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Sharing the effort under a global carbon budget

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Sharing the effort under a global carbon budget

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WWF foreword

In order to avoid dangerous climate change there is a growing consensus among now more than 120 countries that average global temperatures should not increase by more than 2°C over pre-industrial levels. This was affirmed in July of this year by the G8+5 nations, a group of countries encompassing all major emitters from the developed and developing world. This is a giant leap forward and provides large hope for success of the ongoing negotiations for a post-2012 treaty to be agreed in Copenhagen at the Climate Summit in December this year.

How can this objective be met? WWF and other members of the Climate Action Network (CAN) are strongly promoting a legally binding mid-term target of at least 40% emissions reductions by 2020 below 1990 levels for developed countries as a group, under common but differentiated responsibilities that require nations that are rich and have high per capita emissions to 'pay back' their atmospheric debt. Globally, all countries need to have reduced their total greenhouse gas emissions by at least 80% below 1990 levels by 2050 in order for the world to stay below 2°C of warming.

The emissions trajectory between now and 2050 needs to be distributed in an equitable way with the appropriate distinctions made between 'rich' and 'poor' and between 'high' and 'low' per capita emitters. To inform the international debate, WWF asked the leading energy research consultancy ECOFYS to elaborate on the practicalities and implications of some suggested methodologies already under discussion and some that are promising and should receive consideration.

As well as the need for an 80% cut in emissions globally by 2050, another requirement taken into account by the research was the need to cut global emissions by 30% over 1990 levels by 2030 – a feasible as well as necessary target according to a recent climate action cost calculation, the McKinsey Climate Cost Curve 2.0. Also, land use factors globally need to turn from being a net source of CO_2 to becoming a net sink between 2020 and 2030, with major reductions required in emissions from deforestation and clearing in the tropics. Action at this level could ensure the entire world becomes a net emissions sink post 2060.

Although WWF has strong sympathy with the Greenhouse Gas Development Right Framework to distribute the allowable emissions in a social and equitable way in the next decades, at this point in time WWF is not promoting any particular approach to distribute the finite global greenhouse gas budget between 1990 and 2100. But whichever approach the world chooses in order to stay below 2°C, the cumulative greenhouse gas budget cannot change substantially. If we relax on the trajectory of one country, another country needs to pick up the bill. There is no carbon offset for Planet Earth as such. We know, decarbonising the economy in the next 50 years or so will be tough for most nations – and let us be very honest – particularly for many rapidly industrialising nations.

However, unabated climate change will cost much more socially, economically and environmentally. It will wreak havoc on global food security and freshwater availability, and its impacts will be disproportionately felt by poor and vulnerable communities. What WWF seeks to do with this paper is to kick-start a debate on how to globally share the carbon budget consistent with a trajectory to keep global warming below 2°C. This is not about burden sharing – this is about benefit sharing. Compared to unabated climate change, perceived economic 'hardship' is a luxury problem.

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Executive summary

Stringent global greenhouse gas emission reductions by all sectors and all countries will be necessary to keep global average temperature increase below 2°C. This report gives an overview of different methods to share the effort of reducing greenhouse gas emissions between countries to reach a given global carbon budget by 2100 in line with the 2°C limit.

First, we defined the carbon budget, which is the amount of tolerable global emissions over a period of time. Afterwards, we divided the available emission rights among countries according to different rules. To be consistent with the 2°C limit, for this report we assume CO_2eq emissions will have to be reduced by 30% compared to 1990 levels by 2030. By 2050 global emissions excluding those from land-use change and forestry (LUCF) need to be reduced by 80% compared to 1990. This leads to an emission budget of roughly 1800 $GtCO_2$eq between 1990 and 2100 excluding LUCF. Further, we assume that emissions from LUCF remain constant at about 4 $GtCO_2$ until 2010 and decline to zero by between 2010 and 2020. LUCF will become a stable net sink of emissions afterwards. By 2030 LUCF will remain at -4 $GtCO_2$. The global emission budget including LUCF will, thus, be about 1600 $GtCO_2$eq. This is the budget between 1990 and 2100. Until today and because mankind has already increased its global emissions substantively since 1990, the remaining net cumulative budget between 2009 and 2100 is limited to 870 GtCO2eq. This translates to an allowable global annual emission on average for the next 91 years of no more than 9.5 $GtCO_2$eq, or about 20% of today's annual net global emissions.

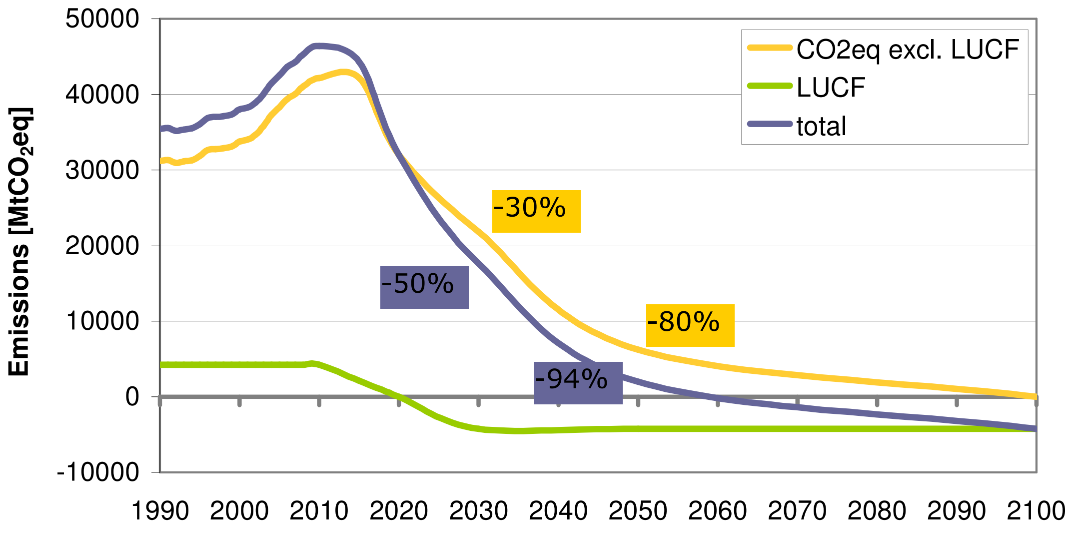

Figure 1. Possible global GHG emissions pathway between 1990 and 2100 according to a global carbon budget of about 1800 Mt CO_2eq (excl. LUCF) and 1600 Mt CO_2eq (incl. LUCF)

Under this strict emission budget, delay in reductions of only 5 years has significant consequences. Starting absolute global emission reductions around the year 2015 requires global average annual emissions reductions of about 5%, which already is very ambitious. Starting absolute global reduction in 2020 requires a global annual reduction of 8% after 2020.

The requirements to reach this are very stringent (see Figure 2). This is also reflected by the resulting target of about 0.5 tCO_2eq per capita as global average in 2050. In

2020 the average per capita emissions are around 9 tCO_2eq per capita for Annex I and 3-5 tCO_2eq per capita for non-Annex I.

We have shared the global emission budget using three methodologies, which are currently under discussion:

- Greenhouse Development Rights (GDRs): All countries need to reduce emissions below their business as usual path based on their responsibility (cumulative emissions) and capacity (GDP). Only emissions and GDP of the population above a development threshold account towards responsibility and capability.
- Contraction and Convergence (C&C): The targets for individual countries are set in such a way that per capita emission allowances converge from the countries' current levels to a level equal for all countries within a given period, here until 2050.
- Common but Differentiated Convergence (CDC): As above, targets are set so per capita emissions for all countries converge to an equal level over the period 2010 to 2050. For developed (Kyoto Protocol Annex I) countries' per capita emission allowances convergence starts immediately. For individual non-Annex I countries' per capita emissions convergence starts from the date when their per capita emissions reach a certain percentage threshold of the (gradually declining) global average.

Generally, the Greenhouse Development Rights approach (GDRs) allows negative emissions where required reductions based on capacity and responsibility are larger than business as usual emissions. Contraction and Convergence (C&C) and Common But Differentiated Convergence (CDC) allow only very low but not negative emission levels. Therefore, Annex I emission targets go to -60% in 2020 under the GDRs, while the other approaches require around -40%.

Negative emission allowances (below 100% of base year) do not mean that the respective countries have to mitigate everything domestically. This is just a method of illustrating the equitable emissions allocations under this methodology. In reality it means that industrialised countries have to substantially support reducing emissions in developing countries via the carbon market, technology and/or funding etc.

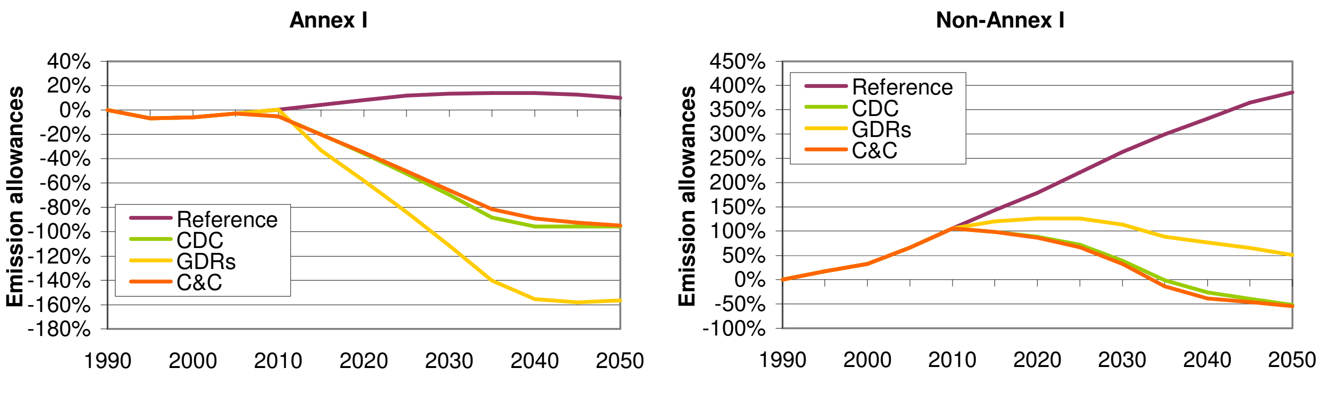

Figure 2. Development of emission allowances for Annex I countries and Non-Annex I countries between 1990 (0%) and 2050 under the effort sharing approaches CDC, GDRs and C&C

Developing countries in general and economies in transition (EITs) have more room to grow under GDRs than under the other approaches. The main reasons for this are the relatively low per capita emissions combined with limited financial capacity.

