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Sharing a quota on cumulative carbon emissions

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Any limit on future global warming is associated with a quota on cumulative global CO_2 emissions. We translate this global carbon quota to regional and national scales, on a spectrum of sharing principles that extends from continuation of the present distribution of emissions to an equal per-capita distribution of cumulative emissions. A blend of these endpoints emerges as the most viable option. For a carbon quota consistent with a 2 °C warming limit (relative to pre-industrial levels), the necessary long-term mitigation rates are very challenging (typically over 5% per year), both because of strong limits on future emissions from the global carbon quota and also the likely short-term persistence in emissions growth in many regions.

Climate modelling studies[1–6] have established a robust near-linear relationship between global warming and cumulative CO_2 emissions since industrialization. This implies that a 'carbon quota' or cap on future cumulative CO_2 emissions is required if global warming is to be kept below any nominated limit (such as 2 °C above pre-industrial temperatures[7]) with a nominated chance of success[8–10]. Estimated carbon quotas are significantly smaller than the known global fossil-fuel reserves[2,11,12].

The carbon quota implies that future cumulative CO_2 emissions consistent with a given warming limit are a finite common global resource that must necessarily be shared among countries, whether through prior agreement or as an emergent property of individually determined national efforts. The problem of sharing the global mitigation effort is addressed in an extensive literature, from the perspectives of equity, international policy and institutions, and economics and financing[13–22]. Here, we combine perspectives from two previously distinct strands of analysis — the global carbon quota and effort sharing — to infer the regional and national implications of global carbon quotas under a wide range of possible sharing strategies.

The need for multiple approaches is heightened by the present impasse in the search for long-term climate safety. Two broad approaches have been pursued hitherto in international negotiations: 'top-down' international agreements, such as the 1997 Kyoto Protocol[23], and 'bottom-up' nationally determined contributions to a global outcome. The top-down approach has made little progress over the last two decades[24]. An approach based on nationally determined contributions is now being explored[25], but current commitments in sum are far short of what is needed to meet internationally agreed climate goals[26–29].

The present impasse arises in part because the sharing challenge forms a 'tragedy of the commons'[30] or collective-action dilemma[31]. The challenge of governing common natural resources has developed a rich literature encompassing issues of governance, institutions, communities and ethics[32–34]. In broad terms, this literature suggests that solutions to the underlying problem of collective action can emerge from individual actions by participants (here, countries), given adequate social capital[35] to support a framework for adaptive governance[33]. When the sharing challenge is framed in this way, the emphasis shifts away from questions about global rules ("What shares of the carbon quota should be allocated to every country?") to questions about consistent local behaviours ("If others acted consistently with our proposed share of the carbon quota, would the global outcome be acceptable to us?"). This view further motivates a direct connection between the global carbon quota and effort-sharing analyses, to explore frameworks that can infer the global implications of a proposed share of the carbon quota by any one country, were others to act on similar principles.

To establish principles, we focus on the sharing of fossil-fuel CO_2 emissions, the largest single contributor to radiative forcing and climate change[36]. Emissions of CO_2 from land-use change are now a relatively small fraction of total CO_2 emissions (8 ± 3%)[37], declining with time, and subject to significant uncertainty at the global scale and even more at regional scales[37,38]. Inclusion of CO_2 emissions from land-use change is straightforward in principle, though data uncertainties would require careful assessment. In the absence of historic attribution, the effects would be small for most regions, but large for tropical forest countries where land clearing is still ongoing. More significant at the global scale is the role of non-CO_2 forcing agents, both those accounted (the major non-CO_2 greenhouse gases) and unaccounted (aerosols) in inventories. However, full inclusion of these forcing agents in extensions to carbon quotas at regional and national scales is beyond the present scope, requiring more complex climate modelling to resolve issues such as local impacts of short-lived climate forcers[39,40], nonlinear force–response relationships[41] and cooling by some aerosol species[36].

