

Supporting Information for One Billion High Emitters: A New Approach for Sharing Global CO₂ Emission Reductions

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1 Data

Emissions and GDP (expressed in constant 2000 \$ PPP) in 2003 form the basis of all subsequent analysis. 2003 is the base year of the International Energy Outlook (IEO) 2007 projections produced by the Energy Information Administration (EIA) of the U. S. The projections go till 2030. Our primary sources of data are:

GDP – current and historical:

Sources, in decreasing order of preference, for current data:

1. World Development Indicators (WDI) 2007 (<http://publications.worldbank.org/WDI>).
2. PWT6.2 (Penn World Tables), Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 6.2, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, September 2006. We use PWT6.2 for historical GDP data. (http://pwt.econ.upenn.edu/php_site/pwt_index.php).
3. CIA: The World Factbook (<https://www.cia.gov/library/publications/the-world-factbook/>).

Emissions – current and historical:

EIA is our source for CO₂ emissions data from energy consumption.
(<http://www.eia.doe.gov/emeu/international/carbondioxide.html>).

Historical population data:

PWT6.2

Projections:

We use EIA's International Energy Outlook -IEO 2007 for emissions, population and GDP projections (<http://www.eia.doe.gov/oiaf/archive/ieo07/index.html>). Our analysis is based on the projections of the 'Reference Case'. The population projections used by IEO 2007 are from the United Nations Statistical Division.

Income/Consumption distribution data - current and historical:

We use income (or consumption) distribution data from the most recent survey obtained from the following sources in order of preference:

1. World Development Indicators 2007.
2. World Bank: PovcalNet – for some developing countries
(<http://iresearch.worldbank.org/PovcalNet/jsp/index.jsp>).
3. World Income Inequality Database (WIID2b) from the UN University - World Institute for Development Economics Research.
(http://www.wider.unu.edu/research/Database/en_GB/database/
http://www.wider.unu.edu/research/Database/en_GB/wiid/).

We also use WIID2b for historical distribution data for income elasticity of CO₂ emissions estimates for select countries.

See the Appendix for details of data coverage and regional definitions used by EIA in IEO 2007.

2 Methodology

We build a global distribution of individual carbon emissions by linking income distributions to national fossil fuel emissions. Three main steps are involved.

- We fit income/consumption distributions using quintiles or deciles data at the country level, for the last available year for which the survey is available in a given country.
- We rescale them to match their nation per capita GDP (in PPP) of 2003.
- Assuming income and emissions are related by a power law, we translate them into emission distributions, ensuring that the averages match the national emission inventories.

In doing so, we attribute all production-based national emissions to their individuals on the basis of their income, although not necessarily in constant proportions. That is, we assume that the emissions generated by government consumption and the investments in the economy are attributed to individuals according to their income, in the same way those deriving directly or indirectly from consumption. The scheme ignores emissions embedded in international (more precisely, inter-regional) trade. The next subsections explore the three steps in some detail.

2.1 Income/Consumption Distributions from Decile Data for Individual Countries

The distribution data from WDI is in the form of income/consumption¹ shares of the five quintiles and the top and bottom deciles. For example, in the case of Indonesia:

| | | | | | | | | |
|-------------------------------|---|-------|-------|------|------|------|------|---|
| Cumulative Population | 0 | 0.1 | 0.2 | 0.4 | 0.6 | 0.8 | 0.9 | 1 |
| Cumulative Income/Consumption | 0 | 0.036 | 0.084 | 0.20 | 0.36 | 0.57 | 0.71 | 1 |

The relevant data for 2003 are:

| | |
|------------------------------|-------|
| Population (millions) | 214.7 |
| GDP per capita (2000 \$ PPP) | 3167 |

¹Note that some surveys measure consumption inequality while others measure income inequality. We do not differentiate between the two as both approaches are prevalent in different parts of the world. This is problematic as income distributions tend to have more inequality than consumption distributions. We also anchor the mean of the distribution to the GDP per capita. This has its detractors as the GDP per capita is often larger than the mean income from the surveys. We refer the interested reader to Refs. (1) and (2) for detailed discussions of issues involved. We use the normalized income distribution to obtain the CO₂ emissions distribution which is insensitive to this issue.

A plot of the cumulative income/consumption share vs. the cumulative population distribution is called the Lorenz curve (see Figure S1). We use a sum of two Gamma probability density functions (PDFs) to model the population distribution as a function of income. Our rationale for using Gamma PDFs is that it facilitates a sensitivity analysis of the simplifying assumptions in the main text. All functions of the form $x^n G(x, a, b)$ of the Gamma PDF $G(x, a, b)$ are also Gamma PDFs (for example, the income distribution is the case where $n = 1$). The population distribution can be obtained by a simple non-linear least square fit of the modeled Lorenz curve with distribution data. We also note that if CO₂ emissions elasticity with respect to (w.r.t.) income is some constant β then the population distribution can be easily converted to a function of CO₂ emissions using generalized Gamma PDFs (see Section 3).

Gamma probability density functions or PDFs ($G(x, a, b)$) and cumulative distribution functions or CDFs ($CG(x, a, b)$) are:

$$G(x, a, b) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-\frac{x}{b}} \quad (1)$$

$$CG(x, a, b) = \int_0^x G(x, a, b) dx. \quad (2)$$

where

$$\Gamma(a) = \int_0^\infty x^{a-1} e^{-x} dx \quad \text{and} \quad \Gamma(a + 1) = a\Gamma(a).$$

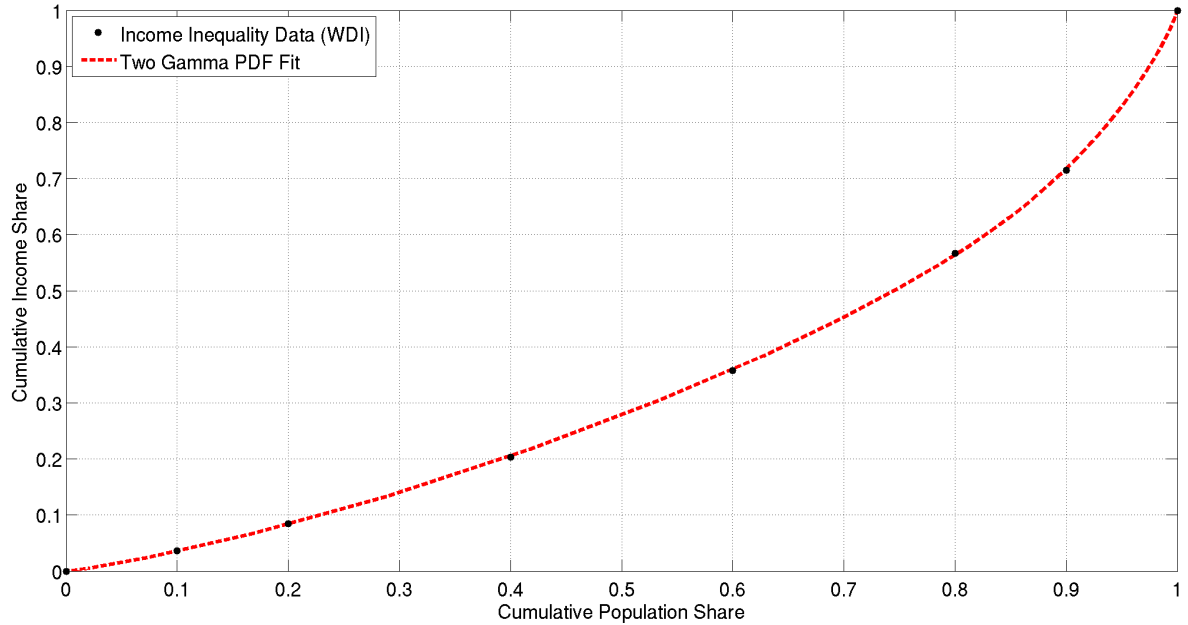


Figure S1: The WDI data and 2-Gamma Fit Lorenz curve for Indonesia.

Recall that we are dealing with probability density functions here, so the CDF should integrate to 1.

$$CG(\infty, a, b) = \int_0^{\infty} G(x, a, b)dx = 1 \quad (3)$$

The Gamma PDF has an interesting property under scaling of x-axis:

$$x \rightarrow z = Ix \Rightarrow G(x, a, b)dx \rightarrow G(z, a, bI)dz. \quad (4)$$

This property is very useful as we can fit the Gamma function to income normalized w.r.t. to GDP per capita (I) and then scale the distribution and the x axis to the real income. More importantly, the Lorenz curve is a function of a only. So we can scale b to produce income distributions that have the same inequality (or Lorenz curve) but different GDP per capita. This property is used to project income distributions into the future using projections of GDP per capita and assuming, conservatively, no change in inequality. For the CDF, we have:

$$x \rightarrow z = Ix \Rightarrow CG(x, a, b) = CG(z, a, bI). \quad (5)$$

Henceforth, we use x to denote income in units of GDP per capita (I) and $z = Ix$ to denote income in PPP dollars. The income share ($IG(x, a, b)$) and cumulative income share ($ICG(x, a, b)$) are (using (1) and (2)):

$$IG(x, a, b) = xG(x, a, b) = abG(x, a + 1, b), \quad (6)$$

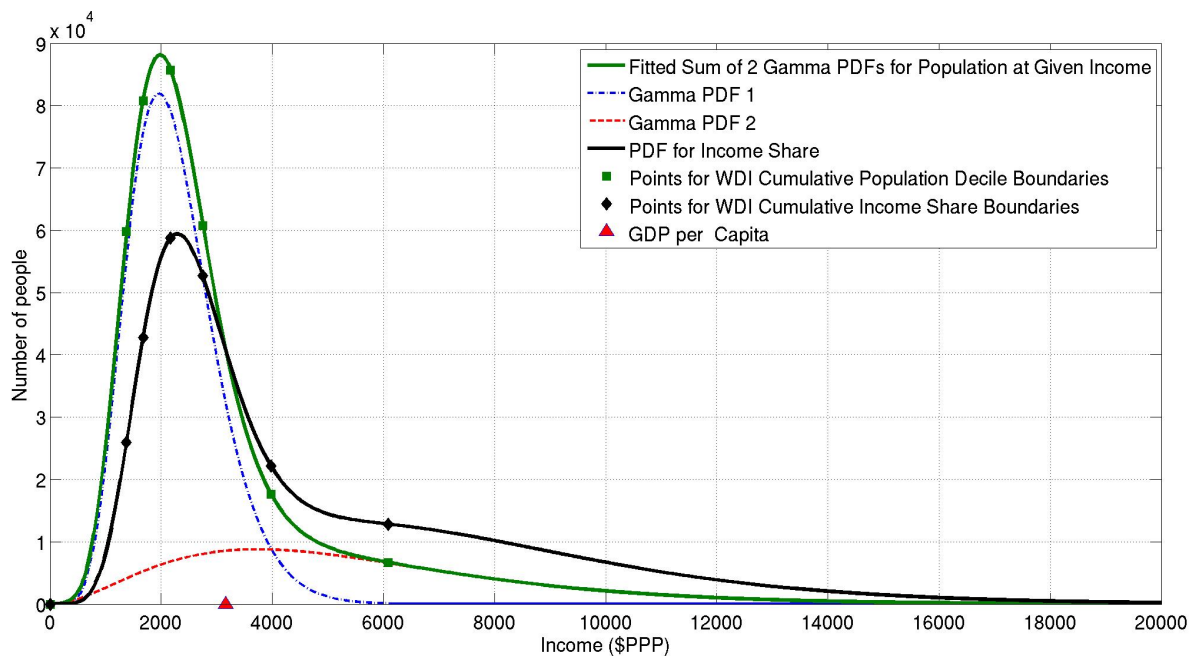


Figure S2: 2-Gamma Fit for Indonesia.

and

$$ICG(x, a, b) = \int_0^x xG(x, a, b) = abCG(x, a + 1, b). \quad (7)$$

We use the trial 2-Gamma PDF for income (normalized w.r.t. GDP per capita I):

$$r_1G(x, a_1, b_1) + r_2G(x, a_2, b_2).$$

The 2-Gamma fit after scaling the distribution from normalized income x to real income z using (4), and multiplying by population N is:

$$F(z) = N[r_1G(z, a_1, b_1I) + r_2G(z, a_2, b_2I)]. \quad (8)$$

Figure S2 shows the 2-Gamma distribution that we obtain from the fit shown in Figure S1.

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2.2 Emissions Elasticities from Surveys

Here we look at the elasticity of energy or emissions vs. consumption expenditure from various studies (See Table S1). These studies consider both direct energy use in households and energy embodied in goods and services consumed in households. The approach, first developed by Robert Herendeen in the 1970s, combines household income and/or consumption expenditure surveys with emissions or energy statistics and input-output table data. Household expenditure in different consumption categories are converted to emissions/ energy use using input-output data. This can be considered a ‘bottom-up’ approach to the question of the emissions elasticity w.r.t income or consumption expenditure. In the next subsection we consider a ‘top-down’ approach to the issue using income distributions and emissions data. The elasticity of energy use with expenditure is not strictly comparable with the emissions elasticity. Nonetheless, in most countries both elasticities vary from 0.7 to 1. Emissions in different countries at the same level of household consumption expenditure vary significantly. In the subsequent analysis we will primarily use an elasticity of 1 and consider other elasticities (0.7-1) for sensitivity analyzes. Most results do not vary by more than 20% so the linear elasticity assumption is used to keep the discussion intuitively simple. Note again that we use income distributions anchored to the average GDP per capita instead of the consumption measured in the household surveys.¹

| Country | Reference | Year | Elasticity of energy ^a | Elasticity of CO ₂ emissions ^a |
|---------------------|-------------------------------|-----------|-----------------------------------|--|
| Australia | (1) Lenzen (1998) | 1993-94 | 0.74 | 0.7 |
| Australia | (2) Lenzen et al. (2006) | 1998-99 | 0.78 | |
| Brazil ^b | (2) Lenzen et al. (2006) | 1995-96 | 1 | |
| Denmark | (3) Wier et al. (2001) | 1995 | 0.9 | 0.9 |
| Denmark | (2) Lenzen et al. (2006) | 1995 | 0.86 | |
| India | (2) Lenzen et al. (2006) | 1997-98 | 0.86 | |
| Japan | (2) Lenzen et al. (2006) | 1999 | 0.64 | |
| Netherlands | (4) Vringer & Blok (1995) | 1990 | 0.83 | |
| New Zealand | (5) Peet et al. (1985) | 1980 | 0.4 ^c | |
| Norway | (6) Herendeen (1978) | 1973 | 0.72 | |
| Norway | (7) Peters et al. (2006) | 1999-2001 | | 0.88 |
| Spain | (8) Roca & Serrano (2007) | 2000 | | 0.91-0.99 ^d |
| U.S. | (9) Herendeen & Tanaka (1976) | 1960-61 | 0.85 | |
| U.S. | (10) Herendeen et al. (1981) | 1972-73 | 0.78 | |
| U.S. | (11) Weber & Matthews (2008) | 2004 | | 0.6-0.8 ^e |

^aw.r.t. to consumption expenditure

^bSurvey covers 11 state capitals only.

^cLow value due to high use of hydroelectric electricity in poor households.

^dRange depends on assumptions used to convert from household emissions to per capita emissions.

^eRange depends on the specific model used to fit data.

Table S1: Elasticity of per capita energy consumption and emissions vs. household expenditure

2.3 ‘Top-down’ Estimation of the Income Elasticity of Emissions

We have attempted a ‘top-down’ analysis of a panel of countries using emission data from EIA, GDP and population data from PWT6.2, and income inequality data from WIID2b. First, we do a simple maximal likelihood analysis where we fit a function of the form

$$c_{it} = A_i \bar{I}_{it}^\beta \quad (9)$$

where c_{it} is the per capita emission of country i in year t , A_i is a country specific constant, β is a universal constant, and \bar{I}_{it} is the GDP per capita in country i and year t . There are 43 time series (one for each country) with at least 5 years of data in the period 1980-2004 adding up to 410 ‘sets’. Each ‘set’ contains GDP per capita, average annual emissions, and decile income shares for a particular country in a given year. We maximize the loglikelihood function of normally distributed observations with a linearly increasing heteroskedastic standard deviation $\sigma(\bar{I}_{it})$ which is a function of the GDP per capita \bar{I}_{it} . $\sigma(\bar{I})$ which is a straight line is parameterized

by its values at two points: $\sigma(\bar{I} = 0)$ and $\sigma(\bar{I} = 50000)$.

$$\ln L = -\frac{1}{2} \sum_{it} [\ln(2\pi) + \ln \sigma^2(\bar{I}_{it}) + \frac{1}{\sigma^2(\bar{I}_{it})} (c_{it} - A_i \bar{I}_{it}^\beta)^2] \quad (10)$$

The country specific A_i can be derived by setting the derivative of $\ln L$ w.r.t A_i to 0. This substitution significantly reduces the number of variables from 46 (43 A_i s, β and two parameters for σ) to 3. The reduced form loglikelihood function $\ln L(x(1), x(2), x(3))$ become a function of the three variables $x(1) = \beta$ and $\sigma(\bar{I})$ parameterized by $x(2) = \sigma(0)$ and $x(3) = \sigma(50000)$. $\ln L$ is maximized at

$$x(1)^* = \beta = 0.718, \quad x(2)^* = 0.057 \quad \text{and} \quad x(3)^* = 2.005$$

with $\max \ln L = -217.244$. This simple analysis is the equivalent of assuming that every country is a representative individual whose income in year t is \bar{I}_{it} with an emissions to income elasticity of β . We repeat the same analysis using income distribution data at the decile level to fit a function of the form

$$c_{it} = B_i \sum_f I_{itf}^\beta \quad (11)$$

where I_{itf} is the mean income in f th decile (or quintile). The loglikelihood estimator is

$$\ln L' = -\frac{1}{2} \sum_{it} [\ln(2\pi) + \ln \sigma^2(\bar{I}_{it}) + \frac{1}{\sigma^2(\bar{I}_{it})} (c_{it} - B_i \sum_f I_{itf}^\beta)^2]. \quad (12)$$

$\ln L'$ is maximized at

$$x(1)^* = \beta = 0.724, \quad x(2)^* = 0.055 \quad \text{and} \quad x(3)^* = 2.007$$

with $\max \ln L' = -215.452$. It is reassuring, that (12) provides a substantially better fit than (10), because this shows that the national-level data carry a substantial signal of the distribution of individual emissions. If we assumed that the two models were equally probable before the analysis (equal prior probabilities), then the data make the model behind (12) approximately six times more likely than the one behind (10) (the posterior probabilities differ by a factor of $e^{1.79}/1$).²

It is also reassuring that three different methods give us approximately the same estimated value of β . The most common value from bottom-up household surveys, and the estimates from the top-down methods behind (10) and (12), all are between 0.7 and 1. Nonetheless, it is possible that all of these methods undercount the emissions of the wealthy, primarily due to non-response to surveys and undercounting of indirect emissions from services, dividend income etc. For this reason, we have we performed all of the analyses in this paper for four values of β – 0.7, 0.8, 0.9 and 1.0 (see Sections 3.2 and 3.3) – and found that all of the paper's findings are quite insensitive to β . Also, the case with $\beta = 1$ is easiest to extend to other data sets and to analyze because each country's emissions distribution is then just its income distribution with a simple change of units. For all of these reasons, we present analyses in which $\beta = 1$ in the main text.