Least Developed Countries (LDCs) are almost all exempt from emission reduction requirements under GDRs, while under C&C they are granted little more allowances than their reference emissions until 2020 and face reduction obligations after 2025. Under CDC they face reductions after 2030.

Cumulative emissions per capita vary considerably under C&C and CDC for Annex I and non-Annex I. For GDRs some non-Annex I countries are even granted higher per capita cumulative emissions than some countries of Annex I.

Under GDRs, non-Annex I countries are allowed to increase their total emissions and peak until 2025 and then need to reduce them to roughly today's level in 2050 (about 50% above 1990). Under C&C and CDC there is less room for growth and their emissions need to be at a third of today's emissions (half of 1990's emissions). This is particularly reflected in the case of China and India. Both countries would be entitled under GDR to grow their emissions by 10% and even 240%, respectively, by 2050 compared to 1990, while being required to reduce by more than 70% and about 2-7% in the same period under the other two models.

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List of Abbreviations

BAU	Business as usual
C	Capacity
C&C	Contraction and Convergence
CDC	Common but differentiated convergence
CDM	Clean development mechanism
CO_2eq	Carbon dioxide equivalents
EIT	Economies in transition
GDP	Gross domestic product
GDRs	Greenhouse Development Rights
LDC	Least developed country
LUCF	Land-use change and forestry
R	Responsibility
RCI	Responsibility Capacity Index
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar

1 Introduction

Further action is needed that goes far beyond what has been agreed so far under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol to "prevent dangerous anthropogenic interference with the climate system", the ultimate objective of the UNFCCC. It is beyond question that developed countries (Annex I countries) will have to take a leading role. They will have to commit to substantial emission reductions and financing commitments due to their historical responsibility and their financial capability. However, the stabilisation of the climate system will require global emissions to peak within the next decade and decline well below current levels by the middle of the century. It is hence a global issue and, thus, depends on the participation of as many countries as possible.

More than 120 countries, including the European Community and many developing nations particularly LDC and Small Island Nations, and numerous development, social justice and environmental NGOs have agreed that global average temperature increase should be limited to 2°C above pre-industrial levels to avoid such dangerous interference. Recent proposals, e.g. of the Alliance of Small Island States, now call for 1.5°C. The risk that a stable greenhouse gas concentration of e.g. 450 ppmv CO_2eq would result in global average temperature above 2°C in the long term is around 50%. At 400 ppmv CO_2eq, the risk is 30% (Meinshausen 2005). Consequently, global emissions have to peak in the next 15 years and decline well below the 1990 level in 2050 and further thereafter.

Under the principle of "common but differentiated responsibilities", one of the guiding principles stipulated in Article 3.1 of the UNFCCC, developed countries (so called Annex I Parties) take the lead in reducing emissions and developing countries (Non-Annex I Parties) act to protect the climate system on the basis of equity and in accordance with the common but differentiated responsibilities and respective capabilities. Current international climate negotiations center around "mitigation commitments and actions" for developed countries and "nationally appropriate mitigation actions" for developing countries.

Developing countries have a lower historical responsibility for climate change but some are already or will become important emitters. A less carbon intensive development path will have positive effects on these countries' sustainable development and on the global climate system. On the one hand, climate change action will contribute directly to achieving sustainable development objectives, such as energy security, sustainable economic development, technology innovation, job creation, local environmental protection and enhancement of capacity to adapt to climate change impacts. On the other hand, especially developing countries will benefit from a more stable global climate because they are the most vulnerable to climate change effects.

In this report for WWF International Ecofys analyses emission allowances for different groups of countries until 2050 under a given carbon budget between 1990 and 2100. The analysed approaches consider all countries but give different weight to Annex I and non-Annex I efforts.

We first describe the carbon budget and the methodology used (Chapter 2), then we briefly describe the considered effort sharing approaches (Chapter 3). Afterwards, we present the results as emission allowances per group under the different effort sharing approaches (Chapter 3.2). Finally, we give a short conclusion of this analysis. Detailed data and a description of the used calculation model (EVOC) are included in the Appendix.

2 Global carbon budget

Different approaches exist for global effort sharing of greenhouse gas emission reductions. One possibility is to define the carbon budget, which is the global amount of tolerable emissions over a period of time. Afterwards the available emission rights can be divided among countries according to different rules. To come close to 2° limit, for this report we assume CO_2eq emissions will have to be reduced by 30% compared to 1990 levels by 2030. By 2050 global emissions excluding LUCF need to be reduced by 80% compared to 1990. This leads to an emission budget of roughly 1800 Gt CO_2eq between 1990 and 2100.

As emissions from land use change and forestry (LUCF) are known only with considerable uncertainty, we took simplifying assumptions about current and future emissions from this sector. We assume that emissions from land-use change and forestry (LUCF) remain constant at about 4 GtCO_2 until 2010 and decline to zero by between 2010 and 2020. Due to reducing deforestation and increasing re- and afforestation LUCF will have to become a net sink of emissions afterwards (see Figure 3 and Table 1 below). We assume that after 2030 LUCF will remain at -4 GtCO_2. The global emission budget including LUCF will, thus, be about 1600 GtCO_2eq between 1990 and 2100.

Because mankind has already increased its global emissions substantively since 1990, the remaining net cumulative budget between 2009 and 2100 is limited to 870 GtCO_2eq. This translates to an allowable global annual emission on average for the next 91 years of no more than 9.5 GtCO_2eq, or about 20% of today's annual net global emissions.

In order to stay within the boundary of the global GHG budget, sometime from 2060 onwards, net global emissions must be negative (little emissions from energy use and larger sequestration of carbon from forests and other technologies).

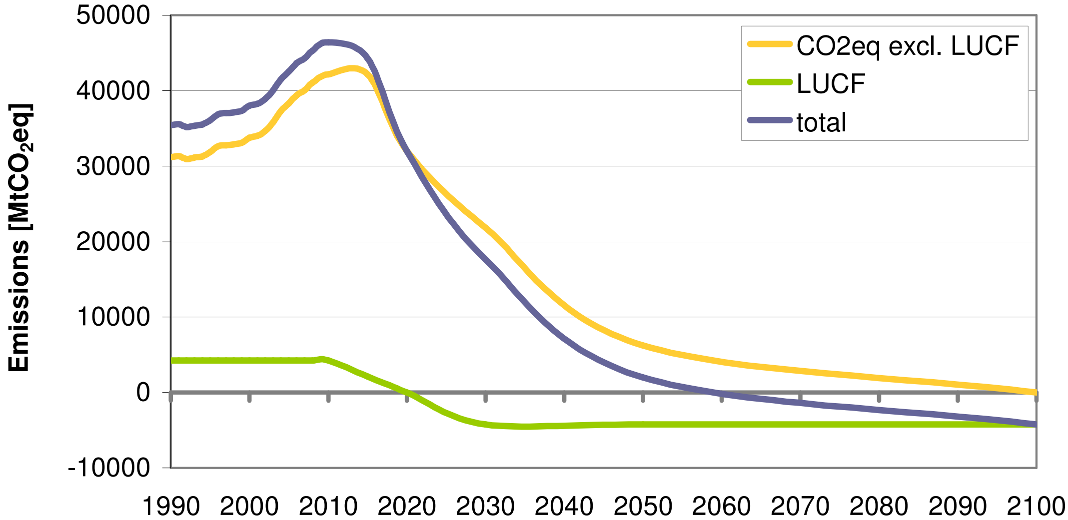

Figure 3. Possible global GHG emissions pathway between 1990 and 2100 according to a global carbon budget of about 1800 Mt CO_2eq (excl. LUCF) and 1600 Mt CO_2eq (incl. LUCF)

Table 1. Assumption on cumulative GHG emissions between 1990 and 2100

	2030 emissions [% change from 1990]	2050 emissions [% change from 1990]	Cumulative emissions				
			1990-2008	2009-2100	1990-2050	2010-2050	1990-2100
CO_2eq excl. LUCF	-30%	-80%	650	1160	1660	970	1820
LUCF	-200%	-200%	80	-290	0	-80	-210
Total emissions	**-50%**	**-94%**	**730**	**870**	**1660**	**880**	**1600**

Generally, one can imagine different pathways to reduce emissions that satisfy the same budget. Figure 4 gives an example of three different emission paths. The yellow path requires absolute global emission reduction comparatively early around the year 2015. The required average annual emissions reduction is about 5%. The medium path (dark violet) starts absolute emission reduction about 2-3 years later. The annual reduction rate is similar about 6%. The third path (light violet) requires absolute global reduction in 2020. As a result also the annual reduction of 8% after 2020 is more challenging to achieve a global carbon budget that is comparable with the yellow path of early reduction.

