Correlations between Human Development and CO_2 emissions: projections and implications (GC51C-0981)

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Although developing countries are called to participate on the efforts of reducing CO2 emissions in order to avoid dangerous climate change, the implications of CO2 reduction targets in human development standards of developing countries remain a matter of debate. We find positive and time dependent correlation between the Human Development Index (HDI) and per capita CO2 emissions from fossil fuel combustion. Based on this empirical relation, extrapolated HDI, and three population scenarios extracted from the Millennium Ecosystem Assessment report, we estimate future cumulative CO2 emissions. If current demographic and development trends are maintained, we estimate that by 2050 around 85(above 0.8) as defined in the United Nations Human Development Report 2009. In particular, we estimate that at least 300Gt of cumulative CO2 emissions between 2000 and 2050 are necessary for the development of developing countries in the year 2000. This value represents 30yielding a 75development has been proved to be time and country dependent, we plead for future climate negotiations to consider a differentiated CO2 emissions reduction scheme for developing countries based on the achievement of concrete development goals.

Consensus emerging in favor of low CO_2 stabilization targets requires the participation of developing countries in the efforts to reduce global emissions. For example, it has been claimed that in order to keep global temperatures below a 2 °C increase, developing countries should attain more than 20% CO_2 reductions below business-as-usual levels by 2020. The potential implications of such reductions on development standards remain unclear as developing countries are expected to extensively rely on fossil energy to fuel their development needs. Developing countries have expressed their concerns if development goals can, or cannot, be met under current technological development and population trends.

In order to tackle above mentioned challenges, the CO_2 allocation and reduction approach here outlined contrasts from existing ones by relying on the Human Development Index (HDI) as a summary measure reflecting the achievement of a country in three basic dimensions of human development: a long healthy life, access to knowledge, and decent living standards. Furthermore, the HDI has been reported to play an important role in raising the political profile of general health and educational policies, to be an indicator of a country's exposure to climate-related extremes and its dimensions determinants of vulnerability and adaptive capacity at national level.

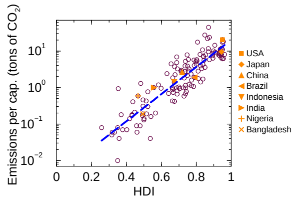

Figure 1

In Fig. 1 per capita emissions are plotted against the corresponding HDI for countries with available data in the year 2000. We find that the per capita CO_2 emissions from fossil fuel burning are exponentially correlated with human development – highlighting the often disregarded social-dimension of emissions reductions. The magnitude of the challenges ahead become clear once the per capita CO_2 emissions guard rail of 2 tons for avoiding dangerous climate change and the HDI threshold of 0.8 and 0.9 characteristic of a developed world are considered. A fair distribution of CO_2 emissions under current technological constraints should allow a convergence of all developing countries towards 0.8 or 0.9 HDI scores and, at the same time, below the 2 tons limit.

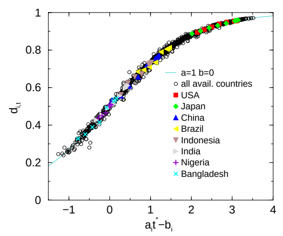

Figure 2

Our approach starts by investigating the evolution of future human development standards. We assume that the HDI, $d_{i,t}$, of a country, i, evolves in time, t, following a logistic regression. This choice is supported by the fact that the HDI is bounded to $0 \leq d_{i,t} \leq 1$ and that countries with high HDI evolve slowly in time. Further, this asymptotic behavior suggests the existence of smooth transitions in development. The logistic regression fulfills these requirements. Therefore, we fit for each country separately

$$\tilde{d}_{i,t} = \frac{1}{1+\mathrm{e}^{-a_i t+b_i}} \tag{1}$$

to the available data (obtaining the parameters a_i and b_i). Basically, a_i quantifies how fast a country develops and b_i represents a delay. In Fig. 2 we display the collapse of the past HDI as obtained from the logistic regressions illustrating how countries have been developing in the scope of this approach. The HDI values of each country are plotted using a transformed time $t^* = \frac{t+b_i}{a_i}$ so that values of all countries (open circles) fall within their spreading on the curve which is used to fit the data. The filled symbols highlight the same countries as in Fig. 1. The solid line corresponds to the function $d_t = \frac{1}{1+\mathrm{e}^{-t}}$. Based on the obtained parameters, a_i and b_i, we estimate the future HDI of each country until 2050 assuming similar development trajectories as in the past.