Ways of sharing a cumulative emissions quota

A common-pool resource can be shared objectively among participants in a social–ecological system by distributing the resource according to a set of observable metrics. In the case of the carbon quota, two generic metrics are measures of 'inertia' (also known as 'grandfathering'[22]) and 'equity', the inertia metric reflecting

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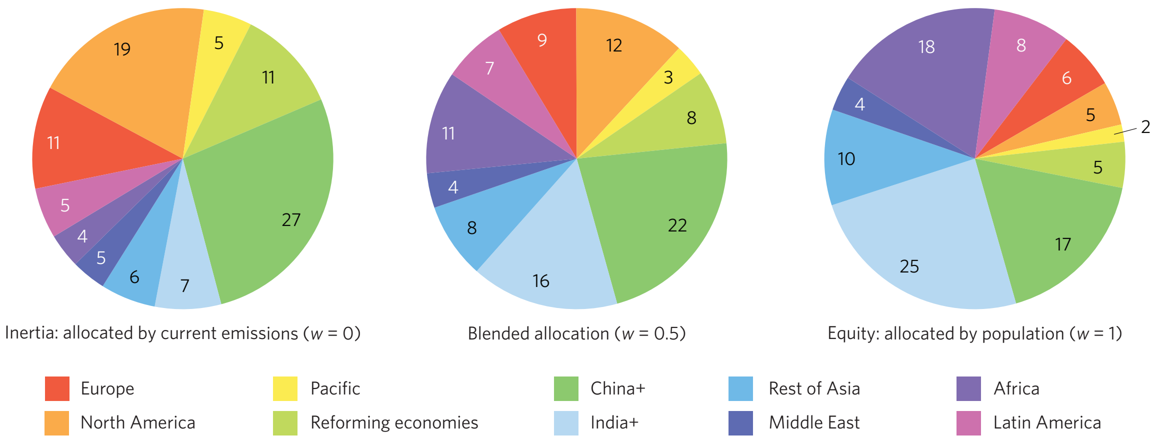

Figure 1 | Sharing the carbon-quota pie. The share of an available carbon quota allocated to 10 regions (Europe, North America, Pacific Organisation for Economic Co-operation and Development countries, reforming economies, China+, India+, Rest of Asia, Middle East, Africa, Latin America) under three sharing principles based on equation (2), with sharing index $w = 0$, 0.5 and 1. Numbers give the percentage share of the global quota allocated to each region, summing to 100 for each chart. Shares are calculated using equation (2) with emissions (f_j) averaged over last five years of data, and population (p_j) averaged over a five-year period centred on the time at which world population reaches nine billion. See Supplementary Text 1 for details.

the distribution of emissions and the equity metric reflecting the population distribution. These metrics would suggest two alternative sharing principles:

$$s_j\,(\text{emissions}) = \frac{f_j}{F}\,;\ s_j\,(\text{population}) = \frac{p_j}{P} \qquad (1)$$

where s_j is the share of the quota to country j; f_j and p_j are the emissions (current or cumulative) and population (present or future), respectively, for country j; and F and P are the corresponding emissions and population for the world. Shares sum to one over all countries ($\Sigma s_j = 1$) because $\Sigma f_j = F$ and $\Sigma p_j = P$. Depending on the choice of reference times for emissions and population, this formulation can accommodate sharing by current or historic emissions, and can account for expected future changes in population.

In their simplest forms, both options in equation (1) face major difficulties. Sharing by present emissions (inertia) would leave developing countries with little access to the energy and development opportunities embodied in remaining future carbon emissions, whereas sharing by population (equity) would impose extremely high mitigation demands on many developed countries. This has motivated the analysis of 'blended' sharing principles[16–18] that can compromise between the endpoint positions. One possibility (among others explored below) is that the share of the quota to country j is:

$$s_j(w) = (1 - w)\,\frac{f_j}{F} + w\,\frac{p_j}{P} \qquad (2)$$

where w is a 'sharing index' between 0 and 1, weighting between the endpoints of sharing by inertia ($w = 0$) and by equity ($w = 1$). This principle also satisfies the requirement $\Sigma s_j = 1$. It can be regarded as a simplified form of the contraction-and-convergence algorithm[16–18], applied to a total carbon quota rather than to emissions trajectories specified through time; the key simplification is independence from specific assumptions about emissions pathways through time.

Using equation (2), Fig. 1 shows how w influences the share of a global carbon quota assigned to 10 regions that span the world (Europe, North America, Pacific Organisation for Economic Co-operation and Development countries, reforming economies, Middle East, China+, India+, Rest of Asia, Africa, Latin America; Supplementary Text 1). The last four regions receive a greater share with increasing weighting of equity (increasing w), while the share for the other six regions decreases. This occurs because the response to increasing w of the share s_j for a region j hinges on whether its per-capita emissions (f_j/p_j) are less or greater than the global average per-capita emissions (F/P) (Supplementary Text 2); the last four regions have below-global-average per-capita emissions (Supplementary Fig. 1).