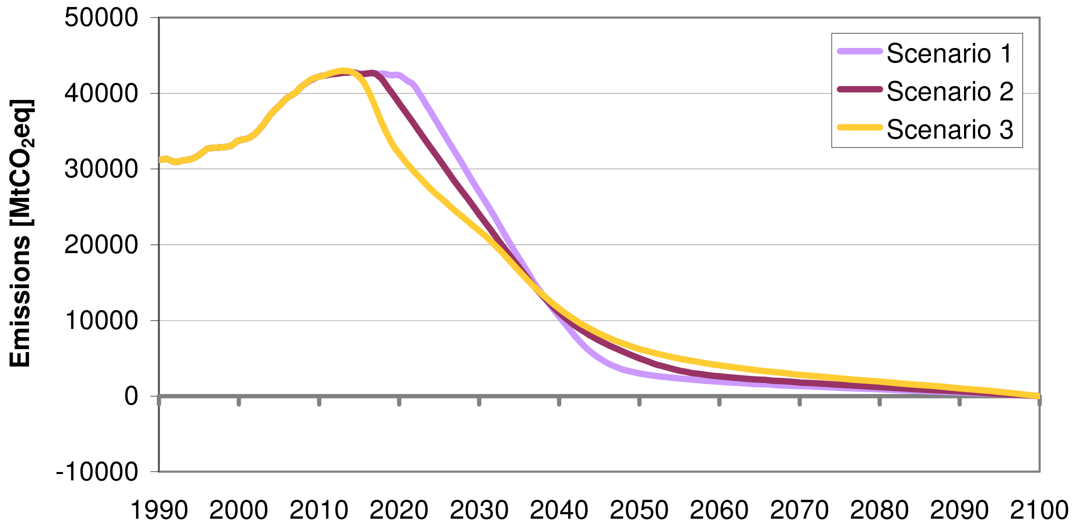

Figure 4. Sensitivity of possible global GHG emissions pathway excl. LUCF between 1990 and 2100

Table 2. Cumulative GHG emissions excl. LUCF between 1990 and 2100

Scenario	2030 emissions [% change from 1990]	2050 emissions [% change from 1990]	Cumulative emissions 1990-2050	Cumulative emissions 1990-2100
Scenario 1	-13%	-80%	~1750	~1830
Scenario 2	-30%	-80%	~1670	~1830
Scenario 3	-23%	-84%	~1700	~1830

3 Global effort sharing

3.1 Parameters

This section presents the parameters applied for three possible future methodological architectures consistent with the considered global carbon budget. This means that the calculation outcomes have to meet the global reference emissions of -30% compared to 1990 levels in 2030 and -80% in 2050 mentioned above. The following approaches are included in the calculation of emission allowances:

- Greenhouse Development Rights
- Common but Differentiated Convergence
- Contraction and Convergence by 2050

For this comparison of the emission rights under different distribution approaches in a future architecture the Evolution of Commitments tool (EVOC) is used. A detailed description of the EVOC model is included in Appendix A.

3.1.1 Greenhouse development rights (GDRs)

The Greenhouse Development Rights (GDRs) approach to share the effort of global greenhouse gas emissions reduction was developed by Baer et al. (Baer et al. 2007, 2008; cp. also Niklas Höhne and Sara Moltmann 2008). It is based on three main pillars:

The right to develop: Baer et al. assume the right to develop as the essential part for any future global climate regime in order to be successful. Therefore a development threshold is defined. Below this level individuals must be allowed to make development their first priority and do not need to contribute to the global effort of emission reduction or adaptation to climate change impacts. Those above this threshold will have to contribute regardless their nationality. This means that individuals above this threshold will have to contribute even if they live in a country that has an average per capita income below this level. The level for this development threshold would have to be matter of international debate. However Baer et al. 2008 suggest an income-level of $7,500 per capita and year. Based on this, the effort sharing of the GDRs is based on the capacity and the responsibility of each country.

Capacity: The capacity (C) of a county is reflected by its income. The income distribution among individuals is taken into account by the gini coefficient of a country. A gini coefficient close to 1 indicates low equality while a value close to 0 indicates a high equality in income distribution. As the countries capacity is needed to define per-country emission allowances the sum of income of those individuals per country above the development threshold is summed and considered to calculate each countries capacity.

Responsibility: The responsibility (R) is based on the "polluter pays" principle. For the GDRs according to Baer et al. it is measured as cumulative per capita CO_2 emissions from fossil fuel consumption since 1990. However, it should be distinguished between survival emissions and luxury emissions. Baer et al. assume that emissions are proportional to consumption, which again is linked to income. Emissions related to that share of income below the development threshold are equivalent to the part of national income that is not considered in calculating a countries capacity. Therefore, they shall be considered as survival emissions. Those emissions linked to income above the development threshold are luxury emissions and shall account for a countries responsibility.

Allocation of emission rights: The allocation of emission reduction obligations and resulting emission rights is based on each country's responsibility and capacity, combined in the Responsibility Capacity Index (RCI). This is defined as $RCI = R^a \cdot C^b$, where *a* and *b* are weighting factors. Baer et al. assume and equal weighting of 0.5 for *a* and 0.5 for *b*. This gives capacity and responsibility an equal weighting.

Two global emissions development paths are considered. First, the business-as-usual (BAU) case and second the reduction path necessary to reach the emission level in order to stabilise global emissions (see Figure 5). The difference of these two is the amount of emissions that need to be reduced globally. Each country's annual share of this reduction is determined by the relative share of its RCI compared to the sum of RCIs of all other countries.

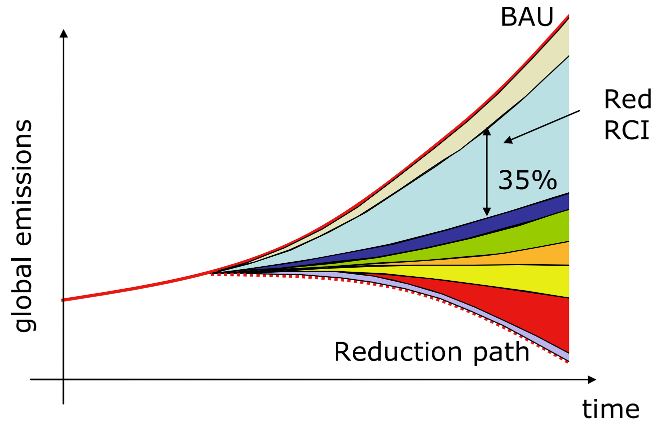

Figure 5. Effort sharing under the Greenhouse Development Rights (GDRs) approach according to the Responsibility Capacity Index (RCI)

Table 3 includes the parameters chosen for the calculations on the GDRs approach in this report.

Table 3. Parameters chosen for the Greenhouse Development Rights approach

Parameter	Unit	
Development threshold	USD (2005) / capita / year	7,500
Start year for cumulative emissions		1990
Weighting of Capacity	%	50%
Weighting of Responsibility	%	50%

3.1.2 Contraction and convergence (C&C)

Under contraction and convergence (C&C) (GCI 2005; Meyer 2000), all countries participate in the regime with quantified emission targets. As a first step, all countries agree on a path of future global emissions that leads to an agreed long-term stabilisation level for greenhouse gas concentrations ('contraction'). As a second step, the targets for individual countries are set in such a way that per capita emission allowances converge from the countries' current levels to a level equal for all countries within a given period ('convergence'). The convergence level is calculated at a level that resulting global emissions follow the agreed global emission path. It might be more difficult for some countries to reduce emissions compared to others, e.g. due to climatic conditions or resource availability. Therefore, emission trading could be allowed to level off differences between allowances and actual emissions. However, C&C does not explicitly provide for emission trading.

As current per capita emissions differ greatly between countries some developing countries with very low per capita emissions, (e.g. India, Indonesia or the Philippines) could be allocated more emission allowances than necessary to cover their emissions (some call this "tropical hot air"). This would generate a flow of resources from developed to developing countries if these emission allowances are traded.

To meet the global emission path of -30% (2030) and -80% (2050) a convergence at about 0.6 to 0.7 tCO_2eq per capita in 2050 is necessary (see Table 4). In this case the average per capita emissions will have to lie around 4.5 tCO_2eq per capita in 2020.

Table 4. Convergence levels of per capita emissions rights in tCO_2eq/cap in 2050 (the global emission level is the same but global population is different per scenario)

Scenario	Average in 2020 [tCO2eq/cap]	Convergence level in 2050 [tCO2eq/cap]
A1B	4.66	0.70
A1FI	4.67	0.70
A1T	4.61	0.73
A2	4.22	0.58
B1	4.39	0.74
B2	4.46	0.69

3.1.3 Common but differentiated convergence (CDC)

Common but differentiated convergence (CDC) is an approach presented by Höhne et al. (2006). Annex I countries' per capita emission allowances converge within, e.g., 40 years (2010 to 2050) to an equal level for all countries. Individual non-Annex I countries' per capita emissions also converge within the same period to the same level but convergence starts from the date, when their per capita emissions reach a certain percentage threshold of the (gradually declining) global average. Non-Annex I countries that do not pass this percentage threshold do not have binding emission reduction requirements. Either they take part in the CDM or they voluntarily take on positively binding emission reduction targets. Under the latter, emission allowances may be sold if the target is overachieved, but no emission allowances have to be bought if the target is not reached.

The CDC approach, similarly to C&C, aims at equal per capita allowances in the long run (see Figure 6). In contrast to C&C it considers more the historical responsibility of countries. Annex I countries would have to reduce emissions similarly to C&C, but many non-Annex I countries are likely to have more time to develop until they need to reduce emissions. Non-Annex I country participation is conditional to Annex I action through the gradually declining world average threshold. No excess emission allowances ("hot air") would be granted to least developed countries.

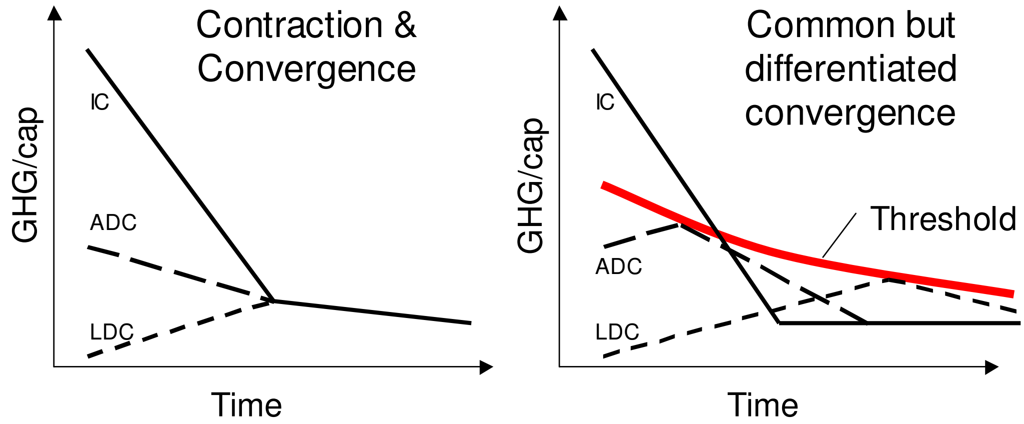

Figure 6. Schematic representation of GHG emissions per capita for three types of countries (an industrialized country (IC), an advanced developing country (ADC) and a least developed country (LDC)) under contraction and convergence (left) and under common but differentiated convergence (right)

The parameters for the convergence time, the threshold for participation and the convergence level used in this report are provided in Table 5.