²1.79 is the difference between $\max \ln L'$ and $\max \ln L$.

2.4 Emissions Distributions for Different Elasticities

The use of Gamma PDFs also makes it easy to transform the population density w.r.t. income to one w.r.t. to CO₂ emissions. The Gamma PDF is modified to a generalized Gamma PDF. Suppose the CO₂ emissions to income relationship for a given country has the functional form

$$c_\beta(z) = \frac{1}{A_\beta} z^\beta \quad (13)$$

where $c_\beta(z)$ is the annual CO₂ emissions and we assume a power law function of income z . The distribution of emissions as a function of income (using the population distribution $F(z)$, see (8)) is $c_\beta(z)F(z)$. Note that the income distribution is a special case where $\beta = A = 1$. The β moment distribution of a Gamma PDF is another Gamma PDF.

$$x^\beta G(x, a, b) = \frac{\Gamma(a + \beta)}{\Gamma(a)} b^\beta G(x, a + \beta, b). \quad (14)$$

Multiplying both sides of equation (13) with the 2-Gamma fit $F(z)$ (see (8)), and using (3) and (14), we obtain

$$NC = \int_0^\infty c_\beta(z)F(z) = \frac{1}{A_\beta} N \left[r_1 \frac{\Gamma(a_1 + \beta)}{\Gamma(a_1)} (b_1 I)^\beta + r_2 \frac{\Gamma(a_2 + \beta)}{\Gamma(a_2)} (b_2 I)^\beta \right], \quad (15)$$

where, C is the CO₂ emissions per capita and N is the population of the country. The above identity provides us with an explicit value for A_β . This gives us, on changing variables (and dropping the β subscript):

$$z(c) = (Ac)^\gamma \quad \text{where } \gamma = 1/\beta. \quad (16)$$

Substituting z using (16) in (8) will give us the probability density function in terms of CO₂ emissions. This replaces the Gamma function with generalized Gamma functions. A generalized Gamma function $GG(y, \gamma, a, \bar{b})$ is

$$GG(y, \gamma, a, \bar{b}) = \frac{\gamma}{\bar{b}^\gamma \Gamma(a)} y^{\gamma a - 1} e^{-(y/\bar{b})^\gamma}. \quad (17)$$

The generalized Gamma function is related to the Gamma function (by definition) as,

$$GG(y, \gamma, a, \bar{b}) dy = G(y^\gamma, a, \bar{b}^\gamma) d(y^\gamma). \quad (18)$$

The population density in terms of CO₂ emissions c is

$$F(c) = N \left[r_1 GG(c, \gamma, a_1, A^{-1}(b_1 I)^\beta) + r_2 GG(c, \gamma, a_2, A^{-1}(b_2 I)^\beta) \right] \quad (19)$$

$$= N \gamma c^{\gamma-1} \left[r_1 G(c^\gamma, a_1, A^{-\gamma} b_1 I) + r_2 G(c^\gamma, a_2, A^{-\gamma} b_2 I) \right], \quad \text{using } \beta\gamma = 1 \quad (20)$$

The emissions share probability distribution (emissions at a given annual emissions level) is $C(c) = cF(c)$. The k th moment function (k integer) of a generalized Gamma function is

$$y^k GG(y, \gamma, a, \bar{b}) = \bar{b}^{k/\gamma} \frac{\Gamma(a + k/\gamma)}{\Gamma(a)} GG(y, \gamma, a + k/\gamma, \bar{b}) \quad (21)$$

Using $k = 1$ and (20)

$$C(c) = N\gamma c^{\gamma-1} [s_1 G(c^\gamma, a_1 + 1/\gamma, A^{-\gamma} b_1 I) + s_2 G(c^\gamma, a_2 + 1/\gamma, A^{-\gamma} b_2 I)], \quad (22)$$

where

$$s_i = r_i A^{-1} (b_i I)^\beta \frac{\Gamma(a_i + 1/\gamma)}{\Gamma(a_i)}.$$

We now have all that we need to fit distributions with different elasticities (see Figure S3). Projections that conserve inequality (defined as keeping the Lorenz curve invariant) are easy. Note that changing the b (or \bar{b}) parameter in the Gamma (or generalized Gamma) functions does change the Lorenz curve. Projections into the future involve changing GDP per capita I or per capita emissions C to which the Gamma or generalized Gamma functions are anchored and these affect b (or \bar{b}) only.

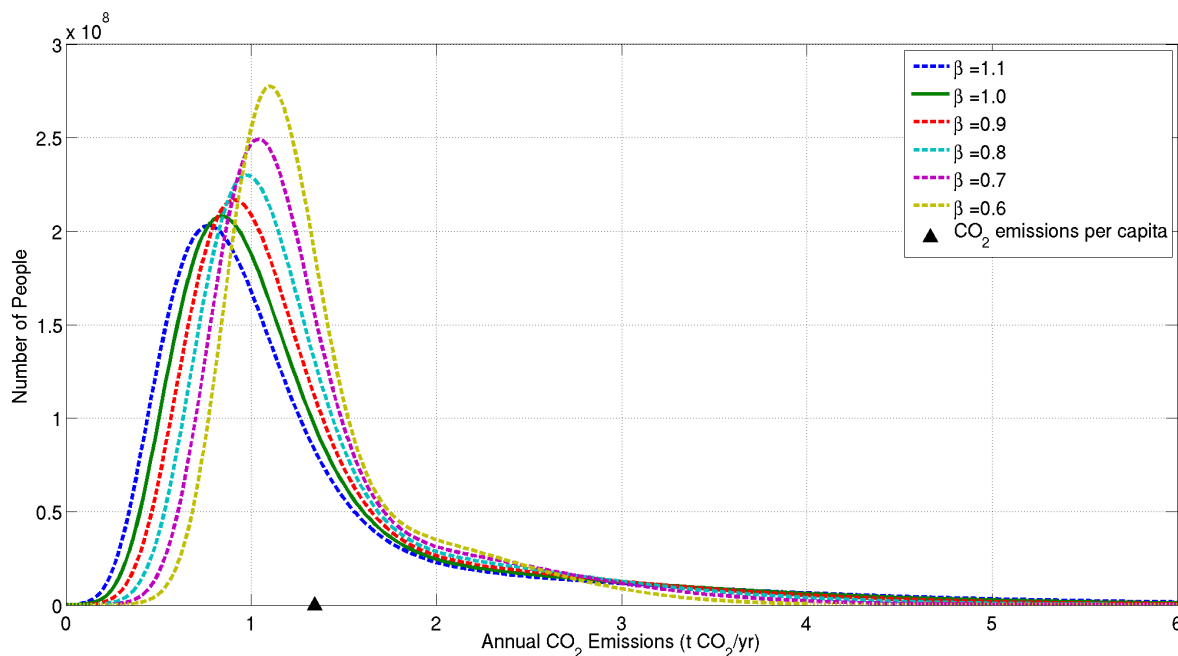


Figure S3: Distribution of emitters vs. annual CO₂ emissions in Indonesia in 2003 for different β 's. Note that the curves become more peaked around the emissions per capita as β decreases. In the limiting case of $\beta = 0$, emissions would be independent of income, so every person would emit the same as the average emissions per capita. The area under the curves is the total population of Indonesia in 2003: 214.7 million.

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3 Projecting Emission Distributions and Caps

This Section explores how we calculate individual caps in the future. It reports first on the projection procedure and then on the way global caps are computed. The importance of the relation between expenditures and emissions is evaluated via sensitivity analysis. Tables at the regional level for 2020 and 2030 for several global emission constraints are provided in Section 3.1 and a few comparisons are made to regional targets currently under discussion.

To obtain a picture of the future, we first need forecasts of regional population and emissions. We use the EIA International Energy Outlook (IEO), as it is a widely used and freely available source of projections. However, the methodology can be straightforwardly replicated using alternative projections, with different regional disaggregation and temporal horizon. Results in this paper are based on IEO 2007.³ We estimate the country level emissions distributions for 2003 (see Section 2.1) using the most recent income distributions available (as of 2003). We make two main assumptions for emissions projection: 1) no change in income inequality at the country level and 2) a single constant global elasticity of emissions to consumption.⁴ Both

³While we were finalizing this paper the IEO 2008 was released. Figures at the global scale show little variations with respect to the 2007 version. However, a redistribution mainly from the US to China is foreseen. This reflects recent upwards trends in Chinese emissions and a lower economic growth rate for the US.

⁴We use a constant global elasticity of $\beta = 1.0$ in Section 3.1.

assumptions are crude approximations of reality. Wealth distribution has changed in the past 30 years, especially in countries that have experienced profound economic transformations. However, within-country inequality projections are not available, to our knowledge. Accordingly, we adopt the ‘future equals past’ rule of thumb. As for emissions/expenditure elasticities, values vary across countries as shown in Table S1, but very few estimates exist for developing countries. In Sections 3.2 and 3.3 we will perform some sensitivity analysis where this elasticity is a parameter.

3.1 Universal Caps

We begin by summing over the country-level emissions distributions (developed in Section 2.2) to obtain regional distributions corresponding to the 16 regions used in EIA’s projections (see Appendix A for region definitions). Using EIA’s regional emissions growth rates, we project these regional distributions forward in time to obtain a global distribution of emissions. We can then easily compute a maximum individual cap above which all emissions are eliminated. The universal emissions cap for a global emission reduction target is obtained from the Lorenz plot of cumulative BAU emissions vs. cumulative population by finding the tangent to the curve that is consistent with the envisioned target. The linearity of the tangent ensures constant individual emissions, at the rate given by its slope. Figure 4 illustrates the general method for the case explored in the main text, where the date is 2030 and we assume an elasticity of 1.0. Keeping world emissions below the target requires that each of 1.13 Billion people is assigned a 10.8 tCO₂ cap.

The corresponding cap for the ‘30P’ scenario where we provide for an emissions floor of 1 tCO₂ per capita are obtained similarly. The extra emissions required to be set aside for the 1 tCO₂ floor is subtracted from the 30 GtCO₂ global target to calculate the new individual emissions cap. From any universal cap, we obtain regional allocations (both the number of people under the regional cap and the required regional emissions reduction) by finding the vertical intercept on the regional Lorenz plot of a line with the slope of the universal cap slope (the same procedure as shown in Figure S4).

In Table S2 we compare the regional target in 2030 for the two schemes proposed in this paper, and the ‘equal per capita’ approach. In the ‘equal per capita’ scheme, allocations are based on global emissions divided equally among the 8.1 billion global citizens. This expands on Figure 7 in the paper. In Tables S3-S10, we report projected emissions targets at the regional level for global targets in 2020 and 2030. In 2020 the global targets are 20 GtCO₂, 25 GtCO₂, 30 GtCO₂ and 33 GtCO₂. In 2030 the global targets are the global targets are 20 GtCO₂, 25 GtCO₂, 30 GtCO₂ and 35 GtCO₂; 30 GtCO₂ is the target explored in the main text. All Tables assume an emissions elasticity of 1.0 w.r.t. income. The Tables show results with and without a floor for low-emitters. Inasmuch as the task of creating and raising a floor is likely to be a multi-decade task, we assume a floor for all the worlds individuals of 0.5 tCO₂ for 2020 and 1.0 tCO₂ for 2030.

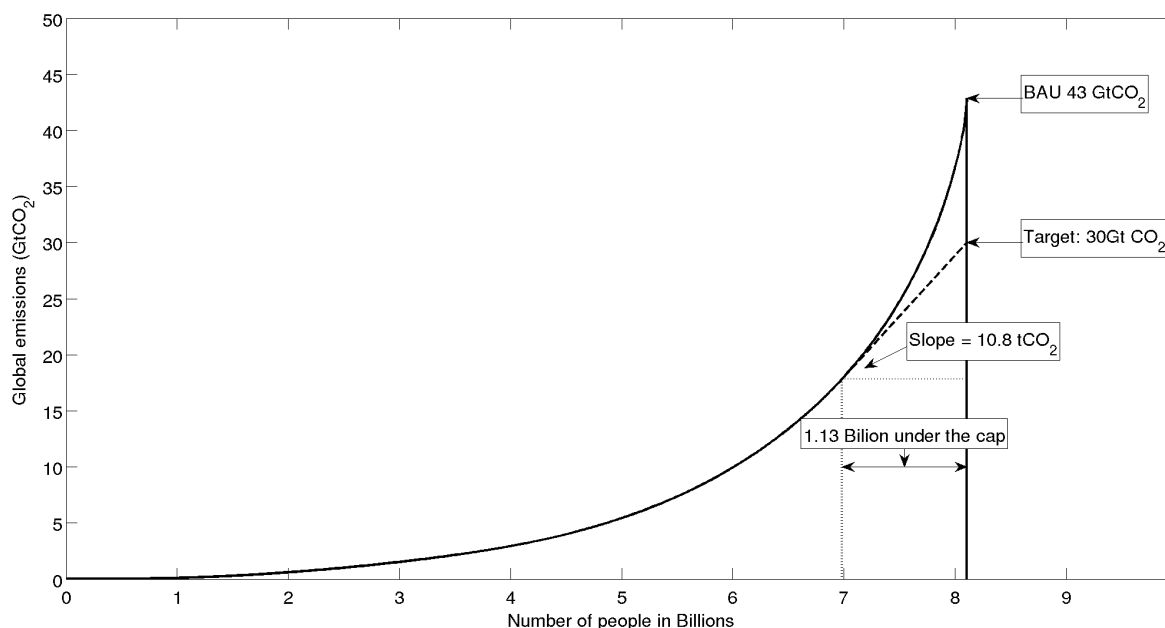


Figure S4: Cumulative emissions vs. cumulative population for 2030. The BAU emissions are 43 GtCO₂ and an individual emissions cap of 10.8 tCO₂ (the slope of the tangent) is needed to meet a global emissions target of 30 GtCO₂ (the ‘30’ scenario).

We can compare specific results in these Tables to two recently proposed climate policies. The European Commission has proposed a regional target of 3.3 GtCO₂ for 2020, a 20% emission reduction with respect to 1990s levels.⁵ Associating the European Commission territory with the OECD-Europe region, our Tables reveal that this goal is roughly consistent with the ‘25P’ scenario in 2020. The Lieberman-Warner Security Act envisions long-term emissions reductions for the U.S. that, according to EIA estimates, correspond to 5.5 GtCO₂ and 4 GtCO₂ targets, 10% above and 20% below 1990 levels, for 2020 and 2030 respectively.⁶ These U.S. goals correspond to the demands of a global cap between ‘30P’ and ‘35P’ in the decade 2020-2030. Europe’s proposed commitment corresponds to a tighter global target in our allocation scheme than the U.S. commitment does. This is due to the fact that 1) Europe’s commitment is an intrinsically tighter regional target compared to the U.S. and 2) our allocation scheme projects more stringent cuts in emissions from the U.S. than Europe as the U.S. has higher average emissions and a higher number of high emitters.