The concept of a blended sharing principle can potentially be generalized to include additional metrics of responsibility and/or capability[19,21] — for example, the distribution of gross domestic product (GDP) as a measure of capability to undertake mitigation efforts (Supplementary Text 2). The influences of emissions and GDP on sharing are broadly similar because both are correlated with development status, and both are very different to the influence of population (Supplementary Fig. 1). Therefore, we focus mainly on emissions and population using equation (2), and briefly explore later the effect of also including GDP in the sharing principle. We also note that allocated shares and quotas are not the same as actual future cumulative emissions if emissions are tradable between countries, as discussed later.

Regional carbon quotas

The global carbon quota from the past to the long-term future (when emissions fall to zero) is:

$$Q_{tot} = Q_{past}(\text{FFI}) + Q_{past}(\text{LUC}) + Q_{future}(\text{FFI}) + Q_{future}(\text{LUC}) \quad (3)$$

where Q_{tot} is the quota for anthropogenic CO_2 emissions from a reference time (here 1870) to the far future, including contributions from fossil-fuel combustion and industrial processes (FFI) and net land-use change (LUC); Q_{past} is the past emissions and Q_{future} is the shared available future emissions. Past cumulative CO_2 emissions from 1870 to the end of 2012 were 1,922 Gt CO_2 (1,396 Gt CO_2 from FFI and 526 Gt CO_2 from LUC)[37]. Global LUC emissions have decreased since 2000 to 8 ± 3% of total emissions in 2013[37] and are expected to continue to decrease; a linear decrease to zero in 2100 would imply $Q_{future}(\text{LUC}) = 137$ Gt CO_2.

Estimation of the global carbon quota Q_{tot} is an ongoing scientific issue. The estimates used here[10] are $Q_{tot} = 3{,}500$, 4,400 and 5,300 Gt CO_2 for warming limits of 2, 2.5 and 3 °C, respectively, with 50% chance of success and accounting for both CO_2 and non-CO_2 forcings (all quota estimates are rounded to nearest 100 Gt CO_2). These are larger (more conservative) quotas than estimated elsewhere[8].

We consider sharing of the available quota of future fossil-fuel emissions $Q_{future}(\text{FFI})$ from equation (3), henceforth Q_{avail}. The above estimates for Q_{tot} imply that $Q_{avail} = 1{,}400$, 2,300 and 3,200 Gt CO_2, for warming limits of 2, 2.5 and 3 °C at 50% chance of success.