Table 5. Parameters used for the Common but Differentiated Convergence approach

Parameter	Unit	A1B	A1FI	A1T	A2	B1	B2
Convergence time	Years	27	27	27	27	27	27
Threshold	% difference from world average	-35%	-35%	-35%	-31%	-22%	-24%
Convergence level	tCO_2eq/cap	0.64	0.64	0.64	0.42	0.51	0.52

3.1.4 Overview of all considered effort-sharing approaches

Table 6 below gives a short overview on strengths and weaknesses of the considered effort-sharing approaches Greenhouse Development Rights (GDRs), Contraction and Convergence (C&C) and Common but Differentiated Convergence (CDC).

Table 6. Strengths and weaknesses of the considered effort sharing approaches

	Strengths	Weaknesses
GDRs	• Uses historical emissions and GDP above a development threshold for differentiation • Uses share of wealthy population in a country as indicator for required action by that country • Assigns responsibility to reduce emissions abroad • Participation of all countries with the same rules • Includes cost-effective reduction options in developing countries through full international emissions trading	• Reduction below BAU assumes that the BAU is equitable • Possibly too simple and not considering detailed national circumstances
C&C	• Emphasis on a common endpoint: equal per capita emissions – does not require BAU • Participation of all countries with the same rules • Simple, clear concept • Includes cost-effective reduction options in developing countries through full international emissions trading • Support for least developed countries through excess emission rights	• Current per capita emissions is the only criterion for differentiation, does not consider differences in historical responsibility • National circumstances (including historical responsibility) not accommodated (optionally countries within one region can redistribute allowances to accommodate national concerns) • Substantial reduction for countries with high per capita emissions, also such developing countries • Also least developed countries need to be capable of participating in emissions trading to receive benefits (national greenhouse gas inventories and emission trading authorities)
CDC	• Emphasis on a common endpoint and equal path towards it: equal per capita emissions – does not require BAU • Applies simple rules, thus, making approach transparent • Delay of non-Annex I countries takes account of the responsibility for past emissions • Eliminates the component of "hot air" (no excess allowances for low emission countries)	• Per capita emissions is the only criterion for differentiation, but the delay of Non-Annex I countries accounts for differences in historical responsibility • National circumstances not accommodated, except per capita emissions and current membership of Annex I • Possibly too simple and not considering detailed national circumstances

3.2 Results

This chapter presents the results for emission rights for different countries and regions under the effort sharing approaches described before.

As all calculations consider six different reference scenarios based on the Special Report on Emission Scenarios from the IPCC (SRES, Nakicenovic et al. 2000). These scenarios include different assumptions concerning growth of GDP, population and other important factors. The bars in the figures indicate the median of the results from all scenarios; the error bars show the highest and lowest values.

Figure 7 shows the emission allowances in 2020 and 2050 as percentage change from 1990 for different reduction approaches. Figure 8 and Figure 9 give the same data as percentage changes from business as usual (BAU) and as emissions per capita, respectively.

Figure 10 shows cumulative emissions between 1990-2020 and 1990-2050 under different effort sharing approaches divided by the population in 2020 and 2050, respectively. Figure 11 gives the cumulative emissions between 1990-2020 and 1990-2050 under the different effort sharing methods. Figure 12 and Figure 13 show the development of national emission allowances between 1990 and 2020 under CDC, GDRs and C&C for Annex I and non-Annex I, respectively. Cumulative emissions are divided by the absolute number of people in that year. For 2020 this means for example that emissions are added from 1990 to 2020 and are then divided by the population of 2020.

All calculations and results comprise emissions *exclude* LUCF. The global emission budget described in Chapter 2 can be met, if in addition emissions from LUCF also follow the path described there (reduction to zero in 2020 and turning to a net sink in 2030 with constant level afterwards). Including LUCF would lead to changes in the distributions, which could be significant for countries with high emissions and/or removals in this sector, e.g. Brazil, USA and Russia.

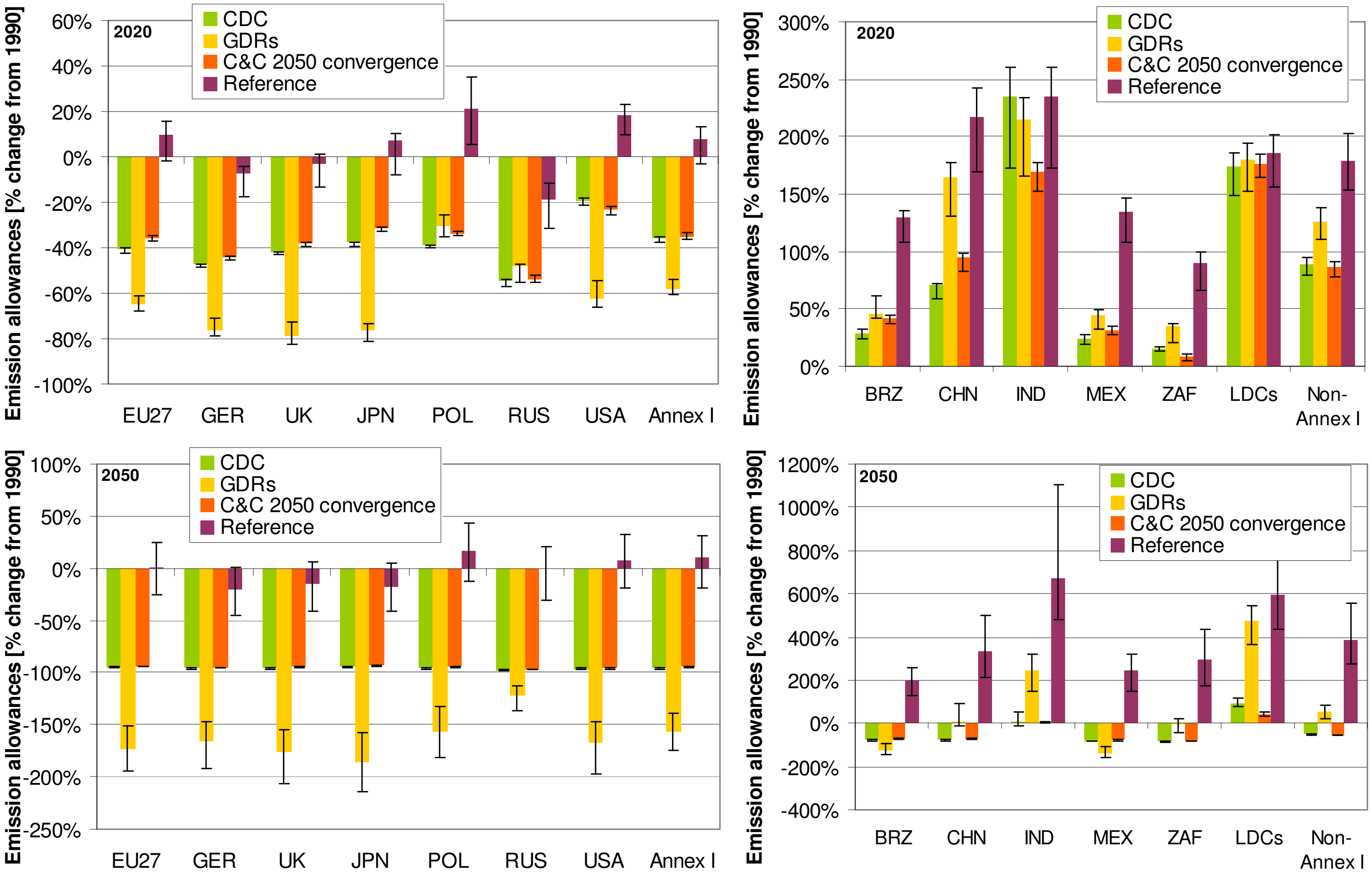

Figure 7. Emission allowances in 2020 and 2050 as percentage change from 1990 for different reduction approaches.

Note: EU27 (European Union), GER (Germany), UK (United Kingdom), JPN (Japan), RUS (Russia), POL (Poland), USA, Annex I, BRZ (Brazil), CHN (China), IND (India), MEX (Mexico), ZAF (South Africa), LDCs (least developed countries), non-Annex I. Data are included in Appendix B.

