissions, it seems—not unexpectedly—that countries explicitly or implicitly align with principles and notions of equity that match their interests (Supplementary Sections 4 and 5 with examples USA, China and EU28). This poses a fundamental problem, because 'notions of fairness can provide a basis for an international regime only if there is a certain minimum of consensus among its members about what is fair and what is unfair'[20].

However, it is not uncommon in negotiation settings for different actors to agree on an outcome while subscribing to very different, possibly incompatible principles. Such settings necessarily call for agreements that focus on the final outcome, while not attempting to reach agreement on principles. Thus, a consensus on the principles is circumvented by 'political consensus'[41–43] of what a fair distribution of the burden would be. Those negotiation outcomes are what Sunstein called 'incompletely theorized agreements'[44], or one could also refer to them as 'incompletely principled agreements'. The likely alternative would be continued disagreement on principles and no agreement. This could lead to ensuing mitigation delay and a very inequitable outcome by exposing those with a low adaptive capacity to high climate change impacts. Therefore, contemporary environmental ethics suggests pragmatism may be a promising guiding principle for achieving fairer outcomes[43,45].

Whereas some countries favour or imply fairness principles, others negate the value of considering such principles as guidelines for target setting[46]. An 'un-principled' approach is not unrealistic, but is outside the scope of this study. In fact, the international negotiations are not 'un-principled'. Arguably, the pledges under the Copenhagen Accord and Cancun Agreements were made within the aforementioned soft guiding of a regime discussion, although they failed to bring the world much closer to its collective goal of keeping temperature increase below 2 °C (ref. 2). In line with the current agreed process, we analyse how self-differentiation can take place within the spectrum of discussed allocation approaches.

Self-differentiation bound to exceed joint goal

By calling for 'nationally determined contributions', the international community departed from an 'ideal' (and possibly unrealistic) scenario of a national emission allocation following a single common allocation approach: countries are asked to provide their own reasons for why they consider their contribution fair and commensurate with the joint target. Neither an un-principled approach nor a single globally applied allocation approach is taken. For the time being, countries apply the logic of 'self-differentiation'. Such a bottom-up architecture avoids one problem—the possibly utopian attempt to agree on a singular set of guiding principles—and might accomplish collective agreement on the outcome. However,

Table 1 | 2030 GHG emission allocations for potential leadership countries to bring world GHG emissions back to 1990 levels by 2030.

Lead nation	Reference year	Necessary lead nation's emissions (%) to reach 2 °C waypoint, if other countries follow 'comparable' efforts on the basis of:					
		Either CDC or ECPC50*	Either CDC, ECPC50 or GDR†	ECPC50	CDC	GDR	ECPC90
Argentina	2010	−47	−62	−24	−28	−34	−24
Australia	2000	−63	−83	−62	−23	−57	−47
	2010	−66	−84	−65	−30	−61	−52
Brazil	2010	−59	−67	−45	−35	−28	−36
Canada	2005	−73	−91	−71	−42	−71	−58
	2010	−72	−90	−70	−41	−71	−57
China	2010	−32	−35	−4	−32	1	−23
EU28	1990	−67	−96	−58	−51	−90	−52
	2010	−61	−95	−49	−41	−88	−43
France	1990	−62	−106	−47	−42	−99	−39
	2010	−59	−107	−43	−37	−99	−34
Germany	1990	−79	−104	−75	−60	−95	−65
	2010	−73	−105	−67	−48	−94	−54
India	2010	80	37	98	84	46	98
Indonesia	2010	−53	−56	−32	−39	−7	−40
Italy	1990	−58	−96	−38	−46	−94	−44
	2010	−53	−96	−32	−41	−93	−39
Japan	2005	−64	−99	−48	−53	−97	−53
	2010	−62	−99	−45	−50	−97	−50
Mexico	2010	−10	−50	13	−9	−40	2
Norway	1990	−61	−146	−47	−40	−145	−38
	2010	−42	−167	−23	−13	−166	−9
Russia	1990	−88	−92	−87	−75	−74	−78
	2010	−76	−83	−73	−48	−45	−55
Saudi Arabia	2010	−51	−60	−38	−22	−22	−34
South Africa	2010	−54	−60	−37	−33	−16	−33
South Korea	2010	−60	−88	−43	−54	−85	−56
Switzerland	1990	−42	−126	−17	−31	−125	−23
	2010	−44	−125	−20	−33	−125	−25
Turkey	2010	−11	−39	6	−5	−20	6
UK	1990	−74	−107	−68	−52	−96	−56
	2010	−67	−109	−58	−37	−95	−43
USA	2005	−76	−97	−75	−44	−84	−59
	2010	−75	−97	−74	−41	−83	−57