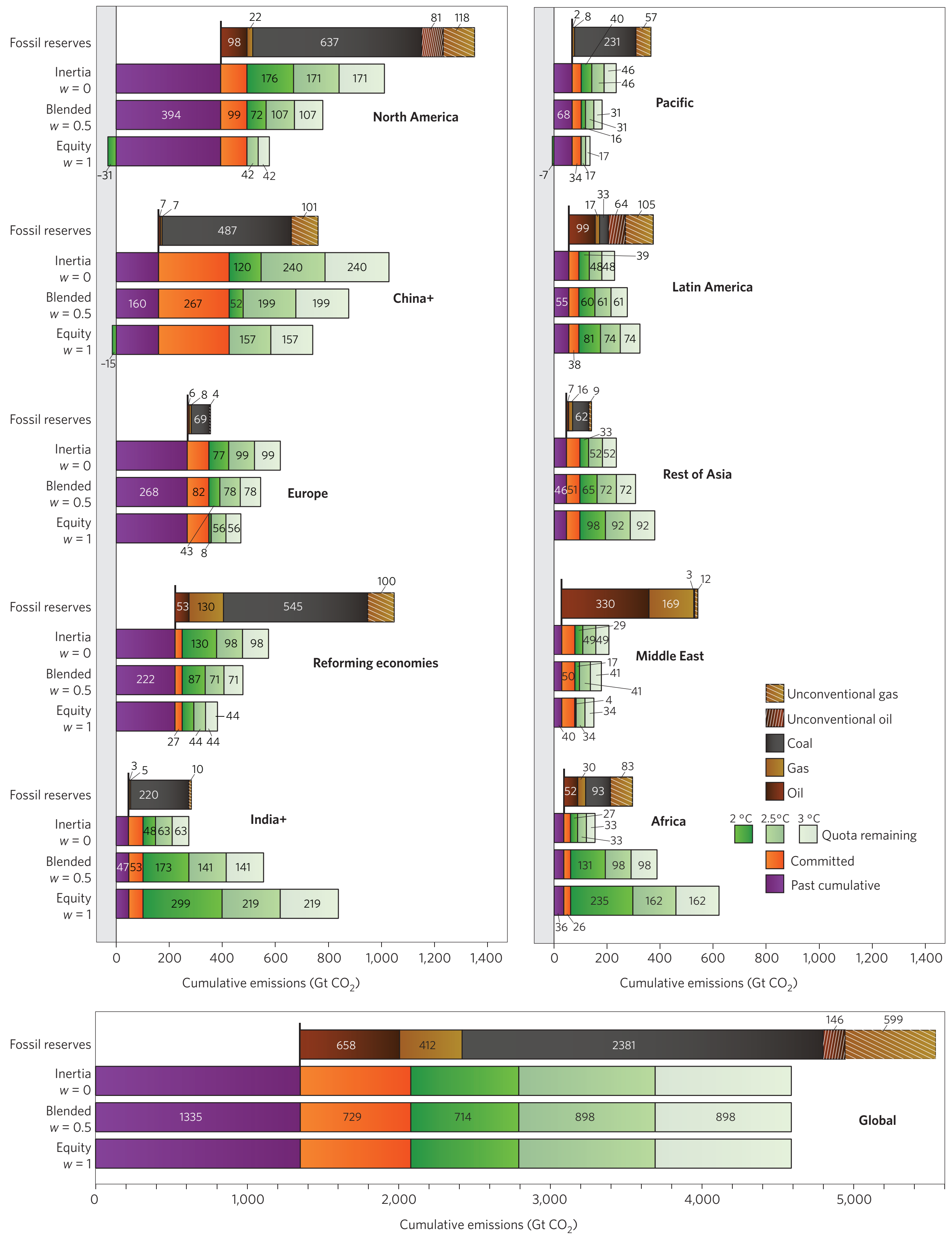

Figure 2 | Quotas, cumulative committed emissions and fossil-fuel reserves. Past cumulative fossil-fuel CO_2 emissions (purple), future committed emissions[42,43] (orange) and available fossil-fuel carbon quotas to meet warming limits of 2, 2.5 and 3 °C with 50% probability (green), for 10 regions and the world, under inertia, blended and equity sharing principles. Stacked bars are cumulative; numbers give the contribution of each increment in Gt CO_2. Negative increments are shown below the zero axis. Also shown are fossil-fuel reserves (coal, oil, gas, unconventional oil, unconventional gas)[12].

The available carbon quota for country j is a share $s_j Q_{avail}$ of the global quota. Figure 2 shows the resulting quotas for 10 regions (Fig. 1) and for the world, with shares s_j from equation (2) for three values of w (0, 0.5 and 1, corresponding to inertia-based, blended and equity-based sharing, respectively), and with available quotas Q_{avail} corresponding to warming limits of 2, 2.5 and 3 °C at 50% chance of success. Global quotas are independent of w, but the regional quotas depend strongly on w, with increasing w causing the quotas to increase for regions with low per-capita emissions, and vice versa (Supplementary Text 2).

The regional quotas can be assessed against two independently determined quantities. First, committed emissions (orange bars in Fig. 2) are estimates of future emissions from existing CO_2-emitting infrastructure that will continue for infrastructure lifetimes without early retirement[42–44] (Supplementary Text 1). Committed emissions in North America, Europe and China exceed quotas for a 2 °C warming limit under equity sharing (w = 1), implying a requirement to either retire or improve such infrastructure before its design lifetime, or to compensate these emissions by negative emissions later in the century or by some form of offset such as emissions trading (see below). For the world, committed emissions are about half of the available quota Q_{avail} for a 2 °C warming limit.

Second, quotas can be compared with fossil-fuel reserves of coal, oil, gas, unconventional oil and unconventional gas (Fig. 2). Reserves are the part of total resources currently identified as economically viable for extraction. Globally and in most regions, estimated reserves[12] substantially exceed the global quota Q_{avail} for warming limits up to and beyond 3 °C, in agreement with other assessments[2,11]. Estimates of total fossil-fuel resources are even larger.