⁵ See http://ec.europa.eu/energy/climate_actions/index_en.htm

⁶ See <http://www.eia.doe.gov/oiaf/service/rpt/s2191/pdf/tbl3.pdf>

| Region | Emissions [1990] | Em. [2003] | Em. (BAU) [2030] | Population [2030] | Em. (20) [2020] | Em. (20P) [2030] | Em. (20E) [2030] | Em. (25) [2030] | Em. (25P) [2030] | Em. (25E) [2030] | Em. (30) [2030] | Em. (30P) [2030] | Em. (30E) [2030] | Em. (35) [2030] | Em. (35P) [2030] | Em. (35E) [2030] |
|---------------------------------|------------------|------------|------------------|-------------------|-----------------|------------------|------------------|-----------------|------------------|------------------|-----------------|------------------|------------------|-----------------|------------------|------------------|
| U.S. | 5 | 5.8 | 8 | 364.7 | 1.7 | 1.5 | 0.9 | 2.5 | 2.3 | 1.1 | 3.6 | 3.2 | 1.4 | 4.9 | 4.5 | 1.6 |
| Canada | 0.5 | 0.6 | 0.7 | 38.6 | 0.2 | 0.2 | 0.1 | 0.3 | 0.2 | 0.1 | 0.4 | 0.3 | 0.14 | 0.5 | 0.5 | 0.2 |
| Mexico | 0.3 | 0.4 | 0.7 | 129.2 | 0.4 | 0.4 | 0.3 | 0.5 | 0.5 | 0.4 | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 |
| OECD Europe | 4.1 | 4.3 | 4.7 | 560.6 | 2.4 | 2.1 | 1.4 | 3.1 | 2.9 | 1.7 | 3.8 | 3.6 | 2.1 | 4.3 | 4.2 | 2.4 |
| Japan | 1 | 1.2 | 1.3 | 122.8 | 0.6 | 0.5 | 0.3 | 0.9 | 0.8 | 0.4 | 1.1 | 1 | 0.5 | 1.2 | 1.2 | 0.5 |
| South Korea | 0.2 | 0.5 | 0.7 | 49.9 | 0.2 | 0.2 | 0.1 | 0.3 | 0.3 | 0.2 | 0.5 | 0.4 | 0.2 | 0.6 | 0.6 | 0.2 |
| Australia and New Zealand | 0.3 | 0.4 | 0.6 | 29.9 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.3 | 0.3 | 0.1 | 0.4 | 0.4 | 0.1 |
| OECD minus U.S. | 6.4 | 7.4 | 8.7 | 930.8 | 4 | 3.6 | 2.3 | 5.3 | 4.9 | 2.9 | 6.6 | 6.2 | 3.4 | 7.7 | 7.4 | 4.0 |
| Total OECD | 11.4 | 13.3 | 16.7 | 1295.6 | 5.7 | 5.1 | 3.2 | 7.8 | 7.2 | 4.0 | 10.2 | 9.5 | 4.8 | 12.6 | 11.9 | 5.6 |
| China | 2.2 | 4 | 11.4 | 1442.1 | 5.6 | 5.2 | 3.6 | 7.2 | 6.7 | 4.5 | 8.5 | 8.2 | 5.3 | 9.8 | 9.5 | 6.2 |
| Russia | 2.3 | 1.6 | 2.2 | 124.7 | 0.6 | 0.5 | 0.3 | 0.9 | 0.8 | 0.4 | 1.2 | 1.1 | 0.5 | 1.5 | 1.4 | 0.5 |
| Transition Economies | 1.9 | 1.1 | 1.6 | 189.7 | 0.8 | 0.7 | 0.4 | 1 | 1 | 0.6 | 1.3 | 1.2 | 0.7 | 1.5 | 1.4 | 0.8 |
| India | 0.6 | 1.1 | 2.2 | 1441.6 | 2.1 | 2.2 | 3.6 | 2.2 | 2.3 | 4.5 | 2.2 | 2.3 | 5.3 | 2.2 | 2.3 | 6.2 |
| Other Non-OECD Asia | 0.8 | 1.4 | 2.8 | 1307.8 | 1.8 | 2.1 | 3.2 | 2 | 2.3 | 4.0 | 2.2 | 2.5 | 4.8 | 2.4 | 2.7 | 5.6 |
| Middle East | 0.7 | 1.2 | 2.3 | 282.3 | 1 | 0.9 | 0.7 | 1.2 | 1.1 | 0.9 | 1.4 | 1.4 | 1.0 | 1.7 | 1.6 | 1.2 |
| Africa | 0.6 | 1 | 1.8 | 1438.2 | 1.2 | 2 | 3.6 | 1.3 | 2.1 | 4.4 | 1.4 | 2.2 | 5.3 | 1.6 | 2.3 | 6.2 |
| Brazil | 0.2 | 0.3 | 0.6 | 236.6 | 0.4 | 0.5 | 0.6 | 0.5 | 0.5 | 0.7 | 0.6 | 0.6 | 0.9 | 0.6 | 0.6 | 1.0 |
| Other South and Central America | 0.5 | 0.6 | 1.2 | 349.2 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 1.1 | 1 | 1 | 1.3 | 1.1 | 1.1 | 1.5 |
| Non-OECD minus China | 7.6 | 8.3 | 14.8 | 5370.1 | 8.7 | 9.7 | 13.3 | 10 | 11.1 | 16.6 | 11.3 | 12.4 | 19.9 | 12.5 | 13.6 | 23.2 |
| Total Non-OECD | 9.8 | 12.2 | 26.2 | 6812.1 | 14.3 | 14.9 | 16.8 | 17.2 | 17.8 | 21.0 | 19.8 | 20.5 | 25.2 | 22.4 | 23.1 | 29.4 |
| Total World | 21.2 | 25.5 | 42.9 | 8107.7 | 20 | 20 | 20 | 25 | 25 | 25 | 30 | 30 | 30 | 35 | 35 | 35 |

Table S2: Comparison of regional emissions for different global targets (20, 25, 30, 35) and allocation schemes. For example, '25' and '25P' refer to the schemes proposed in this paper whereas '25E' is an allocation based on the 'equal per capita' approach.

| Region | Emissions [1990] | Emissions [2003] | Population [2003] | Emissions (BAU) [2020] | Population [2020] | Emissions (20) [2020] | Emissions (20P) [2020] | Population under cap (20) [2020] | Population under cap (20P) [2020] | (20P) change w.r.t. [1990] | (20P) change w.r.t. [2003] | (20P) change w.r.t. (BAU) |
|---------------------------------|------------------|------------------|-------------------|------------------------|-------------------|-----------------------|------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------|---------------------------|
| U.S. | 5.0 | 5.8 | 290.8 | 7.0 | 336.8 | 1.9 | 1.8 | 303.9 | 306.3 | -63.4% | -68.6% | -73.8% |
| Canada | 0.5 | 0.6 | 31.6 | 0.7 | 35.6 | 0.2 | 0.2 | 33.6 | 33.8 | -58.6% | -66.3% | -71.4% |
| Mexico | 0.3 | 0.4 | 101.0 | 0.6 | 121.4 | 0.4 | 0.4 | 25.6 | 27.1 | 32.5% | 4.3% | -32.1% |
| OECD Europe | 4.1 | 4.3 | 528.6 | 4.6 | 553.6 | 2.7 | 2.6 | 324.8 | 335.3 | -36.7% | -40.3% | -43.6% |
| Japan | 1.0 | 1.2 | 127.7 | 1.3 | 126.7 | 0.7 | 0.7 | 112.2 | 114.6 | -31.3% | -44.2% | -46.3% |
| South Korea | 0.2 | 0.5 | 47.9 | 0.6 | 49.9 | 0.3 | 0.3 | 42.9 | 43.5 | 13.1% | -42.9% | -55.8% |
| Australia and New Zealand | 0.3 | 0.4 | 23.9 | 0.5 | 27.9 | 0.2 | 0.2 | 24.6 | 24.9 | -48.3% | -63.6% | -71.1% |
| OECD minus U.S. | 6.4 | 7.4 | 860.7 | 8.3 | 915.1 | 4.4 | 4.3 | 563.7 | 579.1 | -32.9% | -42.1% | -48.2% |
| Total OECD | 11.4 | 13.3 | 1151.5 | 15.3 | 1251.8 | 6.3 | 6.1 | 867.6 | 885.4 | -46.2% | -53.8% | -59.8% |
| China | 2.2 | 4.0 | 1295.5 | 8.9 | 1420.1 | 5.6 | 5.5 | 496.2 | 519.5 | 146.1% | 39.3% | -38.3% |
| Russia | 2.3 | 1.6 | 144.6 | 2.0 | 132.6 | 0.7 | 0.7 | 112.4 | 114.1 | -69.5% | -55.5% | -64.7% |
| Transition Economies | 1.9 | 1.1 | 194.6 | 1.5 | 193.6 | 0.9 | 0.9 | 100.9 | 104.7 | -53.5% | -20.3% | -41.8% |
| India | 0.6 | 1.1 | 1064.6 | 1.7 | 1325.2 | 1.7 | 1.7 | 13.7 | 16.3 | 200.4% | 64.3% | -0.6% |
| Other NON-OECD Asia | 0.8 | 1.4 | 926.6 | 2.3 | 1177.4 | 1.6 | 1.7 | 70.1 | 72.9 | 108.2% | 23.2% | -26.9% |
| Middle East | 0.7 | 1.2 | 175.4 | 2.0 | 243.8 | 0.9 | 0.9 | 90.6 | 93.6 | 27.1% | -26.8% | -55.1% |
| Africa | 0.6 | 1.0 | 854.4 | 1.6 | 1207.2 | 1.1 | 1.3 | 48.1 | 50.7 | 107.0% | 37.4% | -13.6% |
| Brazil | 0.2 | 0.3 | 181.4 | 0.5 | 219.5 | 0.4 | 0.4 | 20.0 | 20.8 | 85.9% | 28.2% | -18.8% |
| Other South and Central America | 0.5 | 0.6 | 256.5 | 1.0 | 318.7 | 0.7 | 0.7 | 45.2 | 47.5 | 57.8% | 10.7% | -30.8% |
| Non-OECD minus China | 7.6 | 8.3 | 3798.1 | 12.6 | 4818.2 | 8.1 | 8.4 | 501.1 | 520.7 | 9.9% | 1.0% | -33.9% |
| Total Non-OECD | 9.8 | 12.2 | 5093.6 | 21.6 | 6238.3 | 13.7 | 13.9 | 997.3 | 1040.2 | 40.9% | 13.4% | -35.7% |
| Total World | 21.2 | 25.5 | 6245.1 | 36.8 | 7490.1 | 20.0 | 20.0 | 1865.0 | 1925.6 | -5.9% | -21.5% | -45.7% |

Table S3: 2020: Global emissions target of 20 GtCO₂ with individual emissions caps of 5.8 tCO₂ and 5.6 tCO₂ for the ‘20’ and ‘20P’ scenarios. The ‘20P’ scenario has a poverty floor of 0.5 tCO₂. The three rightmost columns show the ‘20P’ emissions change w.r.t. emissions in 1990, 2003 and under BAU.

| Region | Emissions [1990] | Emissions [2003] | Population [2003] | Emissions (BAU) [2020] | Population [2020] | Emissions (25) [2020] | Emissions (25P) [2020] | Population under cap (25) [2020] | Population under cap (25P) [2020] | (25P) change w.r.t. [1990] | (25P) change w.r.t. [2003] | (25P) change w.r.t. (BAU) |
|---------------------------------|------------------|------------------|-------------------|------------------------|-------------------|-----------------------|------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------|---------------------------|
| U.S. | 5.0 | 5.8 | 290.8 | 7.0 | 336.8 | 2.8 | 2.8 | 261.0 | 265.7 | -44.7% | -52.6% | -60.4% |
| Canada | 0.5 | 0.6 | 31.6 | 0.7 | 35.6 | 0.3 | 0.3 | 29.5 | 30.0 | -36.7% | -48.5% | -56.3% |
| Mexico | 0.3 | 0.4 | 101.0 | 0.6 | 121.4 | 0.5 | 0.5 | 14.3 | 14.9 | 53.7% | 21.1% | -21.3% |
| OECD Europe | 4.1 | 4.3 | 528.6 | 4.6 | 553.6 | 3.5 | 3.4 | 182.8 | 194.6 | -15.9% | -20.7% | -25.2% |
| Japan | 1.0 | 1.2 | 127.7 | 1.3 | 126.7 | 1.0 | 1.0 | 59.3 | 64.3 | -2.2% | -20.6% | -23.6% |
| South Korea | 0.2 | 0.5 | 47.9 | 0.6 | 49.9 | 0.4 | 0.4 | 31.2 | 32.4 | 65.3% | -16.6% | -35.4% |
| Australia and New Zealand | 0.3 | 0.4 | 23.9 | 0.5 | 27.9 | 0.2 | 0.2 | 20.8 | 21.2 | -22.6% | -45.5% | -56.7% |
| OECD minus U.S. | 6.4 | 7.4 | 860.7 | 8.3 | 915.1 | 5.9 | 5.8 | 337.8 | 357.4 | -9.3% | -21.8% | -30.0% |
| Total OECD | 11.4 | 13.3 | 1151.5 | 15.3 | 1251.8 | 8.8 | 8.6 | 598.9 | 623.1 | -24.8% | -35.3% | -43.9% |
| China | 2.2 | 4.0 | 1295.5 | 8.9 | 1420.1 | 6.9 | 6.8 | 269.1 | 283.7 | 201.7% | 70.8% | -24.3% |
| Russia | 2.3 | 1.6 | 144.6 | 2.0 | 132.6 | 1.1 | 1.0 | 83.3 | 86.2 | -55.5% | -35.2% | -48.6% |
| Transition Economies | 1.9 | 1.1 | 194.6 | 1.5 | 193.6 | 1.1 | 1.1 | 53.6 | 57.2 | -39.7% | 3.3% | -24.5% |
| India | 0.6 | 1.1 | 1064.6 | 1.7 | 1325.2 | 1.7 | 1.8 | 0.8 | 1.0 | 203.6% | 66.1% | 0.4% |
| Other Non-OECD Asia | 0.8 | 1.4 | 926.6 | 2.3 | 1177.4 | 1.8 | 1.9 | 45.3 | 47.0 | 131.5% | 37.0% | -18.8% |
| Middle East | 0.7 | 1.2 | 175.4 | 2.0 | 243.8 | 1.2 | 1.1 | 57.6 | 60.1 | 61.7% | -6.9% | -42.9% |
| Africa | 0.6 | 1.0 | 854.4 | 1.6 | 1207.2 | 1.2 | 1.5 | 24.5 | 25.9 | 125.1% | 49.4% | -6.0% |
| Brazil | 0.2 | 0.3 | 181.4 | 0.5 | 219.5 | 0.5 | 0.5 | 10.5 | 11.2 | 108.9% | 44.0% | -8.7% |
| Other South and Central America | 0.5 | 0.6 | 256.5 | 1.0 | 318.7 | 0.8 | 0.8 | 23.4 | 24.8 | 82.5% | 28.0% | -20.0% |
| Non-OECD minus China | 7.6 | 8.3 | 3798.1 | 12.6 | 4818.2 | 9.4 | 9.7 | 299.0 | 313.4 | 27.1% | 16.9% | -23.5% |
| Total Non-OECD | 9.8 | 12.2 | 5093.6 | 21.6 | 6238.3 | 16.2 | 16.4 | 568.1 | 597.1 | 66.9% | 34.3% | -23.8% |
| Total World | 21.2 | 25.5 | 6245.1 | 36.8 | 7490.1 | 25.0 | 25.0 | 1166.9 | 1220.2 | 17.7% | -1.9% | -32.1% |

Table S4: 2020: Global emissions target of 25 GtCO₂ with individual emissions caps of 9.2 tCO₂ and 8.8 tCO₂ for the ‘25’ and ‘25P’ scenarios. The ‘25P’ scenario has a poverty floor of 0.5 tCO₂. The three rightmost columns show the ‘25P’ emissions change w.r.t. emissions in 1990, 2003 and under BAU.

| Region | Emissions [1990] | Emissions [2003] | Population [2003] | Emissions (BAU) [2020] | Population [2020] | Emissions (30) [2020] | Emissions (30P) [2020] | Population under cap (30) [2020] | Population under cap (30P) [2020] | (30P) change w.r.t. [1990] | (30P) change w.r.t. [2003] | (30P) change w.r.t. (BAU) |
|---------------------------------|------------------|------------------|-------------------|------------------------|-------------------|-----------------------|------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------|---------------------------|
| U.S. | 5.0 | 5.8 | 290.8 | 7.0 | 336.8 | 4.2 | 4.1 | 179.3 | 187.9 | -18.8% | -30.3% | -41.8% |
| Canada | 0.5 | 0.6 | 31.6 | 0.7 | 35.6 | 0.5 | 0.4 | 19.9 | 21.0 | -5.8% | -23.4% | -34.9% |
| Mexico | 0.3 | 0.4 | 101.0 | 0.6 | 121.4 | 0.5 | 0.5 | 7.4 | 8.0 | 74.7% | 37.6% | -10.5% |
| OECD Europe | 4.1 | 4.3 | 528.6 | 4.6 | 553.6 | 4.2 | 4.1 | 57.5 | 65.4 | 0.7% | -5.1% | -10.4% |
| Japan | 1.0 | 1.2 | 127.7 | 1.3 | 126.7 | 1.2 | 1.2 | 17.1 | 19.3 | 18.0% | -4.1% | -7.8% |
| South Korea | 0.2 | 0.5 | 47.9 | 0.6 | 49.9 | 0.5 | 0.5 | 12.7 | 14.2 | 119.8% | 11.0% | -14.2% |
| Australia and New Zealand | 0.3 | 0.4 | 23.9 | 0.5 | 27.9 | 0.3 | 0.3 | 14.2 | 14.8 | 12.6% | -20.8% | -37.1% |
| OECD minus U.S. | 6.4 | 7.4 | 860.7 | 8.3 | 915.1 | 7.2 | 7.1 | 128.8 | 142.7 | 11.4% | -4.0% | -14.0% |
| Total OECD | 11.4 | 13.3 | 1151.5 | 15.3 | 1251.8 | 11.4 | 11.2 | 308.2 | 330.7 | -1.8% | -15.6% | -26.7% |
| China | 2.2 | 4.0 | 1295.5 | 8.9 | 1420.1 | 8.0 | 7.9 | 121.0 | 131.7 | 251.4% | 99.0% | -11.8% |
| Russia | 2.3 | 1.6 | 144.6 | 2.0 | 132.6 | 1.4 | 1.4 | 43.4 | 46.6 | -39.7% | -12.2% | -30.3% |
| Transition Economies | 1.9 | 1.1 | 194.6 | 1.5 | 193.6 | 1.3 | 1.3 | 19.1 | 21.2 | -28.8% | 22.1% | -10.8% |
| India | 0.6 | 1.1 | 1064.6 | 1.7 | 1325.2 | 1.7 | 1.8 | 0.0 | 0.0 | 203.8% | 66.2% | 0.5% |
| Other Non-OECD Asia | 0.8 | 1.4 | 926.6 | 2.3 | 1177.4 | 2.0 | 2.1 | 24.6 | 26.3 | 156.7% | 51.9% | -9.9% |
| Middle East | 0.7 | 1.2 | 175.4 | 2.0 | 243.8 | 1.4 | 1.4 | 30.7 | 32.6 | 97.7% | 13.8% | -30.2% |
| Africa | 0.6 | 1.0 | 854.4 | 1.6 | 1207.2 | 1.3 | 1.6 | 13.5 | 14.1 | 141.5% | 60.3% | 0.8% |
| Brazil | 0.2 | 0.3 | 181.4 | 0.5 | 219.5 | 0.5 | 0.5 | 2.9 | 3.4 | 126.0% | 55.8% | -1.2% |
| Other South and Central America | 0.5 | 0.6 | 256.5 | 1.0 | 318.7 | 0.9 | 0.9 | 9.8 | 10.7 | 103.2% | 42.5% | -10.9% |
| Non-OECD minus China | 7.6 | 8.3 | 3798.1 | 12.6 | 4818.2 | 10.6 | 10.9 | 143.9 | 154.9 | 43.8% | 32.2% | -13.5% |
| Total Non-OECD | 9.8 | 12.2 | 5093.6 | 21.6 | 6238.3 | 18.6 | 18.8 | 264.9 | 286.6 | 91.1% | 53.8% | -12.8% |
| Total World | 21.2 | 25.5 | 6245.1 | 36.8 | 7490.1 | 30.0 | 30.0 | 573.1 | 617.3 | 41.2% | 17.7% | -18.5% |