*Diversity-aware leadership: the shown reductions by benchmark allocation target countries depend on the allocation approach chosen by all other countries. The same benchmark allocation target is expressed relative to the countries' 2010 emissions as well as their 2020 pledge reference year, for example, 1990, 2000 or 2005. See Supplementary Table 9 for 2025 GHG emission allocations.
†Sensitivity-case leadership. Abbreviations: ECPC50, equal cumulative per-capita emissions (all GHG since 1950); CDC, common-but-differentiated convergence; GDR, greenhouse development rights approach (medium setting); ECPC90, equal cumulative per-capita emissions (all GHG since 1990).

self-differentiation creates another problem: the outcome might be insufficient compared to the ultimate collective goal in the absence of additional ambition-enhancing coordinated measures or mechanisms.

That failure to achieve the collective goal is due to the supposed general tendency for a country to choose the allocation approach that offers the higher emission allowance from various options that are consistent with the collective goal. Suppose each country selects the lower ambition approach consistent with 2 °C, then the sum of all individual actions is not going to be consistent with 2 °C (Fig. 3a). One solution could be that countries enhance their collective nominal target (for example, from 2 to 1.5 °C) to offset the effect of self-differentiation—so that the original collective target (2 °C) is still met (Fig. 3b).

However, self-interest manifests itself not necessarily in the 'absolute gains or losses' of a country—that is, what a country's absolute emission allocations are. Rather, the 'relative gains or losses'[47] towards main trading partners or political rivals seem often a better proxy for whether a country enters an international agreement (see, for example, ref. 48). From this viewpoint, it would be less important how strict emission targets are in absolute terms. As long as the target is considered comparable or fair relative to those of its main trading partners, a country might be inclined to partake in the international agreement.

Diversity-aware leadership

Leadership is 'a critical determinant of success or failure in the processes of institutional bargaining', Young argues[49]. We propose here a method that provides the freedom of self-selecting an allocation approach while keeping the collective target, and honours the inclination of most countries to secure 'relative gains' (or avoid 'relative losses'), for example, towards major trading partners.

Table 2 | Analysis of INDCs of selected countries.

Country	INDC			Evaluation of INDC				Leadership benchmark		Gap	
	Announced INDC			Resulting world emissions rel. 2010 (%) if other countries do comparable effort and understand 'fair' to be:				INDC consistent with 2 °C waypoint as 'diversity-aware leader'		Difference between INDC and leadership benchmark	
	Country target rel. ref. year (%)	Ref. year	Country target rel. 2010 (%)	CDC	ECPC50	Least ambitious of the two	Global 2 °C waypoint rel. 2010 (%)	Country target rel. ref. year (%)	Country target rel. 2010 (%)	$GtCO_2eq$ per yr in 2025 or 2030	$billion per yr at $10 per tCO_2eq (illustrative)[$]
Target year 2025											
USA	−26 to −28	2005	−22 to −24	−7 to −9	6 to 4	6 to 5	−15	−54	−52	1.7–1.8	17–18
Switzerland	−35	1990	−37	−25	−43	−19	−15	−29	−31	-	-
Target year 2030											
EU28	−40	1990	−27	−10	−4	−1	−22	−67	−61	1.5	15
(China)**	(35)**	2010	(35)**	33	12	33	−22	−32	−32	7.6	76
Mexico***	−22 to −36	2030*	15 to −6	N/A to −20	N/A to −69	N/A to −20	−22	−39	−10	0.16–0.03	1.6–0.3
Russia	−25 to −30	1990	56 to 46	73 to 64	88 to 79	89 to 80	−22	−88	−76	1.8–1.9	18–19
Switzerland	−50	1990	−52	−38	−62	−28	−22	−42	−44	-	-
Norway	−40	1990	−13	−22	−14	−9	−22	−61	−42	0.01	0.1