The distribution of the mitigation challenge

A simple measure of the challenge implied by the available quota for any region or country (before any possible redistribution by emissions trading) is the time for which the quota would last if emissions were held steady at current levels until the quota is exhausted, $T_j = s_j Q_{avail}/f_j$. This 'emission time'[10] depends strongly on the sharing index w (Supplementary Fig. 2). With pure emission-based sharing (w = 0), the emission time for all countries is the same and equals the global emission time Q_{avail}/F. As w increases to yield pure population-based sharing at w = 1, the emission time increases (decreases) for regions with per-capita emissions less (greater) than the global average. The response of emission times to w is the same as, and is determined by, the response of shares (s_j) to w (Supplementary Text 2).

If emissions were to decrease at a steady exponential rate starting immediately, an emission time T would correspond to a decrease in emissions at a fractional rate $1/T$ (or $100/T$ per cent per year). However, this estimate of a required reduction rate to meet a given quota is too low if the mitigation effort must first overcome existing emissions growth, because of persistence effects. Persistence in emissions growth arises from the time needed to implement new low-emission energy technologies on the energy supply side, and to adopt energy-efficiency measures and make behavioural changes in energy consumption on the demand side. Persistence is evident in emissions data (Supplementary Fig. 3). The supply-side aspects of this persistence arise mainly from the committed emissions in existing, long-lived energy infrastructure[42,43] (Fig. 2).

We account for persistence in emissions growth by representing the future emissions of a country, region or the world with an analytic capped-emissions trajectory that blends an initially linear growth at rate r with eventual exponential decline at a mitigation rate m. Continuity requirements determine this trajectory uniquely (Supplementary Text 3):

$$f(t) = f_0\left(1 + \left(r + m\right)t\right)\exp\left(-mt\right) \quad (4)$$

where $f(t)$ is the emissions at time t, f_0 is the emissions at the start of mitigation (t = 0), and r and m both have units of per year. When mitigation is started at t = 0 (with a positive initial growth rate r), the resulting emissions trajectory increases, peaks and eventually declines exponentially at the rate m (Supplementary Fig. 4). A possible delay in starting mitigation can also be included (Supplementary Text 3). By incorporating such a delay, equation (4) can provide a good representation of the trajectories of CO_2 emissions from fossil fuels in the four representative concentration pathway scenarios[45] before any introduction of negative emissions (Supplementary Fig. 5). This indicates that equation (4) is suitable for empirically describing persistence effects in emissions trajectories.

To meet a specified available cumulative emission quota, persistence in emissions growth causes the necessary eventual characteristic rate of decline in emissions (m) to be typically more than twice the rate $1/T$ that would be required if exponential decline could commence immediately (Supplementary Text 3, Supplementary equation (8)).