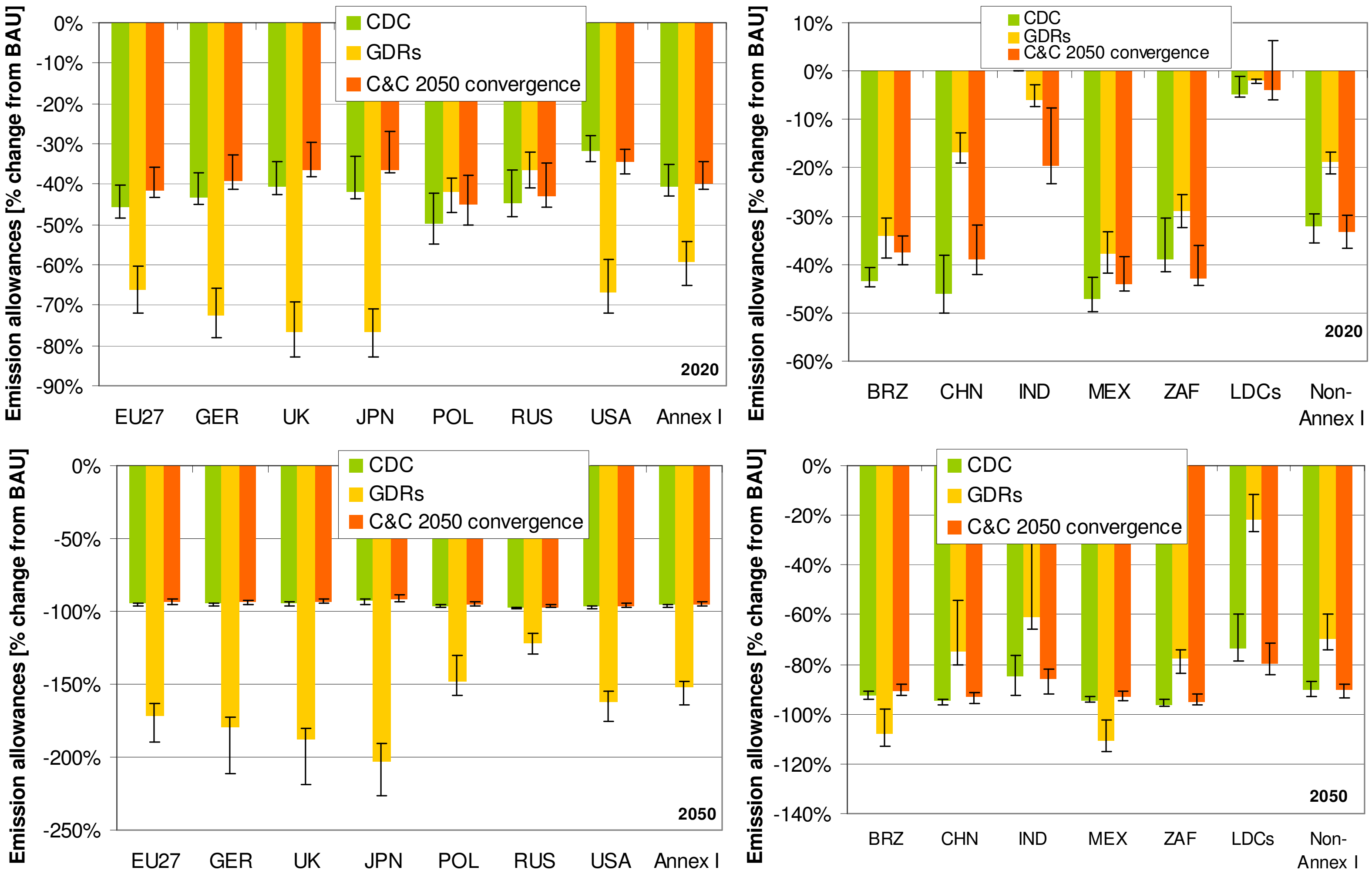

Figure 8. Emission allowances in 2020 and 2050 as percentage change from business as usual (BAU) for different reduction approaches.

Note: EU27 (European Union), GER (Germany), UK (United Kingdom), JPN (Japan), RUS (Russia), POL (Poland), USA, Annex I, BRZ (Brazil), CHN (China), IND (India), MEX (Mexico), ZAF (South Africa), LDCs (least developed countries), non-Annex I. Data are included in Appendix B.

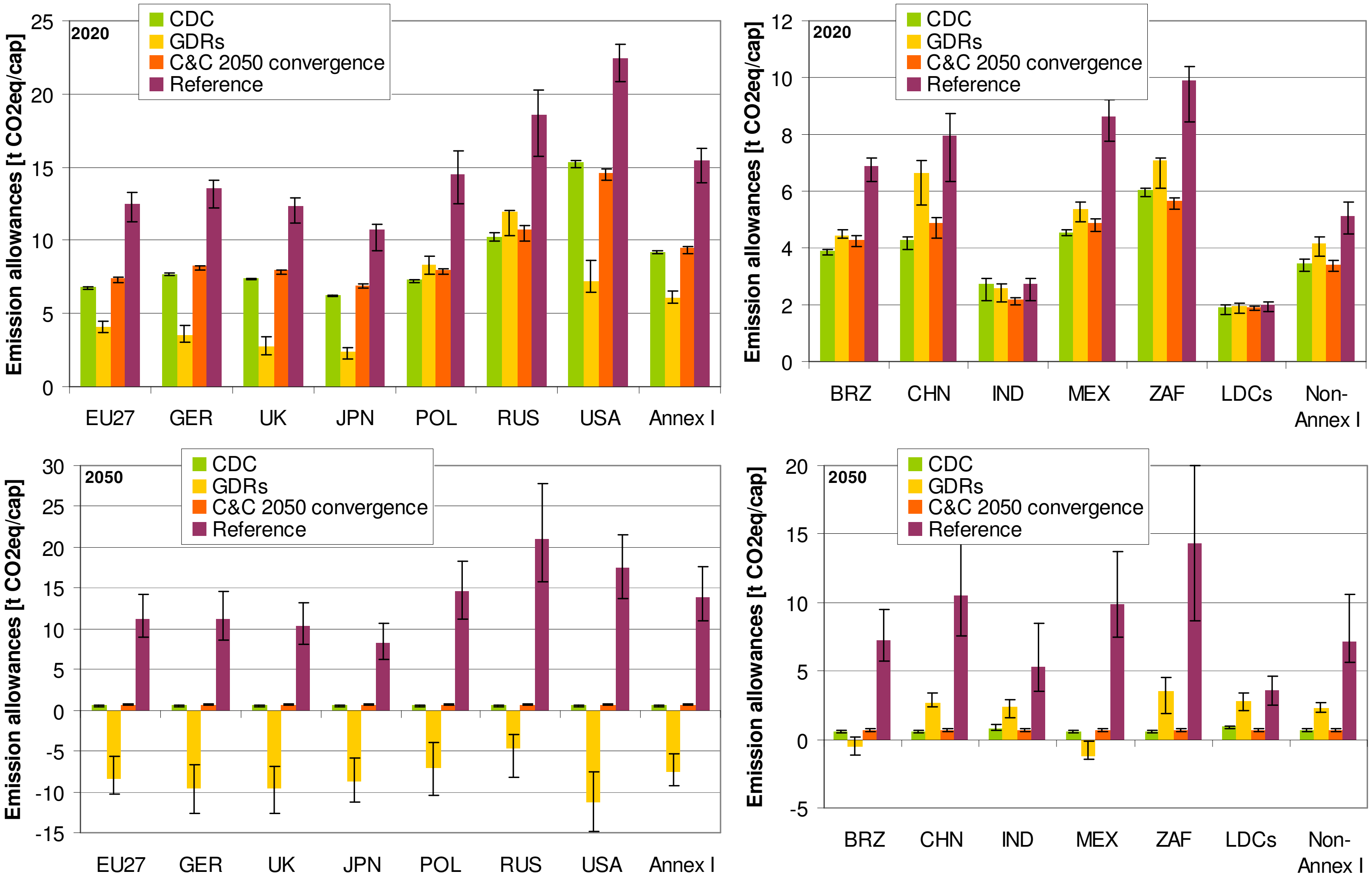

Figure 9. Emission allowances in 2020 and 2050 as emissions per capita for different reduction approaches.

Note: EU27 (European Union), GER (Germany), UK (United Kingdom), JPN (Japan), RUS (Russia), POL (Poland), USA, Annex I, BRZ (Brazil), CHN (China), IND (India), MEX (Mexico), ZAF (South Africa), LDCs (least developed countries), non-Annex I. Data are included in Appendix B.

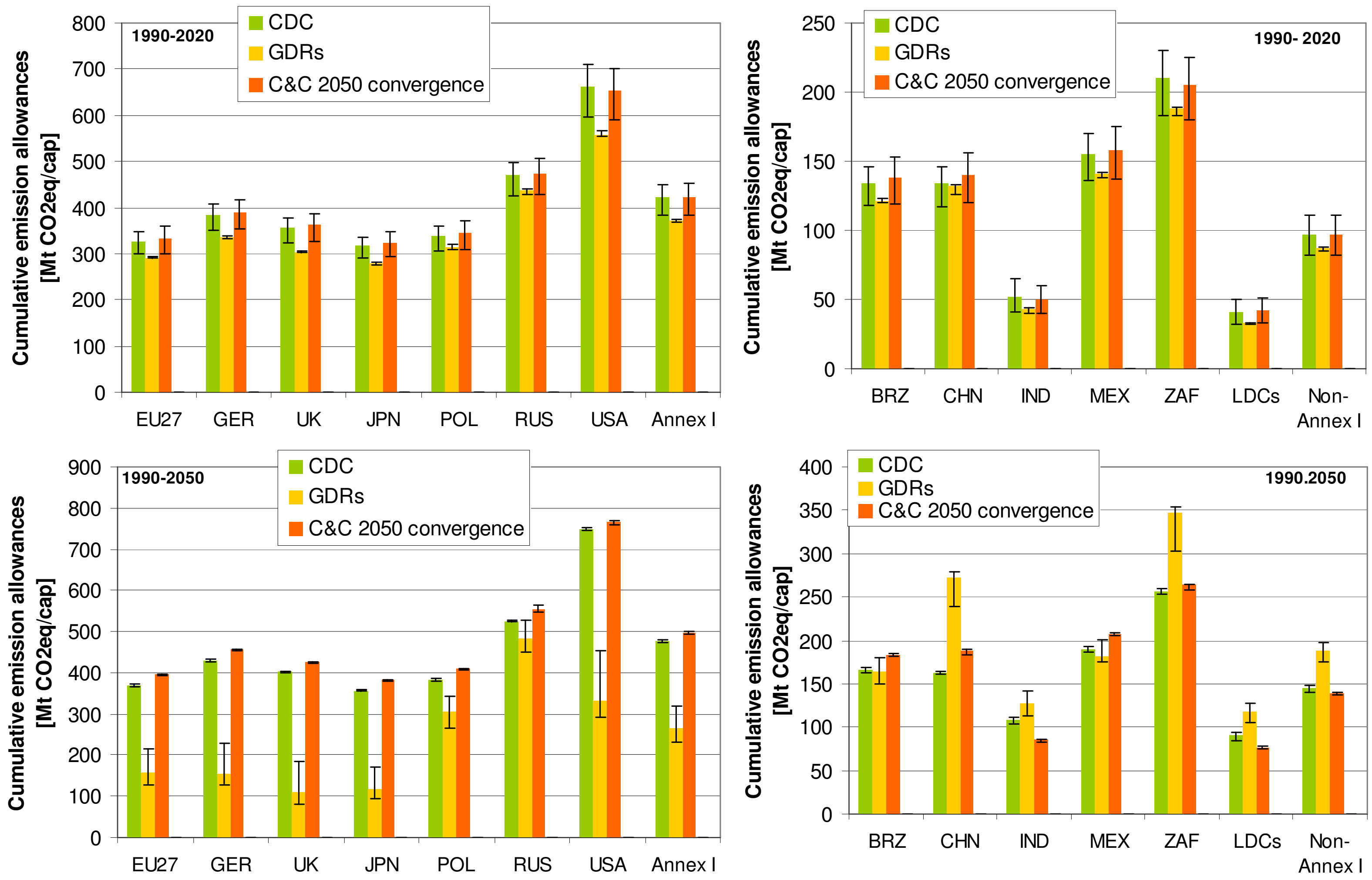

Figure 10. Cumulative emission allowances (1990-2020 and 1990-2050) per capita (2020 and 2050) different reduction approaches.