Table S5: 2020: Global emissions target of 30 GtCO₂ with individual emissions caps of 15.2 tCO₂ and 14.6 tCO₂ for the ‘30’ and ‘30P’ scenarios. The ‘30P’ scenario has a poverty floor of 0.5 tCO₂. The three rightmost columns show the ‘30P’ emissions change w.r.t. emissions in 1990, 2003 and under BAU.

| Region | Emissions [1990] | Emissions [2003] | Population [2003] | Emissions (BAU) [2020] | Population [2020] | Emissions (33) [2020] | Emissions (33P) [2020] | Population under cap (33) [2020] | Population under cap (33P) [2020] | (33P) change w.r.t. [1990] | (33P) change w.r.t. [2003] | (33P) change w.r.t. (BAU) |
|---------------------------------|------------------|------------------|-------------------|------------------------|-------------------|-----------------------|------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------|---------------------------|
| U.S. | 5.0 | 5.8 | 290.8 | 7.0 | 336.8 | 5.2 | 5.1 | 102.8 | 114.5 | 1.6% | -12.9% | -27.2% |
| Canada | 0.5 | 0.6 | 31.6 | 0.7 | 35.6 | 0.6 | 0.6 | 10.0 | 11.5 | 17.2% | -4.6% | -19.0% |
| Mexico | 0.3 | 0.4 | 101.0 | 0.6 | 121.4 | 0.6 | 0.6 | 2.9 | 3.5 | 87.2% | 47.4% | -4.1% |
| OECD Europe | 4.1 | 4.3 | 528.6 | 4.6 | 553.6 | 4.4 | 4.4 | 16.8 | 20.5 | 7.0% | 0.9% | -4.8% |
| Japan | 1.0 | 1.2 | 127.7 | 1.3 | 126.7 | 1.3 | 1.3 | 4.2 | 5.6 | 25.5% | 2.0% | -1.9% |
| South Korea | 0.2 | 0.5 | 47.9 | 0.6 | 49.9 | 0.6 | 0.6 | 2.9 | 3.9 | 143.2% | 22.8% | -5.0% |
| Australia and New Zealand | 0.3 | 0.4 | 23.9 | 0.5 | 27.9 | 0.4 | 0.4 | 8.1 | 9.0 | 40.1% | -1.4% | -21.7% |
| OECD minus U.S. | 6.4 | 7.4 | 860.7 | 8.3 | 915.1 | 7.8 | 7.8 | 44.8 | 54.0 | 21.0% | 4.3% | -6.6% |
| Total OECD | 11.4 | 13.3 | 1151.5 | 15.3 | 1251.8 | 13.0 | 12.8 | 147.6 | 168.6 | 12.5% | -3.3% | -16.0% |
| China | 2.2 | 4.0 | 1295.5 | 8.9 | 1420.1 | 8.6 | 8.5 | 47.0 | 56.3 | 278.5% | 114.3% | -5.0% |
| Russia | 2.3 | 1.6 | 144.6 | 2.0 | 132.6 | 1.7 | 1.6 | 22.5 | 25.0 | -29.7% | 2.3% | -18.8% |
| Transition Economies | 1.9 | 1.1 | 194.6 | 1.5 | 193.6 | 1.4 | 1.4 | 6.7 | 8.1 | -23.8% | 30.5% | -4.7% |
| India | 0.6 | 1.1 | 1064.6 | 1.7 | 1325.2 | 1.7 | 1.8 | 0.0 | 0.0 | 203.8% | 66.2% | 0.5% |
| Other Non-OECD Asia | 0.8 | 1.4 | 926.6 | 2.3 | 1177.4 | 2.1 | 2.2 | 11.4 | 13.2 | 172.7% | 61.4% | -4.3% |
| Middle East | 0.7 | 1.2 | 175.4 | 2.0 | 243.8 | 1.6 | 1.6 | 17.0 | 18.7 | 121.6% | 27.6% | -21.8% |
| Africa | 0.6 | 1.0 | 854.4 | 1.6 | 1207.2 | 1.4 | 1.6 | 8.8 | 9.5 | 153.6% | 68.4% | 5.9% |
| Brazil | 0.2 | 0.3 | 181.4 | 0.5 | 219.5 | 0.5 | 0.5 | 0.5 | 0.7 | 131.3% | 59.5% | 1.1% |
| Other South and Central America | 0.5 | 0.6 | 256.5 | 1.0 | 318.7 | 1.0 | 1.0 | 4.3 | 4.9 | 114.2% | 50.3% | -6.1% |
| Non-OECD minus China | 7.6 | 8.3 | 3798.1 | 12.6 | 4818.2 | 11.4 | 11.7 | 71.3 | 80.1 | 53.8% | 41.4% | -7.4% |
| Total Non-OECD | 9.8 | 12.2 | 5093.6 | 21.6 | 6238.3 | 20.0 | 20.2 | 118.2 | 136.4 | 105.0% | 65.0% | -6.4% |
| Total World | 21.2 | 25.5 | 6245.1 | 36.8 | 7490.1 | 33.0 | 33.0 | 265.8 | 305.0 | 55.3% | 29.5% | -10.4% |

Table S6: 2020: Global emissions target of 33 GtCO₂ with individual emissions caps of 22.8 tCO₂ and 21.4 tCO₂ for the ‘33’ and ‘33P’ scenarios. The ‘33P’ scenario has a poverty floor of 0.5 tCO₂. The three rightmost columns show the ‘33P’ emissions change w.r.t. emissions in 1990, 2003 and under BAU.

| Region | Emissions [1990] | Emissions [2003] | Population [2003] | Emissions (BAU) [2030] | Population [2030] | Emissions (20) [2030] | Emissions (20P) [2030] | Population under cap (20) [2030] | Population under cap (20P) [2030] | (20P) change w.r.t. [1990] | (20P) change w.r.t. [2003] | (20P) change w.r.t. (BAU) |
|---------------------------------|------------------|------------------|-------------------|------------------------|-------------------|-----------------------|------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------|---------------------------|
| U.S. | 5.0 | 5.8 | 290.8 | 8.0 | 364.7 | 1.7 | 1.5 | 342.5 | 347.7 | -69.2% | -73.6% | -80.7% |
| Canada | 0.5 | 0.6 | 31.6 | 0.7 | 38.6 | 0.2 | 0.2 | 37.2 | 37.6 | -65.4% | -71.9% | -77.9% |
| Mexico | 0.3 | 0.4 | 101.0 | 0.7 | 129.2 | 0.4 | 0.4 | 41.1 | 48.9 | 33.1% | 4.9% | -42.2% |
| OECD Europe | 4.1 | 4.3 | 528.6 | 4.7 | 560.6 | 2.4 | 2.1 | 378.8 | 407.9 | -47.6% | -50.6% | -54.4% |
| Japan | 1.0 | 1.2 | 127.7 | 1.3 | 122.8 | 0.6 | 0.5 | 118.3 | 120.6 | -48.4% | -58.1% | -60.1% |
| South Korea | 0.2 | 0.5 | 47.9 | 0.7 | 49.9 | 0.2 | 0.2 | 46.7 | 47.7 | -11.3% | -55.3% | -69.2% |
| Australia and New Zealand | 0.3 | 0.4 | 23.9 | 0.6 | 29.9 | 0.1 | 0.1 | 27.6 | 28.1 | -56.9% | -69.7% | -78.3% |
| OECD minus U.S. | 6.4 | 7.4 | 860.7 | 8.7 | 930.8 | 4.0 | 3.6 | 649.6 | 690.9 | -44.4% | -52.0% | -59.1% |
| Total OECD | 11.4 | 13.3 | 1151.5 | 16.7 | 1295.6 | 5.7 | 5.1 | 992.1 | 1038.6 | -55.2% | -61.5% | -69.4% |
| China | 2.2 | 4.0 | 1295.5 | 11.4 | 1442.1 | 5.6 | 5.2 | 779.3 | 866.9 | 131.2% | 30.9% | -54.6% |
| Russia | 2.3 | 1.6 | 144.6 | 2.2 | 124.7 | 0.6 | 0.5 | 116.0 | 118.5 | -77.4% | -67.1% | -75.9% |
| Transition Economies | 1.9 | 1.1 | 194.6 | 1.6 | 189.7 | 0.8 | 0.7 | 126.8 | 136.6 | -61.5% | -34.0% | -56.5% |
| India | 0.6 | 1.1 | 1064.6 | 2.2 | 1441.6 | 2.1 | 2.2 | 50.1 | 71.5 | 285.1% | 110.6% | 1.6% |
| Other Non-OECD Asia | 0.8 | 1.4 | 926.6 | 2.8 | 1307.8 | 1.8 | 2.1 | 103.7 | 120.5 | 162.9% | 55.6% | -23.6% |
| Middle East | 0.7 | 1.2 | 175.4 | 2.3 | 282.3 | 1.0 | 0.9 | 122.5 | 135.2 | 27.0% | -26.9% | -61.6% |
| Africa | 0.6 | 1.0 | 854.4 | 1.8 | 1438.2 | 1.2 | 2.0 | 70.5 | 82.7 | 206.0% | 103.2% | 9.9% |
| Brazil | 0.2 | 0.3 | 181.4 | 0.6 | 236.6 | 0.4 | 0.5 | 29.0 | 33.2 | 111.6% | 45.9% | -22.6% |
| Other South and Central America | 0.5 | 0.6 | 256.5 | 1.2 | 349.2 | 0.8 | 0.8 | 67.8 | 78.2 | 71.9% | 20.6% | -36.2% |
| Non-OECD minus China | 7.6 | 8.3 | 3798.1 | 14.8 | 5370.1 | 8.7 | 9.7 | 686.3 | 776.4 | 27.8% | 17.4% | -34.2% |
| Total Non-OECD | 9.8 | 12.2 | 5093.6 | 26.2 | 6812.1 | 14.3 | 14.9 | 1465.7 | 1643.3 | 51.3% | 21.8% | -43.1% |
| Total World | 21.2 | 25.5 | 6245.1 | 42.9 | 8107.7 | 20.0 | 20.0 | 2457.8 | 2681.9 | -5.9% | -21.5% | -53.3% |

Table S7: 2030: Global emissions target of 20 GtCO₂ with individual emissions caps of 4.9 tCO₂ and 4.3 tCO₂ for the ‘20’ and ‘20P’ scenarios. The ‘20P’ scenario has a poverty floor of 1.0 tCO₂. The three rightmost columns show the ‘20P’ emissions change w.r.t. emissions in 1990, 2003 and under BAU.

| Region | Emissions [1990] | Emissions [2003] | Population [2003] | Emissions (BAU) [2030] | Population [2030] | Emissions (25) [2030] | Emissions (25P) [2030] | Population under cap (25) [2030] | Population under cap (25P) [2030] | (25P) change w.r.t. [1990] | (25P) change w.r.t. [2003] | (25P) change w.r.t. (BAU) |
|---------------------------------|------------------|------------------|-------------------|------------------------|-------------------|-----------------------|------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------|---------------------------|
| U.S. | 5.0 | 5.8 | 290.8 | 8.0 | 364.7 | 2.5 | 2.3 | 315.6 | 325.4 | -54.5% | -60.9% | -71.5% |
| Canada | 0.5 | 0.6 | 31.6 | 0.7 | 38.6 | 0.3 | 0.2 | 34.7 | 35.7 | -48.6% | -58.2% | -67.1% |
| Mexico | 0.3 | 0.4 | 101.0 | 0.7 | 129.2 | 0.5 | 0.5 | 23.0 | 27.2 | 59.6% | 25.7% | -30.8% |
| OECD Europe | 4.1 | 4.3 | 528.6 | 4.7 | 560.6 | 3.1 | 2.9 | 263.5 | 300.3 | -28.8% | -32.8% | -38.1% |
| Japan | 1.0 | 1.2 | 127.7 | 1.3 | 122.8 | 0.9 | 0.8 | 92.4 | 103.8 | -23.9% | -38.2% | -41.1% |
| South Korea | 0.2 | 0.5 | 47.9 | 0.7 | 49.9 | 0.3 | 0.3 | 40.9 | 43.1 | 30.4% | -34.2% | -54.8% |
| Australia and New Zealand | 0.3 | 0.4 | 23.9 | 0.6 | 29.9 | 0.2 | 0.2 | 25.0 | 25.9 | -36.6% | -55.4% | -68.1% |
| OECD minus U.S. | 6.4 | 7.4 | 860.7 | 8.7 | 930.8 | 5.3 | 4.9 | 479.4 | 535.9 | -23.5% | -34.1% | -43.7% |
| Total OECD | 11.4 | 13.3 | 1151.5 | 16.7 | 1295.6 | 7.8 | 7.2 | 795.0 | 861.3 | -37.1% | -45.9% | -57.0% |
| China | 2.2 | 4.0 | 1295.5 | 11.4 | 1442.1 | 7.2 | 6.7 | 507.2 | 583.3 | 200.7% | 70.3% | -40.9% |
| Russia | 2.3 | 1.6 | 144.6 | 2.2 | 124.7 | 0.9 | 0.8 | 101.8 | 107.1 | -66.9% | -51.7% | -64.6% |
| Transition Economies | 1.9 | 1.1 | 194.6 | 1.6 | 189.7 | 1.0 | 1.0 | 88.5 | 100.5 | -47.6% | -10.3% | -40.9% |
| India | 0.6 | 1.1 | 1064.6 | 2.2 | 1441.6 | 2.2 | 2.3 | 10.0 | 17.5 | 299.8% | 118.7% | 5.5% |
| Other Non-OECD Asia | 0.8 | 1.4 | 926.6 | 2.8 | 1307.8 | 2.0 | 2.3 | 67.8 | 76.1 | 188.4% | 70.7% | -16.2% |
| Middle East | 0.7 | 1.2 | 175.4 | 2.3 | 282.3 | 1.2 | 1.1 | 85.9 | 96.0 | 62.2% | -6.6% | -51.0% |
| Africa | 0.6 | 1.0 | 854.4 | 1.8 | 1438.2 | 1.3 | 2.1 | 39.8 | 47.5 | 227.1% | 117.2% | 17.5% |
| Brazil | 0.2 | 0.3 | 181.4 | 0.6 | 236.6 | 0.5 | 0.5 | 18.7 | 21.5 | 137.9% | 64.0% | -12.9% |
| Other South and Central America | 0.5 | 0.6 | 256.5 | 1.2 | 349.2 | 0.9 | 0.9 | 40.4 | 47.5 | 101.3% | 41.2% | -25.2% |
| Non-OECD minus China | 7.6 | 8.3 | 3798.1 | 14.8 | 5370.1 | 10.0 | 11.1 | 452.9 | 513.7 | 45.8% | 34.0% | -24.9% |
| Total Non-OECD | 9.8 | 12.2 | 5093.6 | 26.2 | 6812.1 | 17.2 | 17.8 | 960.1 | 1097.0 | 81.0% | 45.7% | -31.9% |
| Total World | 21.2 | 25.5 | 6245.1 | 42.9 | 8107.7 | 25.0 | 25.0 | 1755.0 | 1958.3 | 17.7% | -1.9% | -41.7% |

Table S8: 2030: Global emissions target of 25 GtCO₂ with individual emissions caps of 7.3 tCO₂ and 6.5 tCO₂ for the ‘25’ and ‘25P’ scenarios. The ‘25P’ scenario has a poverty floor of 1.0 tCO₂. The three rightmost columns show the ‘25P’ emissions change w.r.t. emissions in 1990, 2003 and under BAU.