*Mexico's 2030 baseline assumed as 973 $MtCO_2eq$ GHG emissions in 2030 as per Mexican INDC submission, compared to 2010 emissions of an estimated 662 $MtCO_2eq$ (own PRIMAP default data). **In a joint announcement with the US, China pledged a peaking of its CO_2 emissions by 2030 or earlier and confirmed that pledge in its INDC on 30 June 2015 and added an intended 60 to 65% emission intensity improvement. We illustrate the Chinese pledge of peaking CO_2 emissions by 2030 with a 35% increase of GHG emissions above 2010 levels (Supplementary Information). ***Our reference scenario emissions are only 13% above 2010 levels for Mexico. Thus, we cannot reliably estimate world emissions corresponding to a 15% increase above 2010 emissions. See Supplementary Fig. 20 on Mexico. [$]These monetary amounts are purely illustrative. The effective conversion rate between emissions and financial support depends on multiple explicit or implicit factors and could legitimately cover a wide range, in which we do not even suggest the illustrative US$10 per tCO_2eq to be a middle value. Furthermore, the economic capability of countries is not taken into account here.

The central pillar of this approach is that one of the countries assumes a leadership role. Specifically, we investigate the situation in which such a benchmark country (or country group) adopts an ambitious 2025 or 2030 target. Other countries, the followers, then adopt 'comparatively' ambitious targets in accordance with their preferred allocation approach that, in line with their self-interest, is assumed to imply the weakest reduction target. We call this approach 'diversity-aware leadership' as it asks the leading country to set its own target commensurate with the collective goal and in awareness of what other countries consider to be a fair allocation approach (Fig. 3c and mathematical description and categorization into common leadership theories in Supplementary Section 1).

Results

Given that major economic powers choose other major economic powers as point of comparison for measuring relative gains and losses[47], we screen all G20 countries as potential leadership countries. In our illustrative default case we assume the diversity-aware leadership approach, with other countries following the leadership country by selecting the approach which is most favourable to them in terms of emissions allocations, either CDC or ECPC50 (see Supplementary Information for full results). Almost half of current, estimated 2014 global GHG emissions (incl. land use) arise from the three biggest emitters China (26%), the USA (11%) and EU28 (8%) (Supplementary Section 6). These actors are hence pivotal for any post-2020 agreement.

For the EU28 as a group, in a world where all countries would agree to follow the CDC approach, global emissions would be brought back towards our 2 °C-consistent waypoint of 1990 emissions levels by 2030 with the EU28 setting a 2030 target of 51% below 1990 (41% below 2010). With the world uniformly following the ECPC50 allocation approach, the EU28 emissions target by 2030 would need to be 58% below 1990 (49% below 2010). For diversity-aware leadership (illustrative default), when each country follows the EU28's leadership, the EU28's benchmark target would need to be at 67% below its 1990 emissions levels (61% below 2010 levels) (Table 1 and Supplementary Table 29).

For China to assume 'diversity-aware leadership', its emissions target would have to be 32% below 2010 levels by 2030. The emissions reduction targets computed with the 'diversity-aware leadership' and CDC approaches are within rounding, as the CDC approach would favour almost all countries if China would be considered the benchmark country. That is because China is a country with relatively high current and projected per-capita emissions (similar to EU28 in 2014), but a history of low per-capita emissions. If all countries follow our illustration (ECPC50) of the Chinese proposal of equalized cumulative per-capita emissions, we estimate that China would only need to reduce emissions by 4% below 2010, as other countries would do comparatively more. In that latter case, Chinese per-capita emissions allocations would be substantially higher than those of industrialized countries in the future.

The USA were the first country to indicate potential 2025 and 2030 targets in its Copenhagen submission[33] (30% and 42% below 2005, respectively). Our analysis suggests that, under a universal CDC approach, those targets would have come close to putting the world on a 2 °C track. Yet, to be a diversity-aware leader in climate change mitigation, the USA would have to strengthen their target to 54% (Supplementary Table 9) for 2025 or 76% for 2030 (Supplementary Table 8) relative to 2005.