Note: EU27 (European Union), GER (Germany), UK (United Kingdom), JPN (Japan), RUS (Russia), POL (Poland), USA, Annex I, BRZ (Brazil), CHN (China), IND (India), MEX (Mexico), ZAF (South Africa), LDCs (least developed countries), non-Annex I. Data are included in Appendix B.

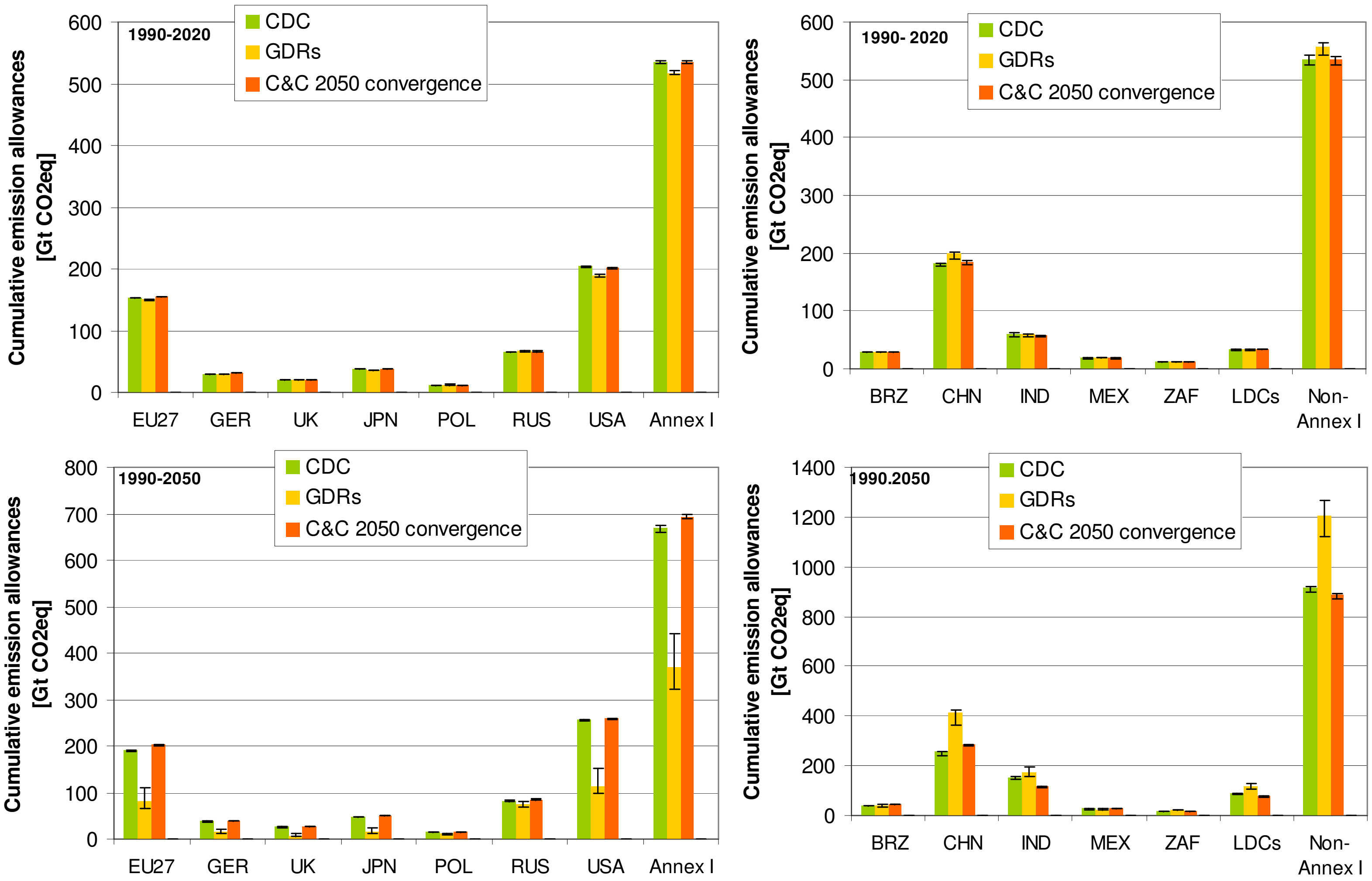

Figure 11. Cumulative emission allowances from 1990 to 2020 and 2050 for different reduction approaches.

Note: EU27 (European Union), GER (Germany), UK (United Kingdom), JPN (Japan), RUS (Russia), POL (Poland), USA, Annex I, BRZ (Brazil), CHN (China), IND (India), MEX (Mexico), ZAF (South Africa), LDCs (least developed countries), non-Annex I. Data are included in Appendix B.

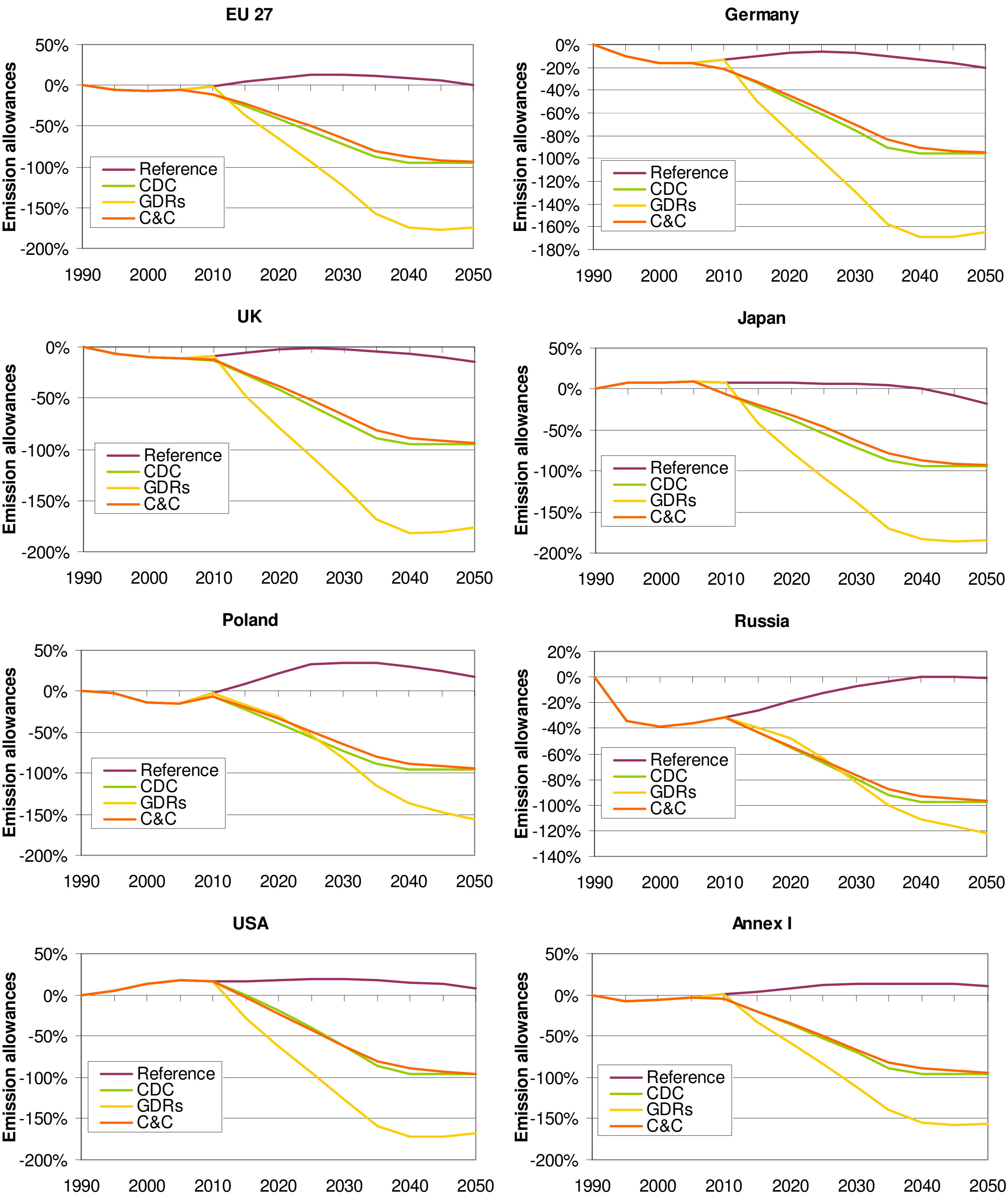

Figure 12. Development of national emission allowances as percentage change from 1990 emissions for Annex I between 1990 and 2050 under CDC, GDRs and C&C.