| Region | Emissions [1990] | Emissions [2003] | Population [2003] | Emissions (BAU) [2030] | Population [2030] | Emissions (30) [2030] | Emissions (30P) [2030] | Population under cap (30) [2030] | Population under cap (30P) [2030] | (30P) change w.r.t. [1990] | (30P) change w.r.t. [2003] | (30P) change w.r.t. (BAU) |
|---------------------------------|------------------|------------------|-------------------|------------------------|-------------------|-----------------------|------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------|---------------------------|
| U.S. | 5.0 | 5.8 | 290.8 | 8.0 | 364.7 | 3.6 | 3.2 | 267.0 | 284.5 | -35.4% | -44.6% | -59.5% |
| Canada | 0.5 | 0.6 | 31.6 | 0.7 | 38.6 | 0.4 | 0.3 | 29.3 | 31.3 | -26.5% | -40.1% | -53.0% |
| Mexico | 0.3 | 0.4 | 101.0 | 0.7 | 129.2 | 0.6 | 0.5 | 14.2 | 16.3 | 81.1% | 42.6% | -21.4% |
| OECD Europe | 4.1 | 4.3 | 528.6 | 4.7 | 560.6 | 3.8 | 3.6 | 138.9 | 175.1 | -11.0% | -16.0% | -22.6% |
| Japan | 1.0 | 1.2 | 127.7 | 1.3 | 122.8 | 1.1 | 1.0 | 43.0 | 57.2 | 0.8% | -18.1% | -22.0% |
| South Korea | 0.2 | 0.5 | 47.9 | 0.7 | 49.9 | 0.5 | 0.4 | 29.6 | 33.6 | 80.9% | -8.7% | -37.2% |
| Australia and New Zealand | 0.3 | 0.4 | 23.9 | 0.6 | 29.9 | 0.3 | 0.3 | 20.7 | 22.2 | -10.8% | -37.3% | -55.1% |
| OECD minus U.S. | 6.4 | 7.4 | 860.7 | 8.7 | 930.8 | 6.6 | 6.2 | 275.7 | 335.7 | -2.5% | -16.0% | -28.3% |
| Total OECD | 11.4 | 13.3 | 1151.5 | 16.7 | 1295.6 | 10.2 | 9.5 | 542.7 | 620.2 | -16.9% | -28.5% | -43.2% |
| China | 2.2 | 4.0 | 1295.5 | 11.4 | 1442.1 | 8.5 | 8.2 | 299.7 | 354.0 | 264.1% | 106.1% | -28.5% |
| Russia | 2.3 | 1.6 | 144.6 | 2.2 | 124.7 | 1.2 | 1.1 | 76.6 | 85.4 | -54.0% | -33.0% | -50.9% |
| Transition Economies | 1.9 | 1.1 | 194.6 | 1.6 | 189.7 | 1.3 | 1.2 | 48.9 | 60.2 | -34.4% | 12.4% | -25.9% |
| India | 0.6 | 1.1 | 1064.6 | 2.2 | 1441.6 | 2.2 | 2.3 | 0.7 | 1.8 | 303.6% | 120.8% | 6.5% |
| Other Non-OECD Asia | 0.8 | 1.4 | 926.6 | 2.8 | 1307.8 | 2.2 | 2.5 | 46.5 | 52.4 | 212.6% | 85.0% | -9.2% |
| Middle East | 0.7 | 1.2 | 175.4 | 2.3 | 282.3 | 1.4 | 1.4 | 55.8 | 64.2 | 96.9% | 13.4% | -40.5% |
| Africa | 0.6 | 1.0 | 854.4 | 1.8 | 1438.2 | 1.4 | 2.2 | 22.8 | 26.6 | 244.0% | 128.4% | 23.5% |
| Brazil | 0.2 | 0.3 | 181.4 | 0.6 | 236.6 | 0.6 | 0.6 | 10.1 | 12.6 | 161.4% | 80.2% | -4.3% |
| Other South and Central America | 0.5 | 0.6 | 256.5 | 1.2 | 349.2 | 1.0 | 1.0 | 22.3 | 26.9 | 126.0% | 58.5% | -16.1% |
| Non-OECD minus China | 7.6 | 8.3 | 3798.1 | 14.8 | 5370.1 | 11.3 | 12.4 | 283.7 | 330.1 | 62.7% | 49.5% | -16.2% |
| Total Non-OECD | 9.8 | 12.2 | 5093.6 | 26.2 | 6812.1 | 19.8 | 20.5 | 583.4 | 684.1 | 108.5% | 67.8% | -21.6% |
| Total World | 21.2 | 25.5 | 6245.1 | 42.9 | 8107.7 | 30.0 | 30.0 | 1126.1 | 1304.3 | 41.2% | 17.7% | -30.0% |

Table S9: 2030: Global emissions target of 30 GtCO₂ with individual emissions caps of 10.8 tCO₂ and 9.6 tCO₂ for the '30' and '30P' scenarios. The '30P' scenario has a poverty floor of 1.0 tCO₂. The three rightmost columns show the '30P' emissions change w.r.t. emissions in 1990, 2003 and under BAU.

| Region | Emissions [1990] | Emissions [2003] | Population [2003] | Emissions (BAU) [2030] | Population [2030] | Emissions (35) [2030] | Emissions (35P) [2030] | Population under cap (35) [2030] | Population under cap (35P) [2030] | (35P) change w.r.t. [1990] | (35P) change w.r.t. [2003] | (35P) change w.r.t. (BAU) |
|---------------------------------|------------------|------------------|-------------------|------------------------|-------------------|-----------------------|------------------------|----------------------------------|-----------------------------------|----------------------------|----------------------------|---------------------------|
| U.S. | 5.0 | 5.8 | 290.8 | 8.0 | 364.7 | 4.9 | 4.5 | 184.9 | 213.6 | -10.2% | -23.0% | -43.8% |
| Canada | 0.5 | 0.6 | 31.6 | 0.7 | 38.6 | 0.5 | 0.5 | 18.9 | 22.6 | 2.3% | -16.8% | -34.6% |
| Mexico | 0.3 | 0.4 | 101.0 | 0.7 | 129.2 | 0.6 | 0.6 | 7.9 | 9.9 | 102.4% | 59.4% | -12.2% |
| OECD Europe | 4.1 | 4.3 | 528.6 | 4.7 | 560.6 | 4.3 | 4.2 | 44.7 | 67.2 | 2.9% | -2.9% | -10.5% |
| Japan | 1.0 | 1.2 | 127.7 | 1.3 | 122.8 | 1.2 | 1.2 | 14.2 | 20.4 | 18.0% | -4.1% | -8.7% |
| South Korea | 0.2 | 0.5 | 47.9 | 0.7 | 49.9 | 0.6 | 0.6 | 13.3 | 18.4 | 135.4% | 18.8% | -18.3% |
| Australia and New Zealand | 0.3 | 0.4 | 23.9 | 0.6 | 29.9 | 0.4 | 0.4 | 14.1 | 16.4 | 22.5% | -13.8% | -38.3% |
| OECD minus U.S. | 6.4 | 7.4 | 860.7 | 8.7 | 930.8 | 7.7 | 7.4 | 113.0 | 154.8 | 15.7% | -0.2% | -14.9% |
| Total OECD | 11.4 | 13.3 | 1151.5 | 16.7 | 1295.6 | 12.6 | 11.9 | 297.9 | 368.5 | 4.4% | -10.2% | -28.7% |
| China | 2.2 | 4.0 | 1295.5 | 11.4 | 1442.1 | 9.8 | 9.5 | 154.5 | 193.8 | 323.0% | 139.5% | -16.9% |
| Russia | 2.3 | 1.6 | 144.6 | 2.2 | 124.7 | 1.5 | 1.4 | 43.4 | 53.5 | -39.2% | -11.4% | -35.0% |
| Transition Economies | 1.9 | 1.1 | 194.6 | 1.6 | 189.7 | 1.5 | 1.4 | 19.7 | 27.0 | -23.3% | 31.5% | -13.4% |
| India | 0.6 | 1.1 | 1064.6 | 2.2 | 1441.6 | 2.2 | 2.3 | 0.0 | 0.0 | 304.0% | 121.0% | 6.6% |
| Other Non-OECD Asia | 0.8 | 1.4 | 926.6 | 2.8 | 1307.8 | 2.4 | 2.7 | 26.6 | 32.7 | 238.7% | 100.4% | -1.6% |
| Middle East | 0.7 | 1.2 | 175.4 | 2.3 | 282.3 | 1.7 | 1.6 | 31.1 | 38.0 | 132.3% | 33.8% | -29.8% |
| Africa | 0.6 | 1.0 | 854.4 | 1.8 | 1438.2 | 1.6 | 2.3 | 14.2 | 16.4 | 259.9% | 139.0% | 29.2% |
| Brazil | 0.2 | 0.3 | 181.4 | 0.6 | 236.6 | 0.6 | 0.6 | 3.1 | 4.9 | 180.2% | 93.2% | 2.6% |
| Other South and Central America | 0.5 | 0.6 | 256.5 | 1.2 | 349.2 | 1.1 | 1.1 | 10.2 | 13.3 | 147.2% | 73.4% | -8.2% |
| Non-OECD minus China | 7.6 | 8.3 | 3798.1 | 14.8 | 5370.1 | 12.5 | 13.6 | 148.4 | 185.8 | 79.2% | 64.7% | -7.7% |
| Total Non-OECD | 9.8 | 12.2 | 5093.6 | 26.2 | 6812.1 | 22.4 | 23.1 | 302.9 | 379.5 | 134.7% | 88.9% | -11.7% |
| Total World | 21.2 | 25.5 | 6245.1 | 42.9 | 8107.7 | 35.0 | 35.0 | 600.9 | 748.0 | 64.8% | 37.3% | -18.3% |

Table S10: 2030: Global emissions target of 35 GtCO₂ with individual emissions caps of 16.8 tCO₂ and 14.6 tCO₂ for the ‘35’ and ‘35P’ scenarios. The ‘35P’ scenario has a poverty floor of 1.0 tCO₂. The three rightmost columns show the ‘35P’ emissions change w.r.t. emissions in 1990, 2003 and under BAU.

3.2 Sensitivity of the Global Cap to the Emissions Elasticity.

For sake of simplicity, throughout the main text we assume proportionality between emissions and expenditures (an elasticity of 1.0), a world where two persons whose expenditures differ by 10% will also differ by 10% in their emissions. Here we explore the consequences of other relationships between emissions and expenditures by treating the corresponding elasticity as a parameter. An elasticity lower than unity is a situation where the poor spend a higher fraction of their consumption budget on energy and emissions than the rich do, a situation where a flat carbon tax would be regressive. We assume a constant global β but let it take the values, 0.7, 0.8, 0.9 and 1.0.

Figures S5 and S6 show the effect of changing the $\beta = 1.0$ rule on the global population distribution and the global emissions distributions, respectively. For both 2003 and 2030, aggregate emissions of the low emitters increase as β falls, as expected. Note the five-fold change of horizontal scale between Figure S5 and Figure S6, expressing the large share of global emissions coming from the highest emitters. Figure 6 shows the expected high-emitter effect of lower β : Lower values of β are associated with lower aggregate emissions by the emitters above 25 tCO₂/yr in 2030. The effect of various expenditure-emission elasticities on the 2020 and the 2030 universal cap is shown in Table S11. The global emissions target ranges from 20 to 35 GtCO₂, and the world does and doesn't have a poverty floor of 0.5 tCO₂ in 2020 and 1.0 tCO₂ in 2030. The individual emissions caps in Table S11 for 2030 are derived from Figure S7 using the method described in subsection 3.1 (see Figure S4).

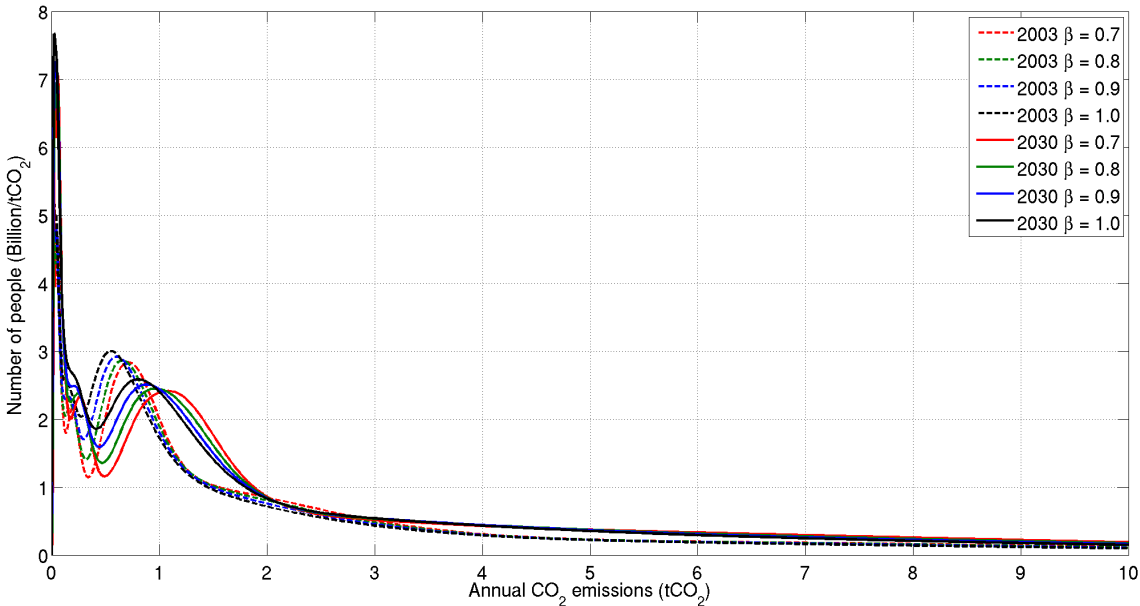


Figure S5: The global distribution of the number of emitters at a given annual individual emissions rate vs. the individual emissions rate in 2003 and 2030 for different values of the elasticity of emissions β .

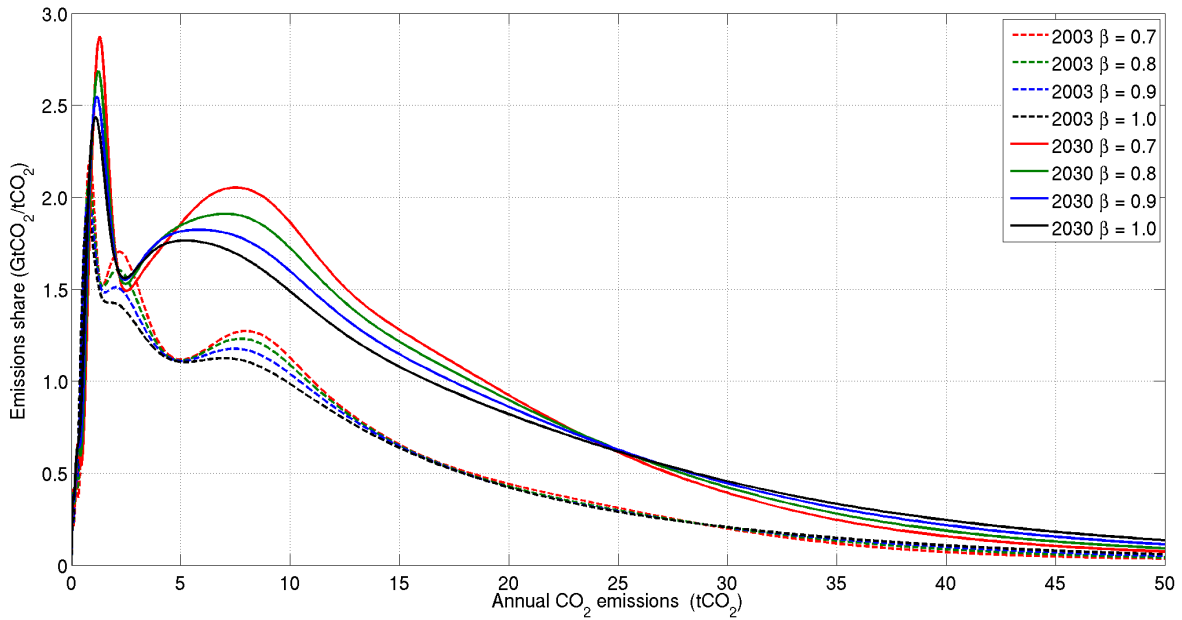


Figure S6: The global distribution of emissions at a given annual individual emissions rate vs. the annual individual emissions in 2003 and 2030 for different values of the elasticity of emissions β .

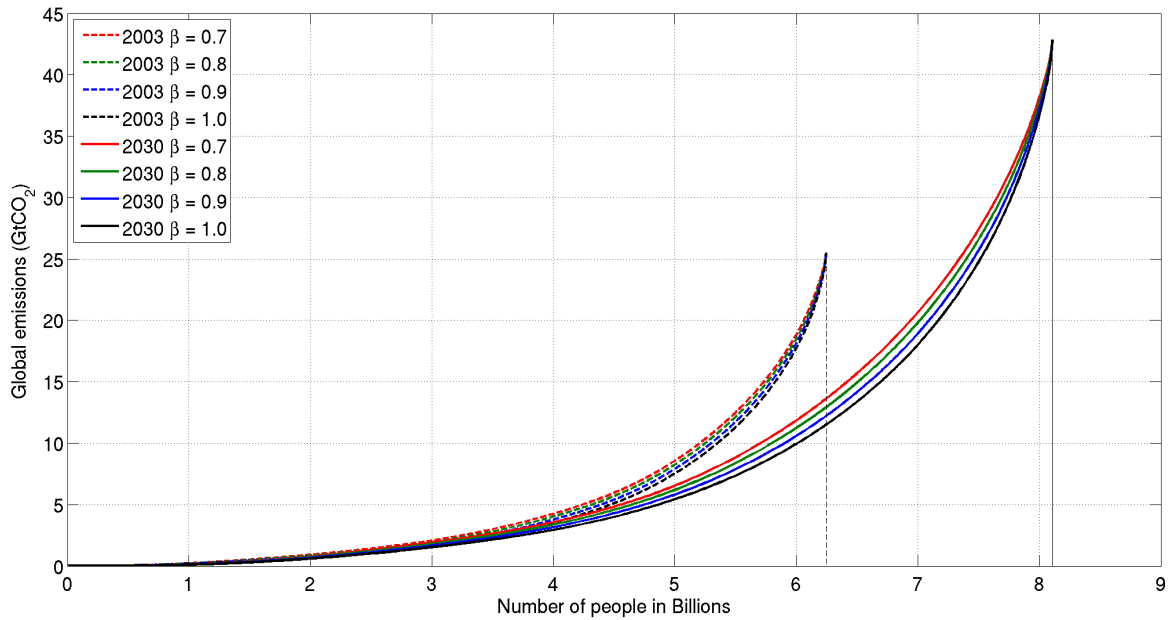


Figure S7: Cumulative emissions vs. cumulative population for 2003 and 2030 for different values of β .

| Year | Elasticity (β) | [Individual emissions cap in tCO ₂ /year] | | | | | | | | | |
|------|---------------------------|--|-----|-----|-----|-------------|------------|------|------|------|------|
| | | 20 | 20P | 25 | 25P | 30 | 30P | 33 | 33P | 35 | 35P |
| 2020 | 1.0 | 5.8 | 5.6 | 9.2 | 8.8 | 15.2 | 14.6 | 22.8 | 21.4 | | |
| | 0.9 | 5.5 | 5.3 | 8.6 | 8.3 | 14.0 | 13.4 | 20.5 | 19.3 | | |
| | 0.8 | 5.3 | 5.1 | 8.1 | 7.8 | 12.9 | 12.4 | 18.6 | 17.6 | | |
| | 0.7 | 5.1 | 4.9 | 7.7 | 7.4 | 12.0 | 11.6 | 17.0 | 16.3 | | |
| 2030 | 1.0 | 4.9 | 4.3 | 7.3 | 6.5 | 10.8 | 9.6 | | | 16.8 | 14.6 |
| | 0.9 | 4.7 | 4.1 | 6.9 | 6.2 | 10.1 | 9.0 | | | 15.4 | 13.6 |
| | 0.8 | 4.5 | 4.0 | 6.5 | 5.9 | 9.4 | 8.6 | | | 14.2 | 12.6 |
| | 0.7 | 4.3 | 3.9 | 6.3 | 5.7 | 8.9 | 8.2 | | | 13.1 | 11.9 |

Table S11: The individual cap for different global targets. For example, ‘20’ and ‘20P’ refer to a global emissions target of 20 GtCO₂. ‘20P’ also includes a poverty floor of 0.5 tCO₂ in 2020 and 1.0 tCO₂ in 2030. The table shows how the cap changes for different constant elasticities of CO₂ emissions with consumption expenditure. BAU emissions in 2020 and 2030 are projected to be 36.8 GtCO₂ and 42.9 GtCO₂ respectively. The individual caps for the ‘30’ and ‘30P’ scenario (**10.8** tCO₂ and **9.6** tCO₂, respectively) in 2030 are extensively used in the main text.