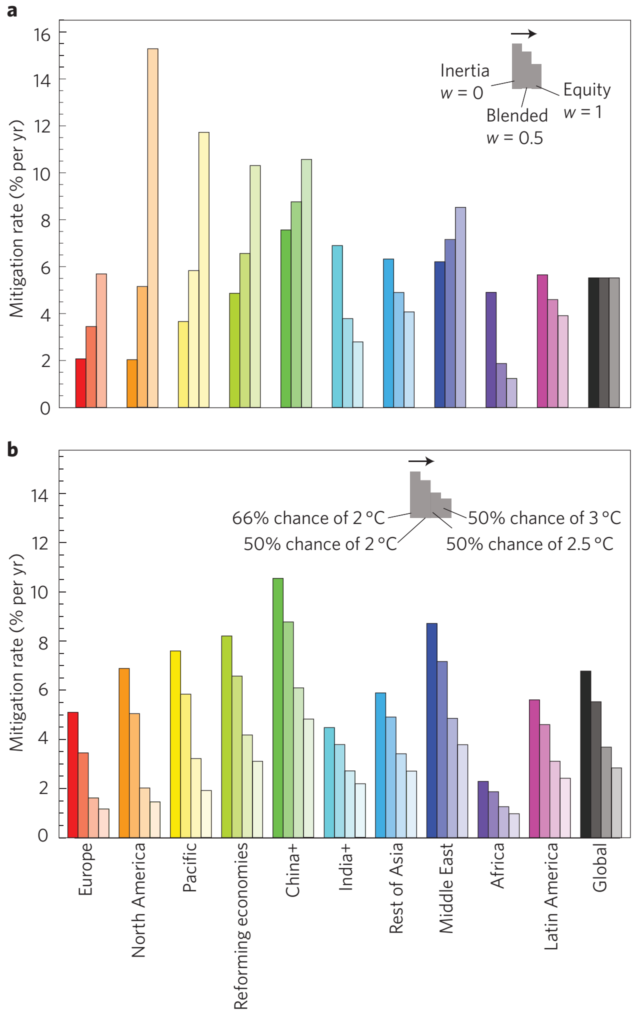

Figure 3 | Dependence of the regional mitigation challenge on the sharing index (w) and the warming limit. a, Mitigation rates for 10 regions and the world at w = 0, 0.5 and 1. Available global fossil-fuel combustion and industrial processes (FFI) carbon quota from 2013 is Q_{avail} = 1,400 Gt CO_2, corresponding to a 2 °C warming limit with 50% success probability. **b**, Mitigation rates under a blended sharing principle (w = 0.5) in four cases with warming limit and success probability, respectively, equal to 2 °C and 50%; 2.5 °C and 50%; 3 °C and 50%; and 2 °C and 66%. The available global FFI carbon quotas for these four cases are Q_{avail} = 1,400, 2,300, 3,200 and 1,100 Gt CO_2, respectively[10].

This occurs because the persistence in emissions growth in the early phase of the mitigation effort has to be compensated by more rapid later decline (larger m).

Figure 3a shows the mitigation rates m needed to meet an available carbon quota Q_{avail} = 1,400 Gt CO_2 (a 2 °C warming limit at 50% success probability), for the world and in 10 regions, with sharing index w = 0, 0.5 and 1. The required global mitigation rate to meet the quota is 5.5% per year (independent of sharing index) — more than twice the reduction rate $1/T$ if exponential decline could start immediately, because of persistence in emissions growth. This result is consistent with scenario-based analyses that account for policy delay[46,47].

With pure emissions-based sharing (w = 0), m varies little among regions (Fig. 3a); it is not identical across regions (in contrast with the emission time T; Supplementary Fig. 2) because of regional variations in the initial growth rate r. With pure population-based sharing (w = 1), m varies greatly among regions, from 1.4% per year (Africa) to over 15% per year (North America). With a blended sharing principle (w = 0.5), required mitigation rates are intermediate between the endpoint options w = 0 and w = 1, but very different in most cases from a simple average of the endpoints. For North America, the required mitigation rate at w = 0.5 is about 30% more than with emissions-based sharing (w = 0); for Africa, it is about 70% less. Therefore, a shift from an emissions-based to blended sharing principle leads to large benefits for developing regions at the cost of a much smaller increase in the demands on developed regions, as quantified by fractional changes in the required mitigation rates m.

Regional mitigation rates are also strongly sensitive to the global carbon quota, determined by the warming limit and probability of success. If the required probability of success for a 2 °C limit is increased from 50% (as in Fig. 3a) to 66%, then the required global mitigation rate m increases from 5.5 to 7% per year, with commensurate increases for regions and countries (Fig. 3b). For warming limits of 2.5 and 3 °C at 50% success probability, the required global mitigation rates fall to 3.7 and 2.9% per year, respectively, with commensurate decreases at regional and national levels. Even a 3 °C limit (with a much higher risk of dangerous climate change[48]) requires significant global and national mitigation.

To explore further the distribution of the mitigation challenge at national level, we focus on a set of 14 representative countries (Supplementary Text 1) that span the development spectrum in terms of both per-capita emissions and rates of development (Supplementary Fig. 6; a national-level counterpart of Fig. 2 is given in Supplementary Fig. 7). The required mitigation rates m for these countries, before any possible emissions trading, are plotted against present per-capita emissions in Fig. 4. Increasing equity (larger w) causes the mitigation challenge to respectively increase and decrease for countries with per-capita emissions above and below the world average, pivoting about that point. For least-developed countries with very low per-capita emissions, a shift from w = 0 (inertia) to 0.5 (blended) reduces the mitigation challenge from near the world average to near zero, because these countries collectively account only for a small share of global emissions.

The implication is that a blended sharing principle can ameliorate the opposite difficulties associated with the endpoint sharing principles at w = 0 (which would be prohibitive for least-developed countries) or w = 1 (which would be prohibitive for developed countries because of required mitigation rates exceeding 15% per year). Such compromises will be necessary in applying "equity principles of responsibility and capability to apportion the burden of emissions reductions [and] address concerns of both the global North and South"[24].