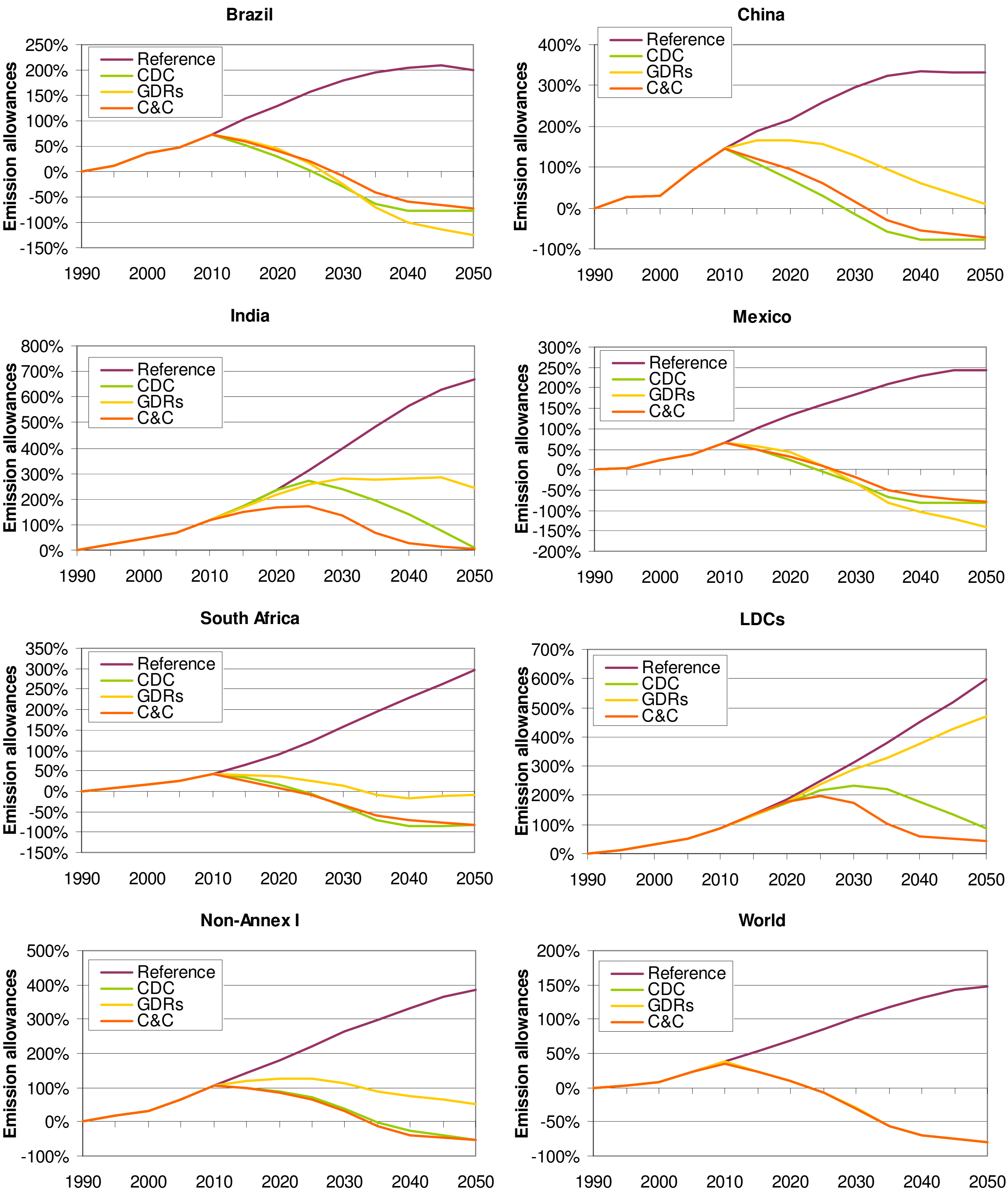

Figure 13. Development of national emission allowances as percentage change from 1990 emissions for non-Annex I and the world between 1990 and 2050 under CDC, GDRs and C&C.

4 Conclusions

The assumptions of -30% emission reduction below 1990 levels by 2020 and -80% by 2050 lead to a global GHG budget excluding LUCF of roughly 1800 Gt from 1990 to 2100. The requirements to reach this are very stringent. This is also reflected by the resulting target of about 0.5 tCO_2eq per capita as global average in 2050. In 2020 the average per capita emission lie around 9 tCO_2eq per capita for Annex I and 3-5 tCO_2eq per capita for non-Annex I.

Generally, the Greenhouse Development Rights approach (GDRs) allows negative emission where required reductions based on capacity and responsibility are larger than business as usual emissions. Contraction and Convergence (C&C) and Common but Differentiated Convergence (CDC) allow only very small but not negative emissions. Therefore, Annex I emission targets go to -60% in 2020 under the GDRs, while the other approaches require around -40%.

Hardly any differences can be seen for Annex I between C&C and CDC results. In the long term C&C leads to slightly less stringent results for high income and high emission countries.

By 2050, GDR requires Annex I countries as a group to reduce emissions by 157% and 'only' by 95% under C&C and CDC.

Developing countries and economies in transition (EITs) have more room to grow under GDRs than under the other approaches. The main reason for this is the relatively low per capita emissions combined with limited financial capacity.

LDCs are almost all exempt from emission reduction requirements under GDRs (+ >450% by 2050) , while under C&C they are granted little more allowances then their reference emissions until 2020 and face reduction obligations after 2025. Under CDC they face reductions after 2030.

Cumulative emissions per capita vary considerably under C&C and CDC for Annex I and non-Annex I. For GDRs some non-Annex I countries are granted higher per capita cumulative emissions than some countries of Annex I.

Under GDRs, non-Annex I countries are allowed to increase their total emissions and peak until 2025 and then need to reduce them to roughly today's level in 2050 (about 50% above 1990). Under C&C and CDC there is less room for growth and their emissions need to be at a third of today's emissions (half of 1990's emissions). This is reflected particular in the case of China and India. Both countries would be entitled under GDR to grow their emissions by 10% and even 240%, respectively by 2050 compared to 1990 but would be required to reduce by >70% and about 2-7% in same period under the other two models.

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Appendix A Description of the EVOC tool

This section describes the Evolution of Commitments tool (EVOC) version 8, developed by Ecofys, that is used to quantify emission allowances under the various approaches in this report. It includes emissions of CO_2, CH_4, N_2O, hydroflourocarbons (HFCs), perflourocarbons (PFCs) and sulphur hexafluoride (SF_6) for 192 individual countries. Historical emissions are based on national emission inventories submitted to the UNFCCC and, where not available, other sources such as the International Energy Agency. Future emissions are based on the IPCC Special Report on Emissions Scenarios (Nakicenovic et al. 2000). The greenhouse gas emission data for 1990 to 2006 is derived by an algorithm that combines emission estimates from various sources.

We first collected historical emission estimates by country, by gas and by sector from the following sources and ordered them in the following hierarchy:

1. National submissions to the UNFCCC as collected by the UNFCCC secretariat and published in the GHG emission database available at their web site. For Annex I countries, the latest available year is usually 2004. Most non-Annex I countries report only or until 1994 (UNFCCC 2008).
2. CO_2 emissions from fuel combustion as published by the International Energy Agency. The latest available year is 2003 (IEA 2008).
3. Emissions from land-use change as published by Houghton in the WRI climate indicator analysis tool (Houghton 2003).
4. Emissions from CH_4 and N_2O as estimated by the US Environmental Protection Agency. Latest available year is 2005 (USEPA 2006)
5. CO_2, CH_4, N_2O, HFC, PFC and SF_6 emissions from the EDGAR database version 3.2 available for 1990 and 1995 (Olivier and Berdowski 2001).[1]

Future emissions are derived from the MNP/RIVM IMAGE implementation of the SRES scenarios (IMAGE team 2001).

The datasets vary in their completeness and sectoral split. We first defined which of the sectors provided in the datasets correspond to 7 sectors. This definition is provided in Table 1. Note that CO_2 emissions from the IEA do not include process emissions from cement production. Hence, if IEA data is chosen, process emissions from cement production are not included.

For each country, gas and sector, the algorithm completes the following steps:

1. For all data sets, missing years in-between available years within a data set are linearly interpolated and the growth rate is calculated for each year step.
2. The data source is selected, which is highest in hierarchy and for which emission data are available. All available data points are chosen as the basis for absolute emissions.
3. Still missing years are filled by applying the growth rates from the highest data set in the hierarchy for which a growth rate is available.

[1] For CH_4 and N_2O, the values of EPA are largely based on the EDGAR database (1990 and 1995), but extended to the year 2000.

As future emissions are only available on a regional basis and not country-by-country, the resulting set of emissions is then extended into the future by applying the growth rates of the respective sectors and gas of the region to which the country belongs. (See Table 1 for detailed information on data sources and definition of sectors.)

For population, GDP in purchase power parities and electricity demand, the country base year data was taken from the United Nations (UN 2008), World Bank (2008) and IEA (2008), respectively. These data are extended into the future by applying the growth rates from the IMAGE model for the region to which the country belongs.

Emissions until 2010 are estimated as follows: It is assumed that Annex I countries implement their Kyoto targets by 2010. It is assumed that the reductions necessary to meet the Kyoto target are achieved equally in all sectors. In 2010, the level of the domestic sector is taken from the relevant reference scenario. The level of the other sectors are taken from the reference scenario and reduced, so that the Kyoto target is met. The years from the last available year to 2010 are linearly interpolated. All non-Annex I countries follow their reference scenario until 2010.