We see that the individual cap tightens with a decrease in elasticity. This happens because with a lower elasticity a larger share of emissions comes from the middle of the distribution. The cap for an elasticity of 0.7 is 10% to 25% lower than for an elasticity of 1.0, for the same target.

3.3 Sensitivity of Regional Emissions Projections to the Emissions Elasticity

In Figures S8-S23 we show the variation in regional emissions with change in the elasticity of emissions: β . We show the projections for $\beta = 1.0$, $\beta = 0.9$, $\beta = 0.8$ and $\beta = 0.7$, with β assumed to be the same for all countries. We also show the range of projected emissions with a random β for each country, sampled independently from a uniform distribution in the interval $0.7 \leq \beta \leq 1.0$.

Some broad patterns emerge from the sensitivity analysis. As shown in Figure S3, reducing the elasticity β from 1.0 to 0.7 has the effect of making a country’s emissions distribution more equitable, thereby increasing the number of people whose emissions are close to the per capita value, and reducing the number of very low and very high emitters. As a result, the emissions of different regions varies significantly. Regions with a large number of high emitters, especially those whose average emissions are significantly above the cap see a further reduction in total allocated emissions as a higher fraction of the population is under the cap (U.S., Russia, Canada etc.). Regions where most of the people emit significantly below the cap see an increase in total allocated emissions with decrease in β as the number of people above the cap decreases (Africa, India etc.). The results are intermediate for regions between these two extremes. The blue and pink rectangles show the range of regional emissions allocations that may be expected in 2020

and 2030, respectively, if we allow countries to have emissions distributions that have different emissions elasticities (randomly distributed between 0.7 and 1.0).

How to read Figures S8-S23?

The figures are all in same format so we provide some extended notes here. Projected regional emissions in GtCO₂ are shown on the Y-axis and the different global scenarios are listed on the X-axis. The four horizontal lines that stretch across the graph are the emissions in 1990, 2003, 2020 BAU and 2030 BAU (labeled likewise on the graphs). The '20', '20P', '25', '25P', '30', '30P' scenarios are for both 2020 and 2030. The '33' and '33P' scenarios are for 2020 only whereas the '35' and the '35P' scenarios are 2030. The numbers refer to the global emissions target in GtCO₂ and the 'P' scenarios provide for a 'poverty emissions floor' of 0.5 tCO₂ in 2020 and 1.0 tCO₂ in 2030. This, of course, results in some redistribution of the projected emissions across the different regions. The red, green, blue and black lines show the regional emissions when the elasticity of emissions β is assumed to be 0.7, 0.8, 0.9 and 1.0, respectively. 2020 values are shown using dashed lines and 2030 in bold lines. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for 100 independent runs of the projections with random β s for different countries using uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$.

The primary difference between the 'P' and the 'non-P' scenarios is that regions with a large number of people who emit below the poverty floor (0.5 GtCO₂ in 2020, and 1.0 GtCO₂ in 2030) are allowed higher emissions. Since the global target remains the same, the individual cap is lower, and other regions have to make more stringent reductions. So, Africa gets to emit more and the U.S. has more stringent reductions.

We also highlight the difference between the 2020 and 2030 regional emissions targets for the same global emissions target ('25P' in 2020 vs. '25P' in 2030, for example). Regions that already have high emitters as a large fraction of their population in 2003 have 2030 emissions targets that are lower than the 2020 targets (the OECD countries except Mexico, Russia and the Transition Economies). This observation is a consequence of two factors: 1) Stable or declining populations and 2) tighter individual caps for the same global targets in 2030, compared to 2020.

Most of the other regions see higher emissions in 2030 compared to 2020 though they might see a reduction compared to BAU. Most of the individuals in these regions have emissions below the 2020 caps. When emissions are rising at a fast pace as a result of population growth and economic development, the increase in emissions from those below the cap can be much higher than any decrease from those above the cap. This remains true even if the cap in 2030 is lower than the cap in 2020.

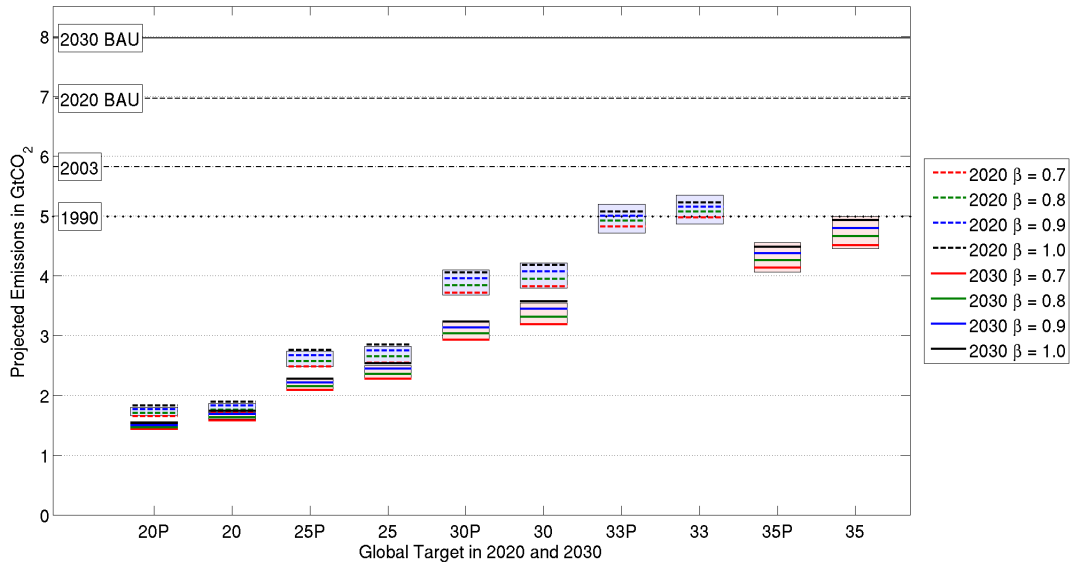


Figure S8: U.S. emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

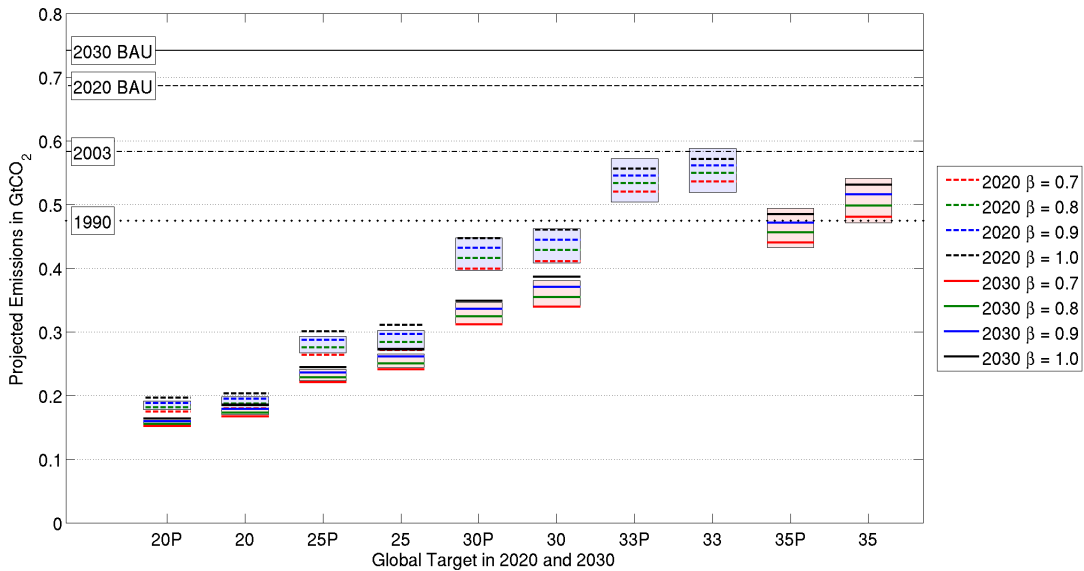


Figure S9: Canada emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

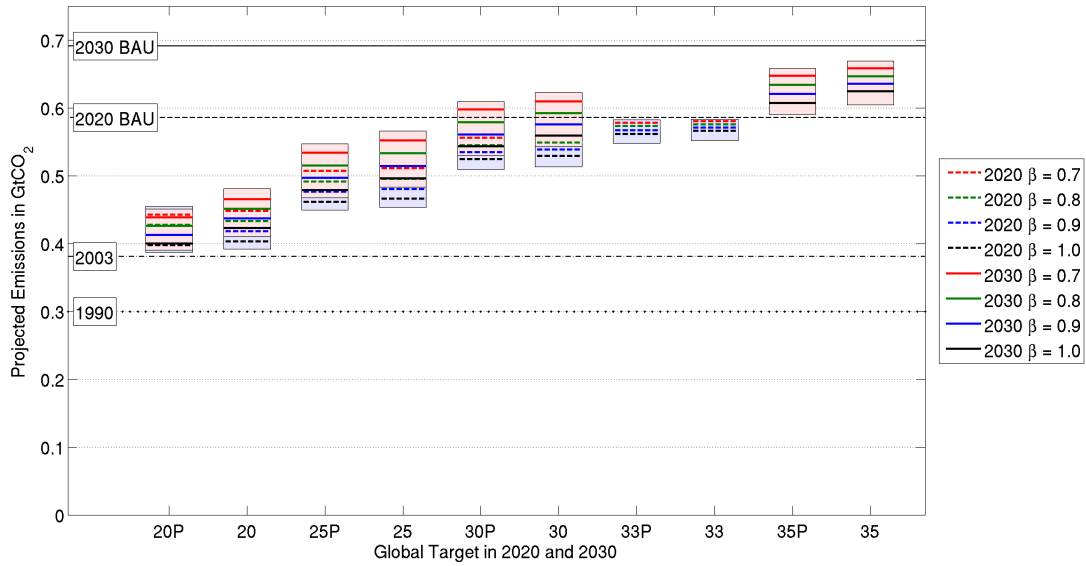


Figure S10: Mexico emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

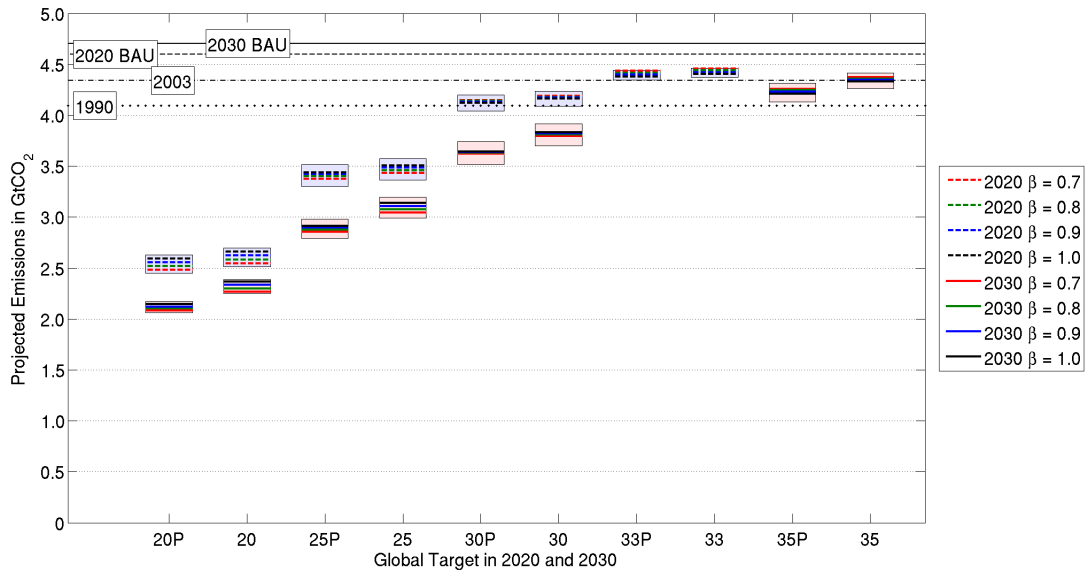


Figure S11: OECD Europe emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27

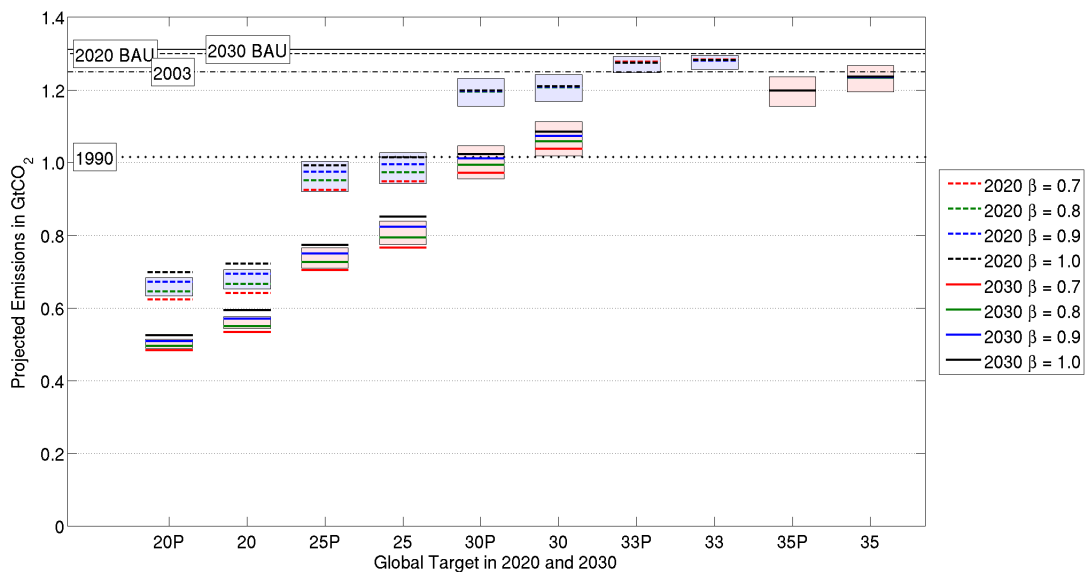


Figure S12: Japan emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

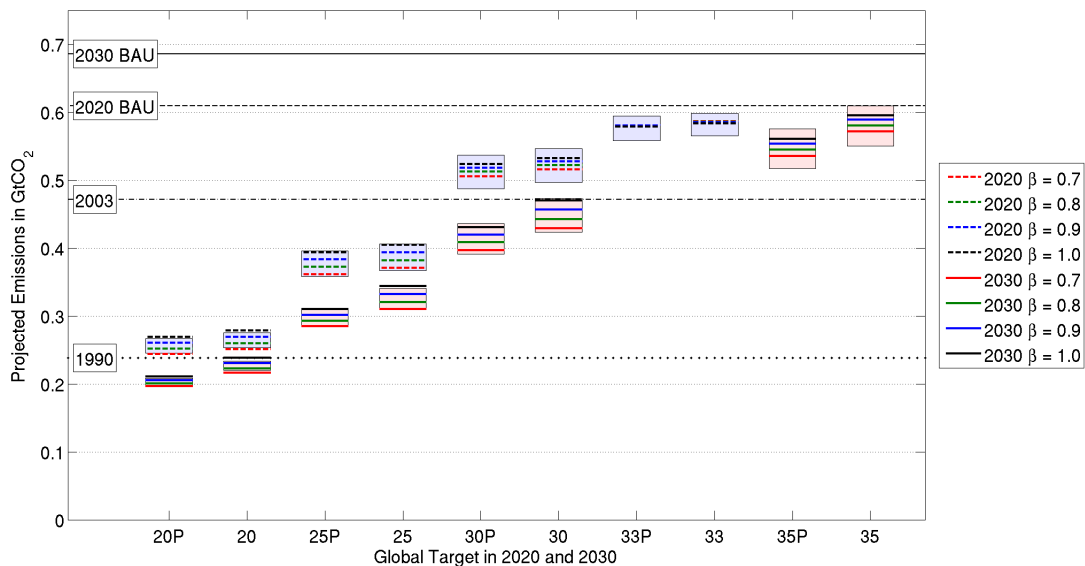


Figure S13: South Korea emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

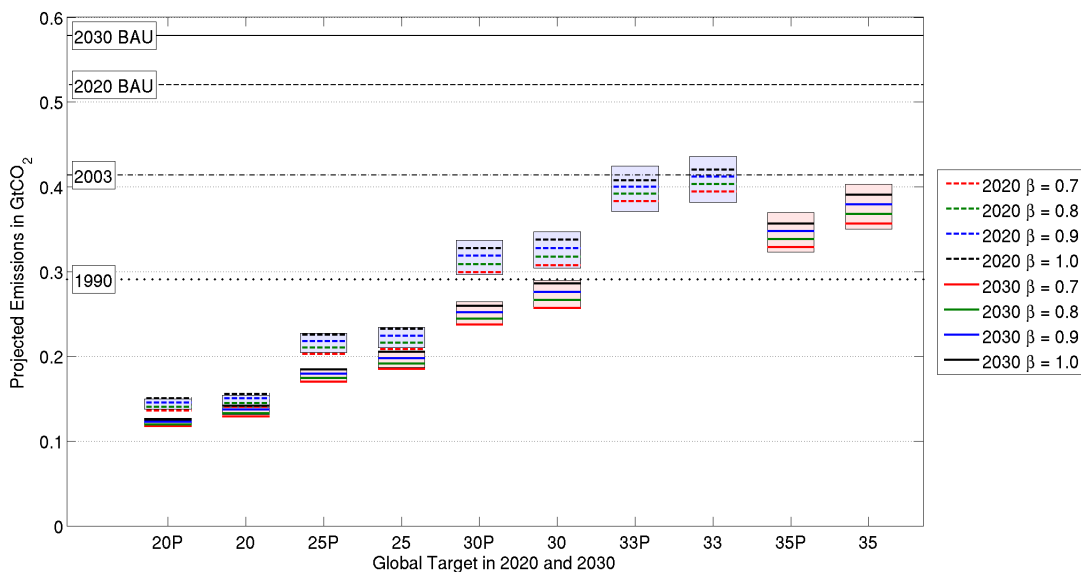


Figure S14: Australia and New Zealand emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