Together, Figs 3 and 4 demonstrate the interplay between the three major factors determining required regional and national mitigation rates: the warming limit, the nominated chance of success and the sharing principle (here w). The first two are comparably important everywhere. The sharing principle (w) has dominant but opposite effects for countries at opposite ends of the development spectrum,

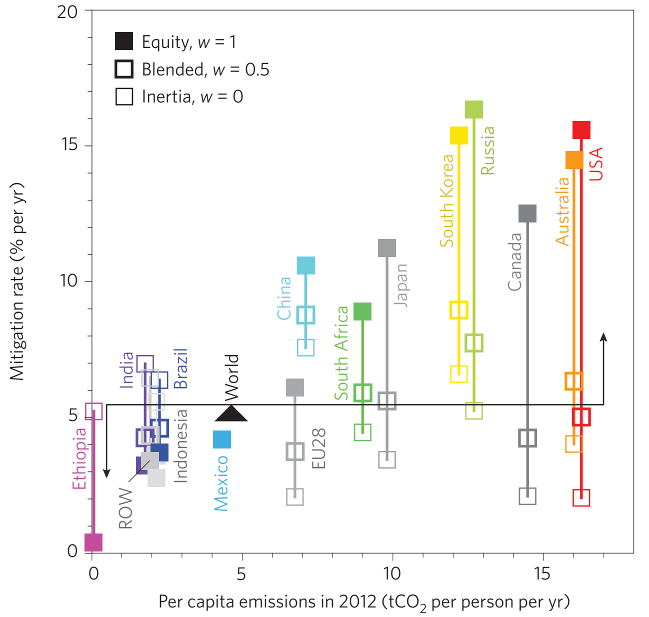

Figure 4 | Distribution of the mitigation challenge among countries. Mitigation rates (m) for 14 countries and regions spanning the development spectrum and for the whole world, with sharing index w = 0 (open squares), 1 (filled squares) and 0.5 (half-open squares). Horizontal axis is 2012 per-capita fossil-fuel CO_2 emissions. Available global fossil-fuel carbon quota from 2013 is Q_{avail} = 1,400 Gt CO_2, corresponding to a 2 °C warming limit with 50% success probability. With increasing equity in the sharing principle, the mitigation challenge increases for countries to the right of the point for the world (the pivot for the see-saw) and decreases for countries to the left. Mexico is so close to the pivot that symbols are indistinguishable. ROW, rest of world; EU28, the 28 member states of the European Union.

but small effects for countries close to the pivot point defined by global-average per-capita emissions (Fig. 4). In particular, China has a high required mitigation rate (because of currently high emissions growth) that is not strongly sensitive to the choice of w.

The regional mitigation rates in Figs 3a and 4 pivot around a very challenging global mitigation rate of 5.5% per year, for a warming limit of 2 °C with 50% chance of success. If the associated global carbon quota from ref. 10 (Q_{tot} = 3,500 Gt CO_2) is reduced to a more stringent 3,000 Gt CO_2 (ref. 8), then the required global mitigation rate increases further to 7.9% per year, and regional rates increase correspondingly.

Additional factors

To this point, we have not yet considered several additional factors that can be assessed within the framework of equation (2) or its generalizations (Supplementary Text 3) as part of future climate policy regimes.

Extent of inclusion of historic emissions. It has been suggested[41,49,50] that historic responsibility for climate change be included in principles for sharing the mitigation challenge. In a carbon-quota approach, this involves defining an attribution start date in the past and then sharing cumulative global emissions from that time onwards rather than from the present (Supplementary Text 4). A shift to this sharing principle has no effect on the required global mitigation rates, but has large implications for regions and countries. With historic attribution, required mitigation rates for developed regions become very large because attributed historic emissions approach (or even exceed) allocated shares for future emissions (Supplementary Fig. 8). The corresponding benefits for developing regions are not as large as might be expected because historic emissions for these regions are low.

Effect of delaying mitigation. It is well known that a delay in starting mitigation has a profound effect on the steepness of the mitigation challenge[51,52]. Noting that our analysis already includes persistence before a peak in emissions is reached, an additional 10-year delay would increase the required global mitigation rate m from 5.5 to over 9% per year (with global quota Q_{avail} = 1,400 Gt CO_2), with commensurate increases in regions (Supplementary Fig. 9).