In addition to China, USA and EU28, medium-sized countries that could exert diversity-aware leadership include Australia (63% below 2000 by 2030), Japan (64% below 2005), South Korea (60%

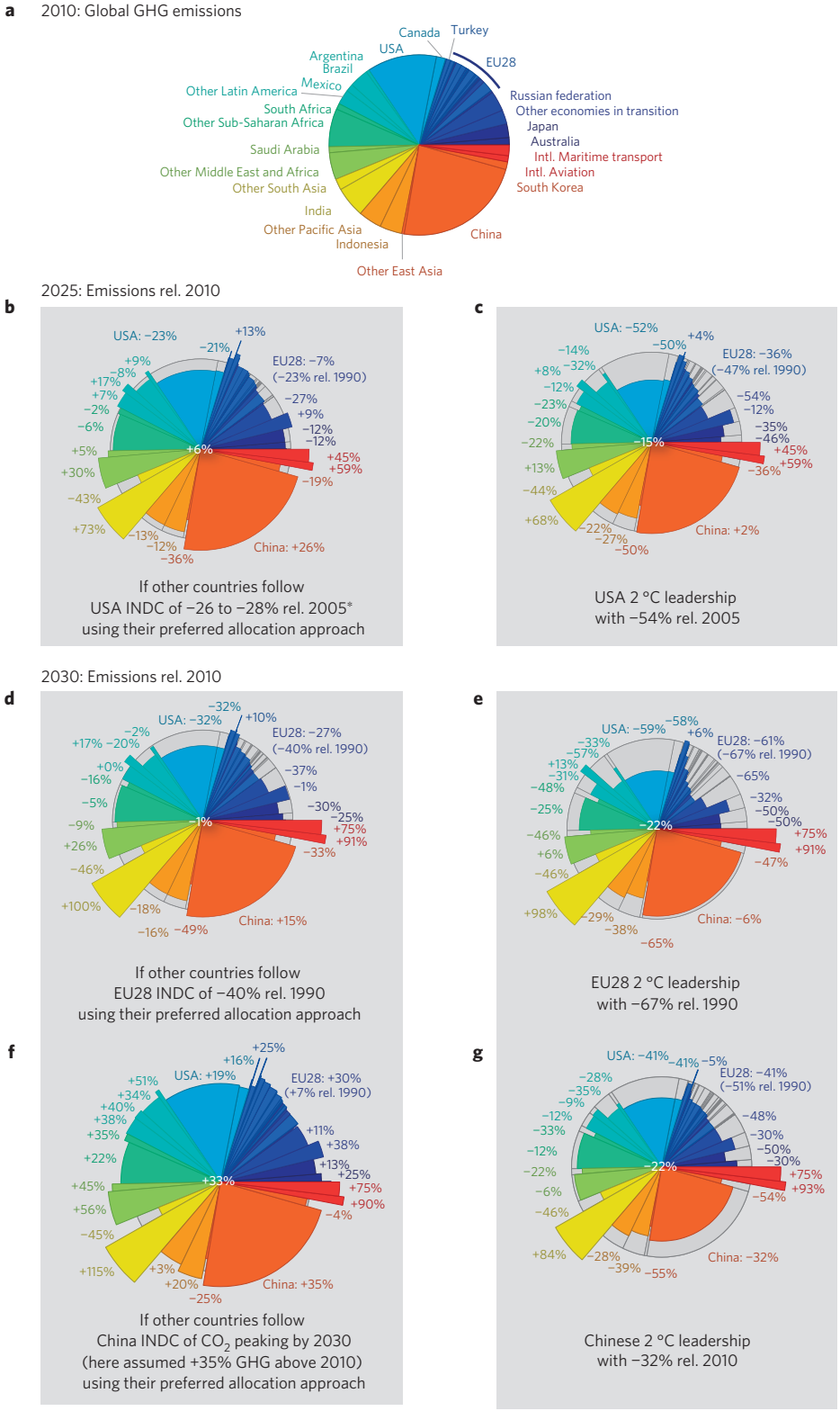

Figure 4 | Global GHG emissions in 2010 and allocations with respect to 2010 for 2025, if countries follow either USA, EU or China as potential leadership countries. a, Global 2010 GHG emissions shares by individual G20 countries or the respective remainders of IPCC's ten world regions (each region with their distinct colour). **b**, 2025 GHG emissions allocations with respect to 2010 if countries follow the USA INDC announcement (here shown for an intermediate 27% reduction below 2005 by 2025). **c**, 2025 GHG emissions allocations, if USA assumes a 'leadership' 2 °C compatible target of −54% by 2025. **d**, 2030 GHG emissions with respect to 2010 if countries follow 'comparable' reductions to the EU28 target of 40% below 1990 levels. **e**, Same as **d**, in the case that the EU28 assumes a target of 67% below 1990, so that global GHG emissions are returning back to 1990 levels (22% below 2010). **f**, Same as **d**, if countries follow a potential Chinese increase of GHG emissions by 35% until 2030 with comparable targets, resulting in 33% higher global emissions by 2030 compared to 2010 levels. **g**, Same as **e**, but countries follow a 2 °C compatible leadership target of −32% by China. World emissions changes with respect to 2010 are provided at the centre of the circles for **b** to **g**.

below 2010), Mexico (10% below 2010), Brazil (59% below 2010), Canada (73% below 2005), Germany (79% below 1990), or Russia (88% below 1990), while India could exert such leadership even with a growth target (80% above 2010 by 2030) owing to its low historical and current per-capita emissions (Table 1 and Supplementary Information). Furthermore, as our sensitivity case we calculate a diversity-aware leadership approach where follower countries can choose from three allocation approaches: CDC, ECPC50 and the Greenhouse Development Rights (GDR) approach (Table 1 and Supplementary Section 6.4).

Analysing INDCs

As of 15 August 2015, 56 countries had presented their INDCs. We briefly analyse a selection of those that submitted before 1 April 2015, as well as China.