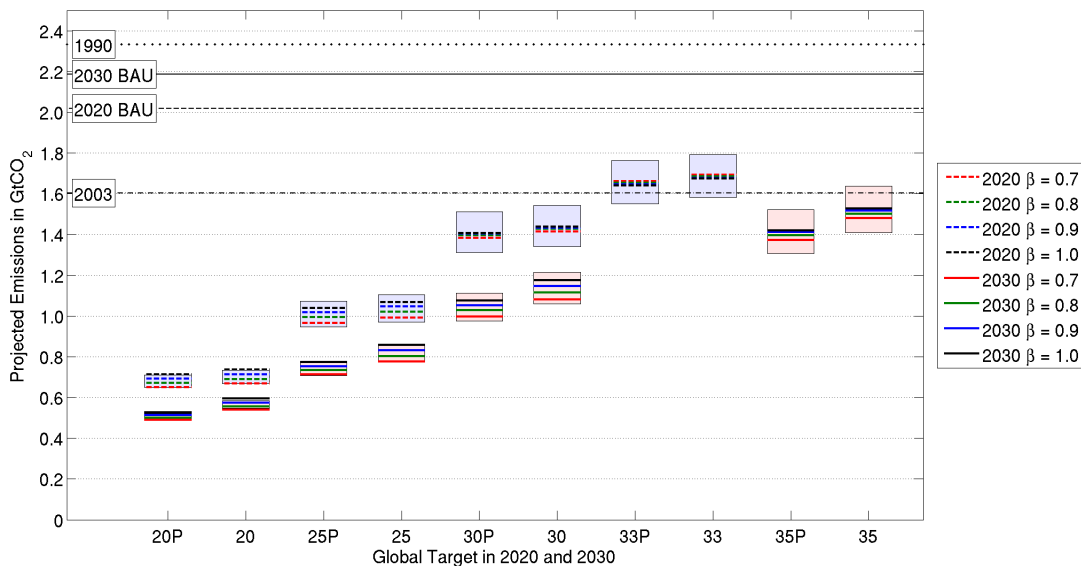


Figure S15: Russia emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

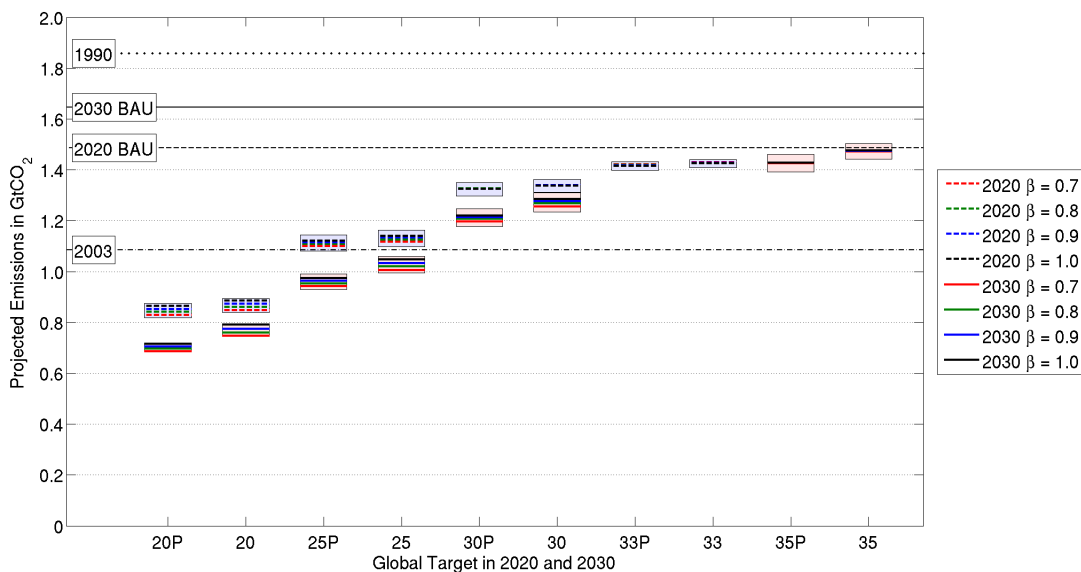


Figure S16: Transition economies emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

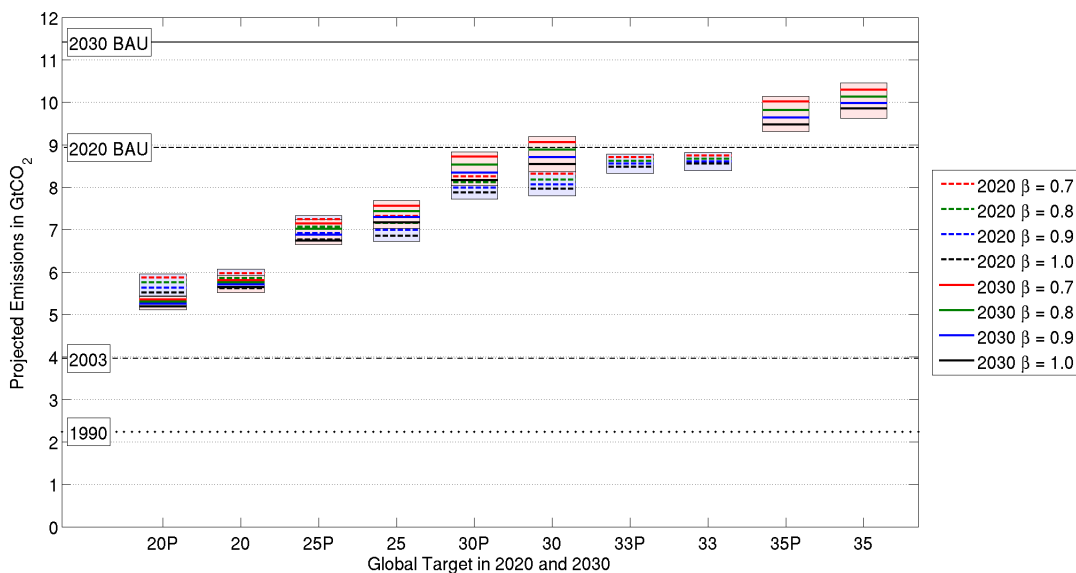


Figure S17: China emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

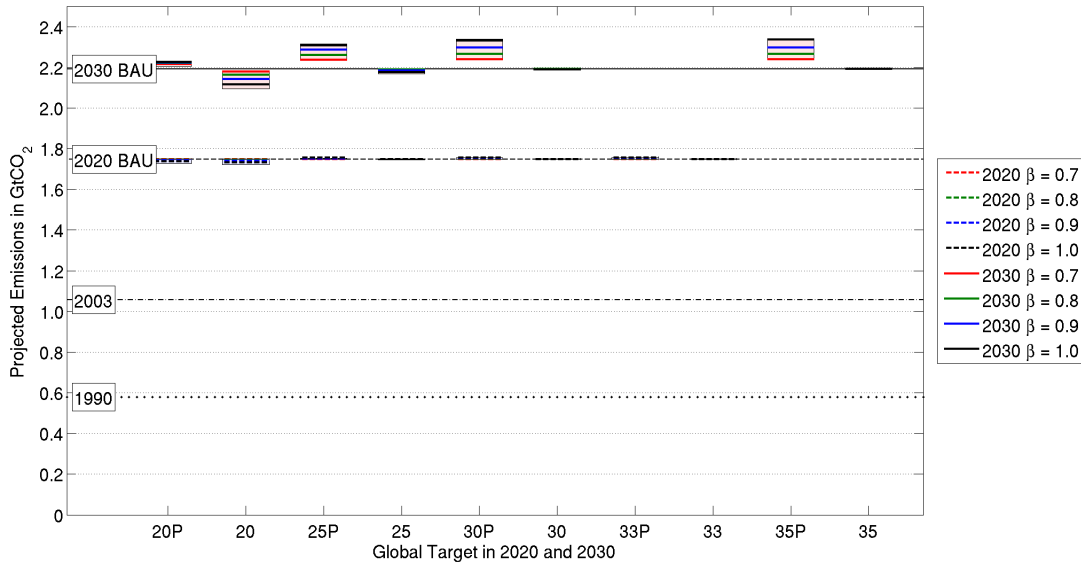


Figure S18: India emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

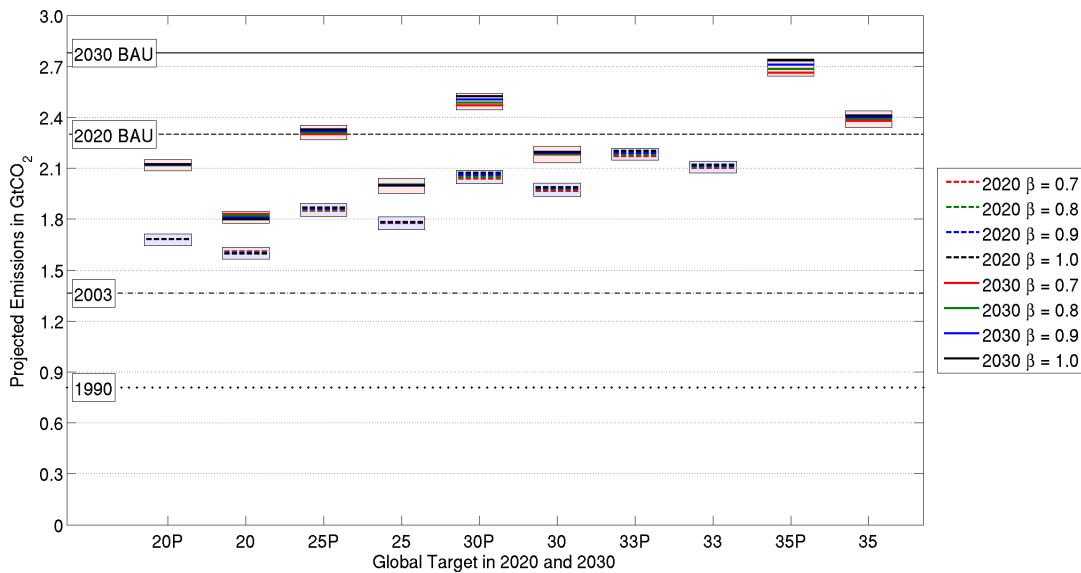


Figure S19: Other Non-OECD Asia emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

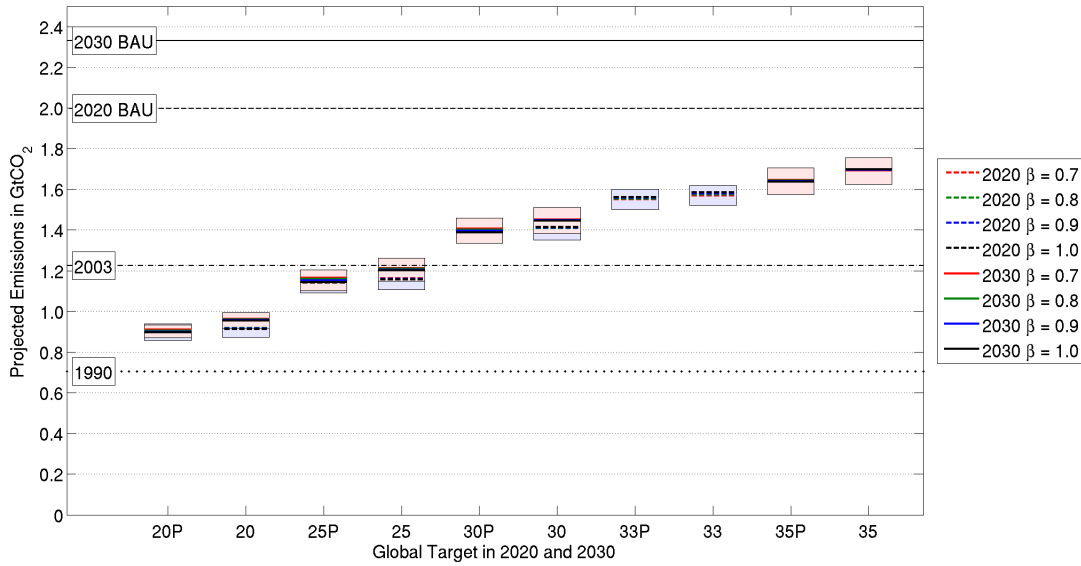


Figure S20: Middle East emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

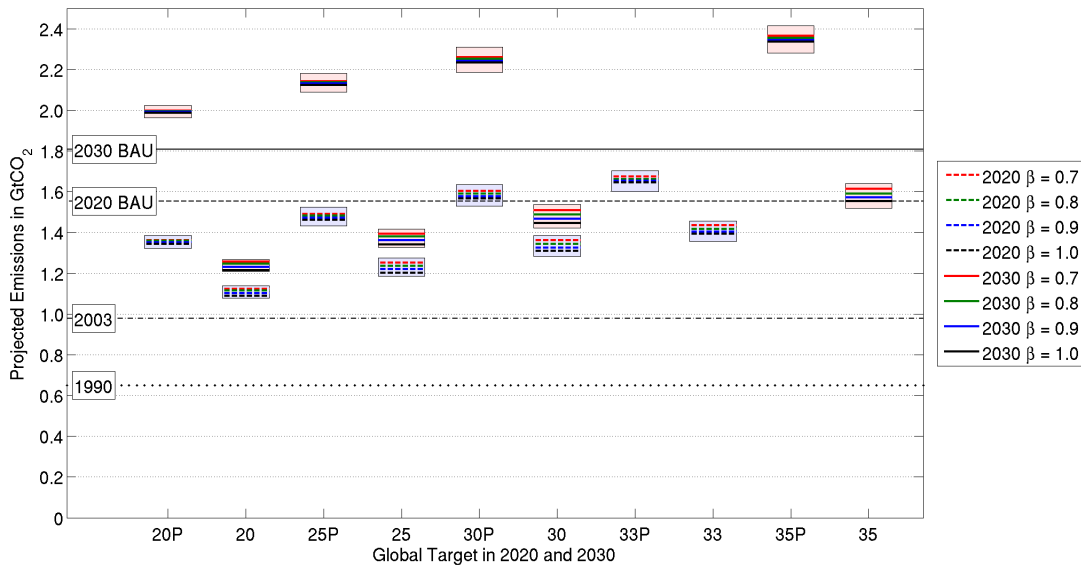


Figure S21: Africa emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

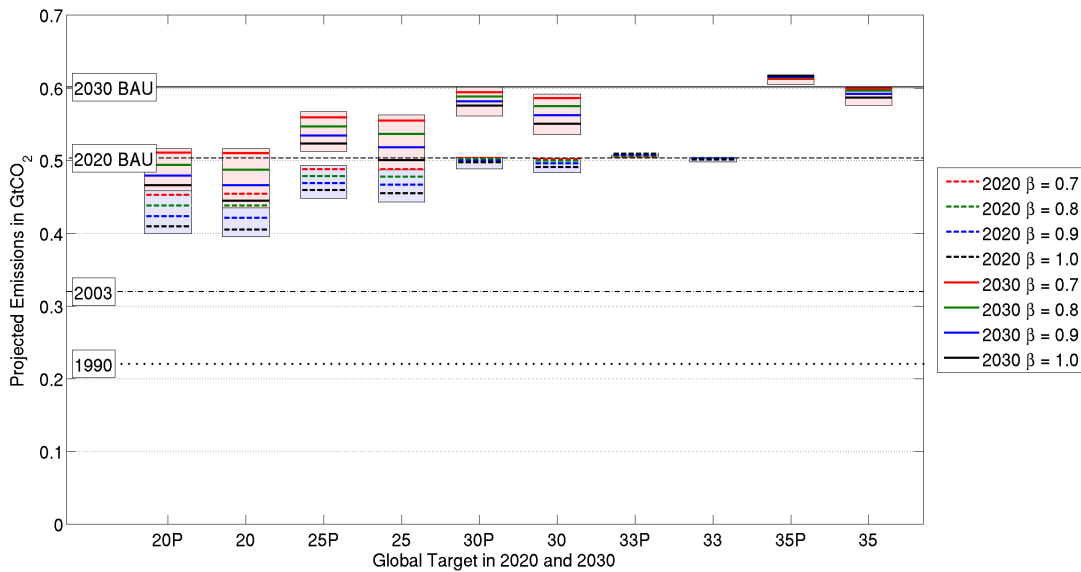


Figure S22: Brazil emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

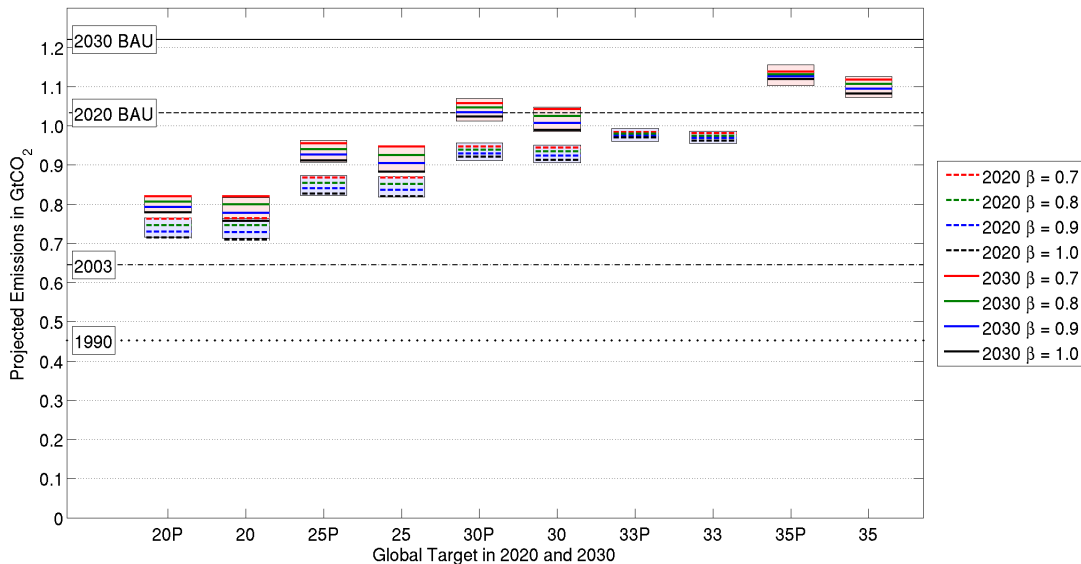


Figure S23: South and Central America emissions for different scenarios in 2020 and 2030. The light blue and the light pink rectangles show the range of values in 2020 and 2030 for uniformly distributed β from the interval $0.7 \leq \beta \leq 1.0$. See detailed note on pg. 27.