Consumption-based and territorial emissions accounting. Consumption-based inventories for national CO_2 emissions[53] augment established territorial inventories[54] by attributing emissions to countries where products are consumed rather than where emissions of manufacture occur[55–57]. Under consumption-based accounting, the emissions of manufacturing-export countries, such as China, are reduced by up to 20% in recent years (relative to territorial accounting) and emissions of importing countries are correspondingly increased[37,58]. Use of consumption-based rather than territorial emissions leads to only a small change in shares and mitigation rates for regions and countries (Supplementary Fig. 10), because the favourable effects of consumption-based accounting for manufacturing-export countries are offset by the effects of their typically high persistence in emissions growth. Still, consumption-based emissions accounting may contribute to negotiation of agreements[24].

Effect of timing of population distribution. Sharing by population can be based on a future population forecast (the default for this Perspective; Supplementary Text 1), or on the present population distribution. There is only a small sensitivity of required mitigation rates to whether sharing occurs on the population distribution at a future time when the global population is nine billion, or on the distribution in 2013 with a global population of seven billion (Supplementary Fig. 11).

Effect of including GDP in the sharing principle. Equation (2) can be generalized to include additional metrics such as GDP (Supplementary Text 2). If the emissions distribution in equation (2) is replaced completely with the GDP distribution, the resulting effect on shares and mitigation rates is moderate, but not large (Supplementary Fig. 12), because both emissions and GDP are correlated with development status. Sharing principles combining three or more metrics (emissions, GDP, population, and so on) can be constructed (Supplementary Text 2). The most important clusters of metrics are those that represent development status (such as emissions and GDP) and those representing population.

Negative emissions. Model-based scenario studies indicate pathways to a range of warming limits, through transformations in energy systems and other mitigation measures[13]. For limits around 2 °C or less, such scenarios often depend on the use of negative emissions[13,59–61] through strategies such as land-based biosequestration or bioenergy with carbon capture and storage. Most 2 °C scenarios propose significant gross negative emissions to offset gross positive emissions that may be difficult or impossible to avoid, and many propose net negative emissions from the late twenty-first century. To the extent that gross negative emissions offset gross positive emissions, they are handled naturally by the cumulative carbon quota approach because the carbon quota applies to net (gross positive less gross negative) emissions. This applies at regional and national scales just as at the global scale.

Shared responsibility and collective achievability

A longstanding idea in analyses of burden sharing has been that countries need to test and explain how their own nominated climate goals fit with a global outcome[16,20,22,62,63]. Engagement in such testing is a key requirement for a robust solution to the climate change challenge through adaptive governance. As a methodological contribution to assist in this kind of testing, the present work combines existing analyses of the global carbon quota and effort sharing. The carbon-quota approach offers the important simplification of independence from assumptions about emissions pathways in time, yielding a transparent methodology for translating global to national carbon quotas under a wide range of possible sharing principles.

The question of achievability is clearly central[13]. The required global mitigation rates emerging from our analysis are high, typically over 5% per year for a 2 °C limit at 50% success probability (and 8% per year for China, a rate that remains very high under any sharing principle; Fig. 4). These rates can be compared with the distribution of maximum mitigation rates in the ensemble of scenarios in the Intergovernmental Panel on Climate Change Fifth Assessment Report (Supplementary Fig. 13). For scenarios with CO_2 peaking below 530 ppm, the median of the distribution of maximum rate of emissions decline is approximately consistent with the required rates from our analysis if there is no delay in starting mitigation, but even a five-year delay causes the required rate to approach the upper edge of the distribution.

Although the global quota is determined biophysically, the resulting distribution of effort among countries can be made more achievable by emissions or quota trading and related instruments. These can help to make very high national mitigation targets achievable, given sufficient globally connected trading systems and an effective price on emissions. Quota trading means that an initial quota does not determine the actual future cumulative emissions for a country; it also can improve the overall cost-effectiveness of the global mitigation effort, and facilitate transfer payments between countries to help achieve desired distributional outcomes. It is an open question whether such payments can be actually implemented on a large scale.

For the emergence of long-term, cooperative solutions to anthropogenic climate change[33,35], one essential element is an ability to perceive the consistent global consequences of local actions, given great differences in national economies and histories. The social capital that underpins cooperative governance of the commons takes time to evolve, but the biophysical realities of climate change demand solutions within decades. This is why the development of new perspectives on the sharing challenge is vital.

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Author contributions

M.R.R. designed the study, carried out calculations and coordinated the conception and writing of the paper. S.J.D. contributed data on committed emissions and drew figures. G.P.P. and R.M.A. contributed data on committed emissions and resources. All authors contributed to the writing of the paper.

Additional information

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Competing financial interests

The authors declare no competing financial interests.