The EU's INDC is a 40% domestic emissions reduction below 1990 levels, which equals 27% below 2010 levels (Table 2). We calculate comparable targets for other countries assuming that this domestic EU28 emissions reduction target is not augmented by additional international mitigation contributions, financial or otherwise. Assuming a universal CDC allocation approach, the EU28 INDC would be comparable to a −17% target for Chinese GHG emissions allocations, or −32% for the USA in 2030 with respect to 2010 (Supplementary Table 30). In this case, global emissions by 2030 would be 10% below 2010 levels, which falls 12% short of our illustrative 2 °C waypoint of 22% (Table 2). Another study[7] reports similar results for the USA (−34%), but less stringent targets for China (0%)—mainly because the other study used 2020 Copenhagen pledges as a starting point rather than the 2013 emissions levels as in this study. If China chooses an equalized cumulative per-capita approach as a measure of comparison (our illustrative ECPC50 implementation), the 'EU-40%-comparable' Chinese 2030 emissions target would be 16% above 2010 emissions levels. For the USA, the ECPC50 approach would indicate that a target of 46% below 2010 levels would be comparable to the EU28's 40% target.

China submitted an INDC on 30 June 2015. The central element in this INDC is to peak fossil CO_2 emissions by 2030 or earlier, reconfirming an earlier US–China Joint Announcement[50]. Although inherently uncertain, we quantify this pledge as a possible 35% increase of Chinese GHG emissions until 2030 with respect to 2010 (Supplementary Section 3.2), which is on the lower side or comparable to other assessments[51–53]. There is a substantial gap between Chinese emissions implied by its INDC by 2030 and any 2 °C-compliant Chinese emissions level for China as a follower to other leadership countries—and even more so, if China wanted to assume a leadership position. This percentage gap is larger than those related to the INDCs of EU28 and USA. Recently, however, there are signs that China's coal demand—and therewith coal-related emissions—might be already decreasing[54].

Russia proposed an increase of emissions from about 33% below 1990 levels at present (2012) up to just 25 to 30% below 1990 by 2030. This INDC stands out as incommensurate with any potential leadership—or even a follower role within a regime that attempts to limit warming to below 2 °C. Russia announced that it would fully account for forestry sinks, which would further weaken the effective target. As an aside, Kyoto Protocol rules would require Russia to limit its emissions to current (2008–2010) levels, which are already 34% below 1990.