4 Poverty floor of 1 tCO₂

The paper introduces an emission floor to allow the 2.7 billion people in 2030 with the lowest personal emissions to increase their annual emissions to 1 tCO₂ by 2030. This provision corresponds approximately to a 1.5 GtCO₂ decrease in the allowance for the high emitters, or about a 10% increase of the global task of reducing 2030 emissions to 30 GtCO₂ relative to BAU. This section aims to show that an emission of 1 tCO₂ per person in a year allows for somewhat more than the standard of living portrayed in the academic literature of Basic Human Needs (1).

We approach the issue from two perspectives. First, we relate 1 tCO₂/person-year to current emissions and future targets from a top-down perspective, relating this emissions level to human development and the stabilization of the atmospheric CO₂ concentration. Second, we provide a bottom-up analysis of what 1 tCO₂ per person per year would provide in terms of energy services.

‘Top-down’ perspective:

Table S12 shows the number of people who emit less than 0.5 tCO₂ and less than 1 tCO₂ per year, as well as their cumulative emissions, based on the methodology described in the main text, for 2003 and 2030. The Table shows that between 2003 and 2030, under BAU conditions, both the number of low emitters and their total emissions remain roughly the same—indicating that global economic growth has no perceptible impact on the low-emissions tail, which is simply shifted to the right (see the inset to Figure 1 of the main text)—i.e., poverty is not reduced substantially under BAU.

| Year | Individual emissions (tCO ₂ /yr) | Number of people (billion) | Total emissions (GtCO ₂ /yr) |
|------|---|----------------------------|---|
| 2003 | < 0.5 | 1.3 | 0.31 |
| | < 1.0 | 2.4 | 1.07 |
| 2020 | < 0.5 | 1.4 | 0.30 |
| | < 1.0 | 2.5 | 1.11 |
| 2030 | < 0.5 | 1.5 | 0.31 |
| | < 1.0 | 2.7 | 1.14 |

Table S12: Number of people who have individual emissions lower than 0.5 and 1 tCO₂/yr, and their total emissions. Data based on the BAU distributions discussed in the main text.

In this context, it is interesting to compare some indices for national development with per-capita CO₂ emissions. The most commonly used index for development is the UNDP’s Human Development Index (HDI). The HDI combines purely economic data (GDP per capita) with data on other development indicators (2), such as adult literacy rate, school enrollment ratios, and life expectancy at birth. In Figure S24 we plot per capita average national CO₂ emissions against HDI for a number of countries and learn that a per capita emission of 1 tCO₂ corresponds

roughly with the transition into an “inelastic regime,” where an increase in emissions gives little gains in HDI (3). In contrast, for countries with per capita average emissions below 1 tCO₂, there is a great potential for rapid increases in HDI, and thus in human development, with only a small increase in emissions.

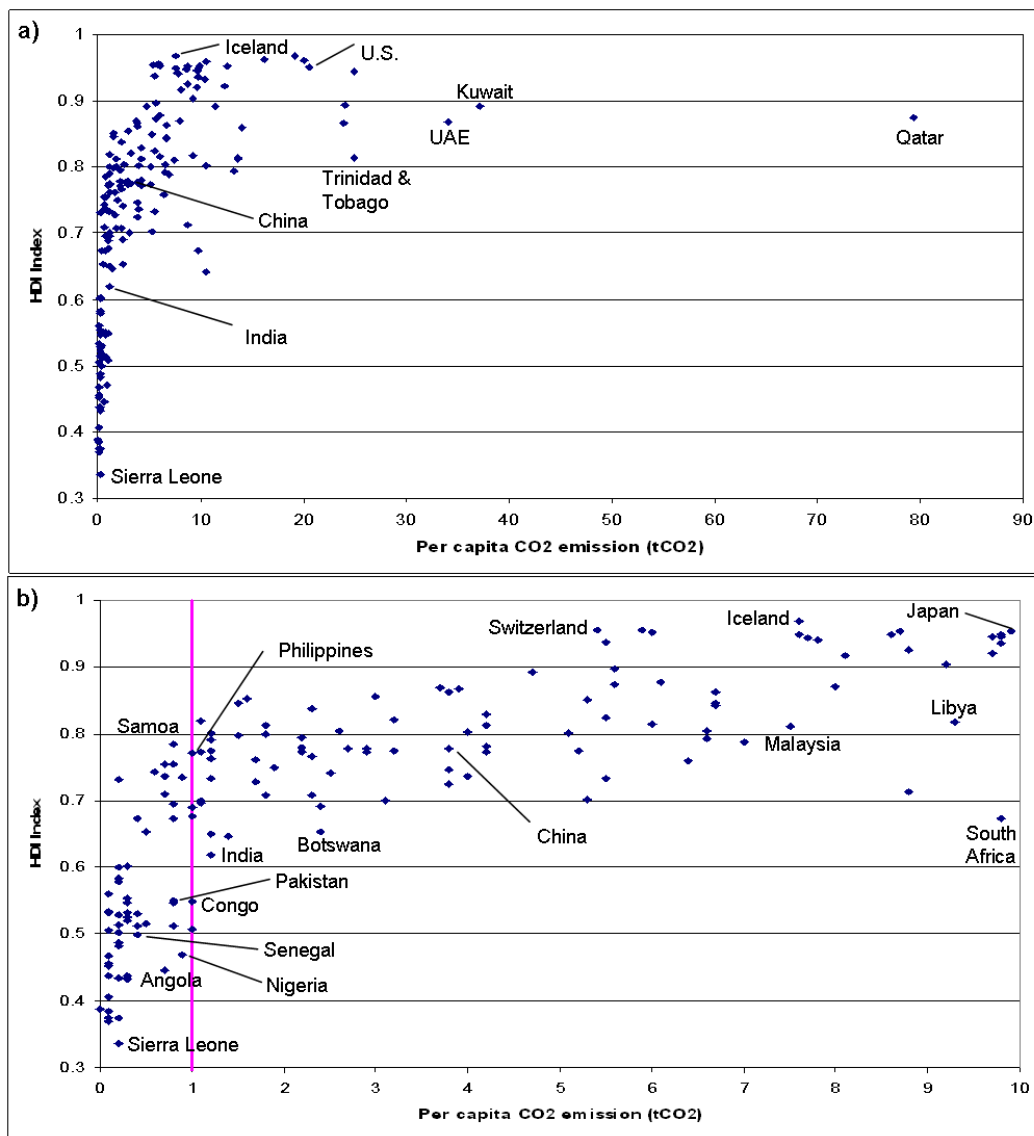


Figure S24: HDI vs. per capita CO₂ emissions. Graphs (a) and (b) show same data with the difference being the scales for the x-axis. The HDI is for year 2005 and per-capita CO₂ emissions are from 2004. The 1 tCO₂ line is also demarcated in (b). Source: Human Development Report 2007/2008 (2)

To be sure, achieving a floor of 1 tCO₂/person on the emissions of all individuals in any coun-

try guarantees that its per capita emissions will be above 1 tCO₂/capita. Nonetheless, Figure S24 assures us that 1 tCO₂ is a floor on personal emissions relevant to human development. An entirely different way to view 1 tCO₂/capita is to look ahead to the time when the world has stabilized greenhouse gas concentrations. By the end of this century, for a wide range of post-SRES scenarios with CO₂ stabilization targets below twice the preindustrial concentration, global emissions will need to be approximately 10 GtCO₂ per year (4), assuming that net CO₂ emissions from land use are close to neutral and direct air capture of CO₂ negligible. Thus, for a world population of approximately 8-10 billion people at the time of stabilization (5), the global per capita emission level should hardly be more than 1 tCO₂/yr.

Accordingly, 1 tCO₂ per person per year is the emission level that emerges from many analyses of international convergence. By implication, the energy system must change dramatically in order for stabilization to be compatible with global economic growth.

‘Bottom-up’ perspective:

The people who are helped by the 1 tCO₂ individual emissions floor are the world’s poorest, and it needs to be assessed how 1 tCO₂ relates to an exit from poverty. Whether any specific target group will actually be able to reach an emissions level of 1 tCO₂ depends on a number of issues, including the success of international efforts to achieve the Millennium Development Goals (6) and potential successor development targets and the successful implementation of associated domestic policies.

| Energy services | Fuel | Rate of use per household | Emission factor | CO ₂ emission per household (kgCO ₂ /yr) | CO ₂ per person (kgCO ₂ /yr) |
|---------------------------------------|-------------|---------------------------|--|--|--|
| Cooking | LPG | 14 kg/month | 3.12 kgCO ₂ /kg propane (LHV) | 532 | 118 |
| Lighting and appliances | Electricity | 200 kWh/yr | 0.937 kgCO ₂ /kWh | 187 | 42 |
| Total emission from direct energy use | | | | 719 | 160 |

Table S13: Basic human needs per person. They consist of low levels of private and some communal electricity use, and about one canister (14 kg) per month for cooking. The household size is 4.5. For electricity, the emission factor is based on IEA’s (7) estimate of average CO₂ emissions from electricity generation (4.652 GtCO₂/yr) and electricity consumption (4966 TWh/yr) in developing countries.

A.K.N. Reddy and his collaborators have assessed energy requirements for “Basic Human Needs” (1). As typical values, we assume one 14 kg canister of liquid petroleum gas (LPG) per household per month and roughly 200 kWh per household per year for electricity (see Table S13). Electricity consumption, for example, could be accounted for by three 11-W compact

fluorescent bulbs and a 100-W fan or a small television, all operated 4 hours/day. At this stage, we make no allowance for energy needed for transportation nor for community-level power (e.g., for a school or health clinic). The CO₂ consequences per person, assuming 4.5 persons per household, are shown in Table S13.

| Energy services | | Rate of use per household | Emission factor | CO ₂ emission per household (kgCO ₂ /yr) | CO ₂ per person (kgCO ₂ /yr) |
|--|-------------|---------------------------------|---|--|--|
| Cooking | LPG | 14 kg/month | 3.12 kgCO ₂ /kg propane (LHV) | 532 | 118 |
| | Two-wheeler | 22.5 km/day | 57gCO ₂ /person- km | 464 | 103 |
| Transport | Bus | 22.5 km/day | 23gCO ₂ /person- km | 189 | 42 |
| | Shared car | 22.5 km/day | 39gCO ₂ /person- km | 321 | 72 |
| Total from Transport | | 67.5 km/day | | 974 | 217 |
| Lighting and appliances | Electricity | 794 kWh/yr | 0.937 kgCO ₂ /kWh | 744 | 165 |
| Total Emissions from direct energy use | | | | 2250 | 500 |

Table S14: Extended human energy needs per person. The same cooking demand is assumed as in Table S13, an estimate for transport is added, and the balance is assigned to electricity. As in Table S13, the household size is 4.5 and the emission factor for electricity is 0.937 kgCO₂/kWh. The transport assumptions are 113 gCO₂/vehicle-km and 2 passengers/vehicle for the two-wheeler, 920 gCO₂/vehicle-km and 40 passengers/vehicle for the bus, and 196 gCO₂/vehicle-km and 5 passengers/vehicle for the shared car.

The emissions from direct energy use are about 160 kgCO₂/person-year. In the Basic Human Needs literature, these estimates of “direct” energy use are multiplied by a factor to take into account the “indirect” energy use associated with energy embodied in the purchases of non-energy goods and services, such as tools, clothing, and other intersections with the market economy (1,9). A factor of 2 for this multiplier was developed in Figure 3.6 of (1) and in (7). Using it here gives a total of 320 kgCO₂/person year for Basic Human Needs. Evidently, there is considerable room for additional consumption within the quota of 1 tCO₂/person-yr, resulting in a standard of living somewhat better than that of a person who has satisfied only Basic Human Needs.

We illustrate how this gap might be filled in Table S14, first by adding emissions associated with a representative demand for transport and then filling in the balance with electricity. We retain the two-to-one ratio for total vs “direct” emissions. Our estimate is that a little over 200 kg CO₂/person year of direct emissions are associated with transport. This follows from the

assumption that, on average, one person in a household will travel 15 km/day (5 km/day each in a motorized two-wheeler, a bus, and a shared car). Vehicle emission factors and load factors are given in Table S14.

After allowing for transport emissions, there is room for an expansion of power consumption from 200 kWh/household-year value in Table S13 to about 794 kWh/household-year in Table S14. Electricity usage of 794 kWh/household-year is consistent with Reference 3 for achieving the “elastic development threshold”. Compared to the smaller electricity use for Basic Human Needs in Table S13, it would allow for the operation of more lights, a refrigerator, an additional TV or fan, and some commercial activities.

References

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- (2) UNDP, Human Development Report 2007/2008 (United Nations Development Programme, United Nations, 2007).
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- (4) IPCC, 2007. *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- (5) UNDESA, *World Population to 2300* (United Nations Department of Economic and Social Affairs, 2004).
- (6) Millennium Development Goals: See <http://www.un.org/millenniumgoals/>
- (7). IEA, *World Energy Outlook 2007* (International Energy Agency, 2007).
- (8). Hoen, A., R.M.M. van den Brink, J.A. Annema, 2006. *Verkeer en vervoer in de Welvaart en Leefomgeving Achtergronddocument bij Emissieprognoses Verkeer en Vervoer*. MNP rapport 500076002/2006: Bilthoven, Netherlands. pp. 119, 132, 145, 158.
- (9) R A. Herendeen, C. Ford, and B. Hannon, *Energy* **6** (12), pp. 1433-1450 (1981).

5 Appendix A

We use the International Energy Outlook 2007 projections for projecting the CO₂ distributions into the future. The EIA divides the world into 16 regions as listed below. We have only included countries which have a population above 1 million. We estimated the income distribution of some countries using the average quintile income shares of the geographical area they belong to. For example, we used the average of the Middle East and North Africa for **Saudi Arabia**. These countries are listed below in boldface. North Korea is missing as we did not have any

estimate of its GDP. Our coverage is approximately 99.5% of the world's population (153 countries/territories) in 2003 and almost 100% of the emissions.

OECD

1. USA
2. Canada
3. Mexico
4. OECD Europe:
Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, and United Kingdom.
5. Japan
6. South Korea
7. Australia & New Zealand

NON OECD

8. Russia
9. Other NON-OECD Europe & Eurasia:
Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Estonia, Georgia, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Macedonia (Former Yugoslav Rep. of), Moldova, Romania, Serbia and Montenegro, Slovenia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.
10. China:
China, and Hong Kong.
11. India
12. Other NON-OECD Asia:
Bangladesh, Cambodia, Indonesia, Laos, Malaysia, Mongolia, Nepal, Pakistan, Papua New Guinea, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam, **Afghanistan**, and **Myanmar**.
13. Middle East:
Iran, Israel, Jordan, Yemen, **Iraq**, **Kuwait**, **Lebanon**, **Oman**, **Saudi Arabia**, **Syrian Arab Republic**, and **United Arab Emirates**.

14. Africa:

Algeria, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Cote d'Ivoire, Egypt, Ethiopia, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Swaziland, Tanzania, Tunisia, Uganda, Zambia, Zimbabwe, **Angola, Chad, Dem. Rep. of Congo, Rep. of Congo, Eritrea, Gabon, Liberia, Libya, Mauritius, Somalia, Sudan, and Togo.**

15. Brazil

16. Other Central & South America:

Argentina, Bolivia, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, St. Lucia, Trinidad and Tobago, Uruguay, Venezuela, **Cuba, and Puerto Rico.**