The correlations between HDI and the CO_2 emissions per capita, $e^{(c)}_{i,t}$, were assessed for all years (1980-2006), see example of Fig. 1. We apply the exponential regression

$$\hat{e}^{(c)}_{i,t} = \mathrm{e}^{h_t d_{i,t}+g_t} \tag{2}$$

to the data by linear regression through $\ln e^{(c)}_{i,t}$ versus $d_{i,t}$ for fixed years t and obtain the parameters h_t and g_t. At a global level, correlation coefficients varied between a minimum of 0.89 in 2005 and a maximum of 0.91 in 2006. The individual components of HDI were found to be as well correlated with per capita emissions, in the following decreasing order of correlation coefficient: GDP, education, and life expectancy.

We take advantage of these correlations and assume that the system is ergodic, i.e. that the process over time and over the statistical ensemble is the same. In other words, we assume that these correlations also hold for each country individually and apply the exponential regression

$$\hat{e}^{(c)}_{i,t} = \mathrm{e}^{h_i d_{i,t}+g_i} \tag{3}$$

and obtain the parameters h_i and g_i, which are now country dependent. Based on the estimated parameters the CO_2 per capita emissions are extrapolated country wise.

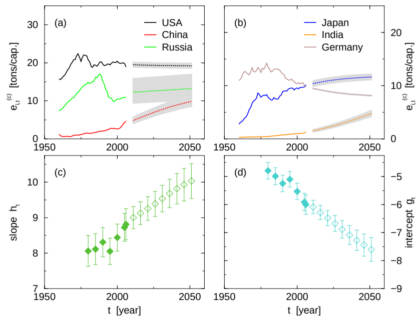

Figure 3

In Fig. 3 the panels (a) and (b) show examples of extrapolated CO_2 emissions per capita for six countries according to the described methodology. Measured values (solid lines) and extrapolated values are plotted up to the middle of the 21st century (dashed lines). The gray uncertainty range is obtained by including the statistical errors of the regressions (one Standard Deviation (SD) each). For the set of countries for which data is available we obtain the parameters h_t and g_t as displayed in the panels (c) and (d) of Fig. 3 for the past values (filled symbols) and for projected values (open symbols). The parameters imply that in average, for a given HDI, the corresponding CO_2 emissions decrease during the time frame under investigation. It is apparent that these correlations are hard to overcome since they are intrinsic to the energy supply systems.

Future country-based emissions estimates are obtained multiplying the extrapolated CO_2 per capita values by population numbers extracted from three scenarios published in the Millennium Ecosystem Assessment report.

The statistical approach undertaken in this work can be named "Development As Usual" (DAU) in the sense that development and emission trends continue as in the past. Accordingly, we are not claiming that the calculated HDI and CO_2 extrapolations are predictions, instead, they represent a plausible near-future world (by 2050) where CO_2 emissions from fossil fuel combustion are still closely linked to human development. This assumption is supported by (i) the findings that no discernible decarbonizing trends of energy supply among world regions can be identified and (ii) the existence of substantial obstacles to large scale implementation of renewable energy in the near future.

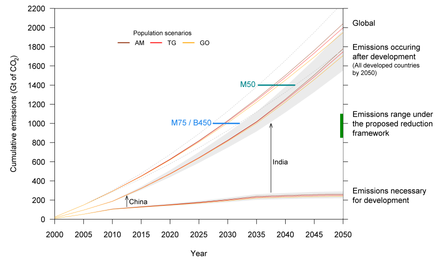

Figure 4

Figure 4 depicts the estimated cumulative emissions for the three population scenarios together with a set of CO_2 budgets for particular warming and concentration targets. According to the DAU approach, global cumulative CO_2 emissions by 2050 range from 1700 up to 2300 Gt of CO_2 with about 85% of the world's population living in countries with an HDI above 0.8. When assessed on a per year basis, emissions range between 45.6 and 62.4 Gt CO_2 in 2050.

Of a total of 165 countries, 104 were found to be developing countries (HDI below 0.8) in the year 2000. By using the UNDP HDI threshold of 0.8 to differentiate countries with high human development from developing countries with medium to low human development, estimated global CO_2 emissions are divided into two budgets. The first budget includes the emissions necessary for the development of countries with HDI below 0.8 while the second budget accounts for emissions occurring after development, this is, emissions from countries with HDI above 0.8. Emissions from countries carrying out a development transition (i.e., crossing the HDI threshold between 2000 and 2050) are added correspondingly to each budget. For example, we estimate India to achieve an HDI above 0.8 between the years 2035 and 2040. Until the HDI threshold is reached the emissions are accounted to be necessary for development, from then on CO_2 emissions from India are accounted to occur after development.