Switzerland submitted a 50% reduction by 2030 compared to 1990 levels as its INDC, which—in our default leadership case—makes it the only country that submitted its INDC before 1 April and qualifies as a 'diversity-aware leader' (benchmark: 42% below 1990 by 2030). However, in our sensitivity case in which we include the GDR approach as an option for follower countries, only a Swiss target of 126% below 1990 levels would qualify as leadership. This is because Switzerland is one of the richest countries in the world, and 'capability' is one of the indicators for differentiation within the GDR approach (Table 1 and Supplementary Table 8). Similarly, when including the GDR approach, Norway could only attain leadership with a 146% reduction below 1990 levels in 2030. With its constant emissions pledge between 2020 and 2030 of a 40% reduction below 1990 levels, Norway also misses the benchmark (−61%) of our default leadership definition (allowing for CDC and ECPC50, Supplementary Table 8).

Any financial pledges by the US, the EU and/or China to enable mitigation elsewhere (for example, as part of their contribution to the Green Climate Fund) would have to be added on top of any domestic mitigation pledges when assessing whether the overall contributions amount to 'leadership'. In other words, either via enhanced domestic mitigation or financial support, the USA, the EU28 or China could bridge the gap between current INDCs and the leadership benchmarks. Assuming a purely illustrative (and low) conversion rate between not-mitigated tons of emissions and foreign financial support of US\$10/tCO_2eq, this gap amounts to US\$76 billion per year in the case of China and US\$17–18 and US\$15 billion for the USA and EU28, respectively (Table 2).

Discussion and conclusion

For any country that claims a leadership position in tackling climate change, taking into account the diverse views on equity implies a substantial challenge. The domestic 2030 reduction targets of both the EU28 and the US would have to be more than doubled (61% versus 27% below 2010 by 2030, and 52% versus 22–24% below 2010 by 2025, respectively). This ambition enhancement could either happen via additional international mitigation support, additional domestic mitigation or other means (Fig. 4 and Table 2).

Given their economic power, per-capita emissions levels and global emissions share, the USA, China and the EU28 might well be considered benchmark countries by much of the rest of the world. Based on the first submitted INDCs, however, 'following' countries could replicate and reinforce insufficient ambition levels for 2025 and 2030. In fact, current INDCs of the USA or the EU28, if taken as leadership by example, would cause the world to miss the 2 °C-consistent benchmark of returning 2030 emissions to 1990 levels (that is, −22% below 2010, Table 2) by a wide margin. An agreement on emissions reductions until 2025 or 2030 cannot be the final step in our endeavour of keeping warming to below 2 °C. Avoiding the climate impacts beyond 1.5 °C and 2 °C hence hinges on the international community's capability to increase the ambition of 2025 and 2030 targets and to demonstrate how any remaining lack of ambition up to 2030 can be compensated by additional action thereafter. The position of a country exerting diversity-aware leadership to catalyse the transition to more adequate ambitions of mitigation targets seems vacant at the moment on the international stage.

Methods

Methods and any associated references are available in the online version of the paper.

Received 10 September 2014; accepted 14 September 2015; published online 26 October 2015

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Acknowledgements

We acknowledge the work by IAM modellers that contributed to the IPCC AR5 scenario database and IIASA for hosting the IPCC AR5 Scenario Database. M. Meinshausen is the recipient of an Australian Research Council (ARC) Future Fellowship (grant number FT130100809). Furthermore, we offer thanks for discussions and comments on an earlier version of this manuscript by P. Christoff, R. Eckersley, K. Dooley and R. Lethbridge, and general discussions with N. Wilke, C. Zerger and L. Morgenstern.

Author contributions

All authors contributed to interpreting the results and writing the manuscript. M.M. designed the study and performed the calculations. Y.R.d.P. assisted in data management. N.M. provided the quantile regression method. J.R. compared the 2025 and 2030 waypoints to the UNEP GAP Report estimates. L.J. programmed the GDR allocation approach and J.G. downscaled RCP emissions scenarios using SSP data to the national level for the RCPs. L.J. and J.G. contributed the composite PRIMAP4 data (Supplementary Information). M.d.E. and N.H. compiled the allocation database used in IPCC. M.S. complemented the IPCC AR5 scenario database emissions pathways with missing gases.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to M.M.

Competing financial interests

The authors declare no competing financial interests.

Methods

We employ two IPCC databases. The first database is the IPCC AR5 Scenario Database available at https://secure.iiasa.ac.at/web-apps/ene/AR5DB. We used a total of 807 harmonized scenarios (shown in Fig. 1) after following the same historical harmonization procedures as in the RCP process[55]. These scenarios form the basis for the IPCC WG3 assessment in Table SPM.1 (ref. 56).

The second IPCC database concerns allocation approaches, named here 'IPCC Allocation Database', and is described and made available by ref. 11. This database comprises data from a total of 36 publications that examine 52 different regimes, from multi-stage, per-capita convergence to GDR, categorized for IPCC WG3 in six regime categories, namely 'Responsibility', 'Capability', 'Equality', 'Responsibility, Capability, Need', 'Equal Cumulative Per-Capita Emissions', and 'Staged' approaches[11,12]. In addition, the IPCC Allocation Database summarizes studies that examine the 'Equal Marginal Abatement Costs' (from IPCC Scenario Database) and show no-climate policy 'Baselines'. Information from original publications was used to categorize scenarios in five stabilization groups: 'Cat. 0 (400 ppm)', 'Cat. 1 (450 ppm)', 'Cat. 2 (500 ppm)', 'Cat. 3 (550 ppm)', 'Cat. 4 (650 ppm)'. We here re-categorize scenarios by using the gradual scale of cumulative global GHG emissions between 2012 and 2049 which characterizes a scenario's mitigation stringency. This gradual scale provides higher accuracy in determining the overall 2 °C compliance of pathways, but implies that those literature studies that provide emissions only up to 2030 (for example, ref. 57) are excluded. We harmonize all IPCC Allocation Database scenarios towards 2010 GHG regional emissions levels at the level of ten RCP regions provided in the underlying database of ref. 11, with a scaling factor converging linearly to unity in 2050—as was applied in the RCP scenario construction process[55]. The net effect on individual regions' 2010 to 2030 reduction rates is rather small (with the 20 to 80% range between 2.2% less to 0.6% more ambitious reductions across 9,637 harmonized regional time series) compared to a constant scaling factor (Supplementary Information).

First, we complement the IPCC Allocation Database. Single data points for 'cumulative 2012–2049 GHG emissions' (x-axis in Fig. 2e,f) versus 'regional reductions' (y-axis) are extrapolated for each of the ten RCP regions across lower and higher cumulative GHG emissions levels. This extrapolation uses 100 randomly sampled $\Delta y/\Delta x$-slopes from the studies that investigated multiple stabilization groups. Studies that assign the same regional reduction targets for pathways of different stringency were excluded. Second, we now calculate country-by-country level allocation approaches with the PRIMAP model[58], representing four equity allocation approaches (Supplementary Information), and check them against the literature range (Fig. 2e,f).

To derive 'comparable' emissions allocations of a country/region 'A' to the 2025 or 2030 emissions reduction target of a country/region 'B' given a specific 'pure' allocation approach, we proceed as follows (mathematical description in Supplementary Information and graphical depiction in Fig. 3). First, we look up the global cumulative emissions level over 2012–2049 (x-axis in Fig. 2e,f) that corresponds to the prescribed emissions allocations for country or region B (y-axis in Fig. 2e,f)—based on the mean (bold lines) across all extra- or interpolated literature-based datapoints that belong to a specific allocation approach. Using that global cumulative emissions level, we can then use a 'reverse' approach to look up the corresponding reduction target for country A and all other countries, using again the mean of the implementations of a specific allocation target. For calculating the 'diversity-aware leadership' set of country-specific reductions, we operate analogously, only that we calculate corresponding reductions in other countries for the two considered allocation approaches CDC and ECPC50 separately and choose the less ambitious of the resulting emissions reduction target for each potential leadership country or remainder region (Fig. 4). We had sufficient data to calculate our country-specific allocation approaches for most ($n=176$) UNFCCC countries and calculated allocation approaches individually by country before aggregating them to the 'remainder' regions in the case they are not part of the highlighted countries (in which case we do not aggregate). The EU28 were treated separately, however. All calculations in regard to allocation approaches are based on the GHG basket (incl. land use) of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6—aggregated using IPCC AR4 100-year GWPs.

Our quantile regressions on 2025 and 2030 scenario data versus cumulative CO_2 emissions shown in Fig. 1b,c use a local linear quantile regression[59] with a uniform kernel and a bandwidth of plus/minus 1,000 $GtCO_2$.

An interactive data appendix is available at http://www.mitigation-contributions.org.

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