In a DAU future we estimate that between 200 and 300 Gt of cumulative CO_2 emissions will be necessary for developing countries to proceed with their development. In the scope of our approach, 61 developing countries are expected to overcome the HDI of 0.8 by 2050 consuming roughly 98% of the above-mentioned 200-300 Gt budget. The remaining 43 countries are likely to stay below the UNDP high human development threshold in the considered time frame. Total cumulative emissions occurring after development range from 1500 to 2000 Gt of CO_2. This amount is similarly divided among countries carrying out a development transition (700 to 1000 Gt) and those whose development occurred before the year 2000 (800 to 1000 Gt).

We further compare our estimates with previously calculated CO_2 budgets for particular time frames, global warming targets and atmospheric CO_2 concentrations. We find that the emissions necessary for development consume up to 30% of the 1000 Gt CO_2 limit for a 75% probability of keeping global warming below 2 °C, as calculated by Meinshausen *et al.* and indicated as M75 in Fig. 4. According to our projections, the 1000 Gt budget limit by 2050 would already be exhausted around 2030 if human development proceeds as in the past.

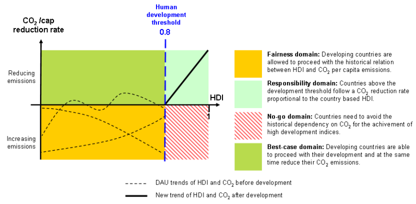

Figure 5

Human development framework for CO_2 allocation and reduction

A fair approach implies that an hypothetical developing country should not be limited in its emissions of CO_2 until it reaches a particular threshold of human development. In practice, the development path made by current developed countries in the past should be possible for developing countries in the future if they choose to do so. Figure 6 makes use of the 0.8 HDI threshold to differentiate four areas of action regarding climate policies. Countries whose HDI trails below the minimum human development standard evolve in the context of a *Fairness domain*. In this domain the developing country is allowed to fulfill the basic development needs by following a development path where HDI is highly correlated with CO_2 emissions from fossil fuel burning. In the *Best-case domain* developing countries are able to proceed with their development goals and at the same time reduce their CO_2 emissions. After basic development needs are fulfilled, countries are no longer said to be developing and transit to the *Responsibility domain* where they engage in CO_2 reduction rates proportional to their HDI in order to preserve a global warming limit of 2 °C by 2050. The *No-go domain* needs to be avoided by future developed countries and quickly abandoned by current ones on the basis that resulting emissions would be largely incompatible with future climatic policies. A generalized convergence of countries towards the *Responsibility domain* should be operated.

To formalize this, we propose that a developed country i reduces it's per capita emissions at year t according to $e^{(c)}_{i,t-5y} \rightarrow (1-r_{i,t})\, e^{(c)}_{i,t}$ with the 5-year reduction rate $r_{i,t}$, given by

$$r_{i,t} = f\,(d_{i,t} - d^*) \quad for \quad d_{i,t} > d^* \tag{4}$$

where d^* is the development threshold and f a proportionality constant which determines how strong the reduction rate increases with increasing HDI. Based on the above discussed development threshold ($d^* = 0.8$) we estimate that $f = 3.3$ (as a lower bound) would lead to global cumulative emissions ranging between 850 and 1100 Gt of CO_2 by 2050 if reduction starts in 2015 (assuming the same uncertainty as in DAU). This amount is within the range of allowed cumulative CO_2 emissions that provide between 80% and 66% change of keeping global temperatures below a 2 °C increase.

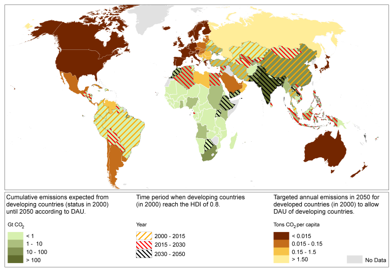

Figure 7

The value of $f = 3.3$ implies that in each time step of 5 years, countries with an HDI of 0.85 would need to reduce their per capita emissions by approx. 17 % and countries with an HDI of 0.9 by 33 %. As a result of applying these reduction rates, emission curves of current and future developed countries decrease approximately exponentially. Developing countries unable to reach an HDI of 0.8 during the time frame of this analysis are allowed to emit following DAU. For example, Pakistan is entitled to increase emissions to a maximum of approx. 2.5 tons per capita in 2050, the year when its expected to become a developed country following our approach. In Fig. 7 we provide an overview of our results according to the current political world map. The Figure highlights the geographic trade-offs between the necessary achievements in CO_2 reduction by current developed countries (brown shading) and cumulative CO_2 emissions for the DAU of current developing countries (green shading) in order to comply with the 2 °C target.

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