Table 1. Data sources and definition of sectors

	UNFCCC		**Edgar 3.2 database**		**USEPA**		**LUCF Houghton**		**IEA**		**IMAGE CD**	
	Regional:	country by country	**Regional:**	country by country	**Regional:**	country-by country	**Regional:**	country-by country	**Regional:**	country by country	**Regional:**	17 regions
	Temporal:	1990 to 2002 (various)	**Temporal:**	1990 and 1995	**Temporal:**	1990-2020	**Temporal:**	1950-2000	**Temporal:**	1970-2000	**Temporal:**	1970 to 2100
	Gas:	CO2, CH4, N2O, HFCs, PFCs, SF6	**Gas:**	CO2, CH4, N2O; HFCs, PFCS, SF6	**Gas:**	CH4, N2O	**Gas:**	CO2	**Gas:**	CO2	**Gas:**	CO2, CH4, N2O, HFCs, PFCs, SF6
Industry												
	1A2	Manufacturing Industries and Construction	**F10**	Industry					3T Other Energy Industries		ENERGY 01 Industry	
	2A0	Mineral Products	**F30**	Other transformation sectors					401 Iron and Steel		ENERGY 07 Other energy transformation	
	2B0	Chemical Industry	**B10CH4N2O**	Biofuel industry CH4 N2O					402 Chemical and Petrochemical		INDUS 01 Feedstocks	
	2C0	Metal Production	**B30CH4N2O**	Biofuel charcoal production CH4 N2O					403 Non-Ferrous Metals		INDUS 02 Industrial activities	
	2D0	Other Production	**I10**	Iron and steel					404 Non-Metallic Minerals			
	2G0	Other (Industrial Processes)	**I20**	Non-ferrous metals					409 Paper, Pulp and Printing			
			I30	Chemicals					405 Transport Equipment			
			I40	Building materials					406 Machinery			
			I50	Pulp and paper					407 Mining and Quarrying			
			I60	Food					408 Food and Tobacco			
			I70	Solvent use/Miscellaneous					410Wood and Wood Products			
			I80	Transport evaporation					411 Construction			
			I90	Miscellanecus industry					412 Textile and Leather			
			F60	non-energy use and feedstocks					413 Non-specified Industry			
									414 Non-Energy Use Ind/Transf/Energy			
									If the IEA data set is chosen, process emissions from industry (e.g. from cement) are not covered			
Electricity												
	1A1	Energy Industries	**F20**	Power generation					11 Public Electricity Plants		ENERGY 06 Electric power generation	
			B20CH4N2O	Biofuel power generation CH4 N2O					12 Public CHP Plants			
									13 Public Heat Plants			
									14 Own Use in Electricity, CHP and heat plants			
									21 Autoproducer Electricity Plants			
									22 Autoproducer CHP Plants			
									23 Autoproducer Heat Plants			
Domestic												
	1A3	Transport	**F40**	Residential, commercial and other sectors					5T Transport		ENERGY 02 Transport	
	1A4	Other Sectors (Fuel Combustion)	**F51**	Transport road					6T Other Sectors		ENERGY 03 Residential (households)	
	1A5	Other (Fuel Combustion)	**F54**	Transport land non-road					*MB Memo: International Marine Bunkers*		ENERGY 04 Services (commercial and public)	
	2E0	Production of Halocarbons and Sulphur Hexafluoride	**F57**	Transport air (international and domestic)					*AB Memo: International Aviation Bunkers*		ENERGY 05 Agriculture and other enduse	
	2F0	Consumption of Halocarbons and Sulphur Hexafluoride	***F58***	*Transport international shipping*							*ENERGY 09 Marine bunkers*	
	3TT	TOTAL Solvent and Other Product Use	**B40CH4N2O**	Biofuel residential CH4 N2O							FGAS	
	9TT	*TOTAL International Bunkers*	**B51CH4N2O**	Biofuel transport road CH4 N2O								
			C10	HFC-byproc.								
			C20	HFC use								
			C30	PFC-byproc.								
			C40	PFC use								
			C50	SF6 use								
	Secotors in italics are excluded when the user chooses to exclude international transport											
Fossil fuel production												
	1BT	TOTAL Fugitive Emissions from Fuels	**F70**	Coal production	02 Coal production				7T Differences due to Losses and/or Transformation		ENERGY 08 Fossil fuel production	
			F80	Oil production, transmission and handling	03 Natural gas production							
			F90	Gas production and transmission	04 Oil production							
			F95	Fossil fuel fres								
Agriculture												
	4TT	TOTAL Agriculture	**L10**	Fertiliser use	06 Manure management						LAND 10 wetland rice	
			L15	Rice cultivation	07 Enteric fermentation						LAND 11 animals	
			L20	Enteric fermentation	08 Rice production						LAND 12 animal waste	
			L30	Animal waste management (confined N2O, all CH4)	09 Agricultural soils						LAND 14 fertilizer	
			L50	Crop production							LAND 15 indirect fertilizer	
			L60	Animal waste management (deposited on soil- N2O)							LAND 16 indirect animal waste	
			L71	Atmospheric deposition							LAND 17 crop residues	
			L75	Leaching and run-off							LAND 18 biological N-fixation	
LUCF												
	5TT	TOTAL Land-Use Change & Forestry	**L41**	BB-Deforestation	10 Biomass combustion		Land-use				LAND 01 biomass burning	
			L42	BB-Savanna burning							LAND 02 burning of traditional biomass / fuelwood burning	
			L43	BB-Agricultural waste burning							LAND 03 timber pool (short lifetime)	
			L44	BB-Vegetation fires							LAND 04 timber pool (long lifetime)	
			L45	BB-deforestation post burn effects							LAND 05 carbon release by regrowing vegetation (-NEP)	
											LAND 06 agricultural waste burning	
											LAND 07 savanna burning	
											LAND 13 land clearing	
Waste												
	6TT	TOTAL Waste	**W10**	Landfills	11 Landfills						LAND 08 landfills	
			W15	Humans/pets	12 Wastewater						LAND 09 (domestic) sewage	
			W20	Waste water treatment								
			W30	Human waste disposal								
			W40	Waste incireration								
			W50	Miscelaneous waste handling (hazardous waste)								
	CO2 emissions from Biaomass buring (UNFCCC sector 1A8 and EGRAR sectors B10 to B51) are not included as they are not to be included in the national totals according to teh IPCC guidelines and the UNFCCC repsoting guidelines)											

As a default setting, all Annex I countries are assumed to reach the lower of their Kyoto target and their reference scenarios in 2010. Only the USA is assumed to follow its BAU emissions until 2010. All non-Annex I countries also follow their reference scenario until 2010. After 2010, the emission allowances per country are calculated according to the effort sharing approaches.

A limitation of the tool is the unknown future development of emissions of individual countries. Here, we have used the standard set of future emissions scenarios, the IPCC SRES scenarios, as a basis. They provide a broad range of storylines and therefore a wide range of possible future emissions. We cover this full range of possible future emissions, economic and population development in a consistent manner. But the SRES scenarios are only available at the level of up to 17 regions (as in the IMAGE implementation) and scaling them down to individual countries introduces an additional element of uncertainty. We applied the growth rates provided for 17 world regions to the latest available data points of the individual countries within the respective regions. So, on the level of regions, we cover the full-range uncertainty about future emissions. When again aggregating the regions, the effect of downscaling cancels out. But the full level of uncertainty is not covered on the national level as substantial differences may exist for expected growth for countries within one of the 17 regions.

The future reference development of emissions, economic and population is affected by the starting values (which is data available from the countries or other international sources and which can be substantially different for countries in one region) and the assumed growth rates (which are derived from the 17 regions).

The assumed growth rates may affect the results of countries to a different extent. Some countries are less affected as they dominate their regional group, such as Brazil, Mexico, Egypt, South Africa, Nigeria, Saudi Arabia, China and India. It is for second or third largest countries in a region or for members of an inhomogeneous group, for which this method may lead to an over or underestimation of the future development.

Second or third largest countries in a region are e.g. Argentina, Venezuela, United Arab Emirates and South Korea. In the Contraction and Convergence approach, the error would be small as countries follow their reference scenario only until 2010 and converge afterwards. For Common but Differentiated Convergence and Multistage, the downscaling method may influence the time of participation. But the countries listed above would all participate at the earliest possible moment, based on their already today high per capita emissions. In the Triptych approach, growth in industrial and electricity production and a reduction below reference for agriculture is used, which may be affected by the downscaling method.

Members of an inhomogeneous group would be those of South East Asia, which includes Indonesia and the Philippines as lower-income countries and Malaysia, Singapore and Thailand as higher-income countries. Here the growth is averaged over the region, probably underestimated for Indonesia and the Philippines and overestimated for Singapore. The dominant element here is the starting point. The low per capita emissions of the Philippines and Indonesia lead to their late participation, while the high per capita emissions in Malaysia, Singapore and Thailand lead to their immediate participation. In the Triptych approach, growth in industrial and electricity production and a reduction below reference for agriculture is used, which may be affected by the downscaling method.

For Annex I countries, the future reference development is not as relevant since they always participate in the regime on the highest stage and have to reduce emissions independent of the reference development. Future values are only relevant for intensity targets (GDP) or for the Triptych approach (industrial and electricity production).

A different uncertainty is introduced since our future emissions are static, meaning that emissions in non-participating developing countries do not change as a result of ambitious or relaxed emission reductions in developed countries. Stringent reductions could affect emissions of non-participating countries in two ways. There could be increased emissions through migration of energy-intensive industries or decreased emissions due to technology spill-over. Overall, we assume that this effect is small and not significantly influencing the results of this analysis.

Appendix B Emission allowances distributed with EVOC

For methodological reasons an overall carbon budget of 1600 Gt by 2050 is assumed instead of 1660 Gt by 2050 as estimated in Chapter 2.

Table 2. Emission allowances as percentage change from 1990 for 2020 and 2050 under CDC, C&C and GDRs excluding LUCF

	Emissions [Mt CO2 eq.]			CDC % change from 1990 2020			GDRs % change from 1990 2020			C&C 2050 convergence % change from 1990 2020			Reference % change from 1990 2020		
Year	**1990**	**2000**	**2010**												
Country group			BAU	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
World	31196	33764	43250	6%	10%	12%	6%	10%	12%	6%	10%	12%	55%	68%	83%
EU27	5802	5371	5767	-42%	-41%	-40%	-68%	-65%	-61%	-37%	-36%	-35%	-2%	9%	16%
GER	1253	1055	1086	-49%	-48%	-47%	-79%	-76%	-71%	-45%	-44%	-44%	-18%	-8%	-4%
UK	800	718	731	-43%	-42%	-42%	-83%	-79%	-73%	-39%	-38%	-37%	-13%	-3%	1%
JPN	1318	1427	1423	-39%	-38%	-38%	-81%	-76%	-73%	-33%	-32%	-31%	-8%	7%	11%
POL	456	392	445	-40%	-39%	-39%	-35%	-30%	-25%	-35%	-34%	-32%	5%	21%	35%
RUS	3361	2060	2288	-57%	-55%	-54%	-55%	-48%	-47%	-55%	-54%	-52%	-31%	-19%	-12%
USA	6341	7240	7403	-21%	-19%	-18%	-66%	-62%	-54%	-26%	-23%	-22%	10%	18%	23%
Annex I	19699	18545	19746	-37%	-36%	-35%	-60%	-58%	-54%	-37%	-35%	-33%	-3%	8%	13%
BRZ	680	931	1175	24%	29%	33%	42%	45%	61%	37%	42%	45%	108%	130%	135%
CHN	3546	4604	8703	59%	71%	73%	130%	165%	177%	82%	94%	98%	169%	218%	242%
IND	1087	1560	2343	173%	235%	261%	165%	215%	234%	152%	169%	177%	173%	235%	261%
MEX	457	562	763	19%	23%	27%	32%	44%	49%	27%	31%	34%	107%	135%	146%
ZAF	337	391	483	14%	16%	17%	21%	35%	37%	5%	8%	11%	66%	90%	99%
LDCs	682	888	1270	149%	174%	186%	152%	180%	195%	165%	176%	184%	156%	186%	202%
Non-Annex I	11263	14850	23124	79%	89%	95%	111%	126%	138%	78%	86%	91%	154%	179%	202%

	Emissions [Mt CO2 eq.]			CDC % change from 1990 2050			GDRs % change from 1990 2050			C&C 2050 convergence % change from 1990 2050			Reference % change from 1990 2050		
	1990	**2000**	**2010**												
			BAU	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
World	31196	33764	43250	-80%	-80%	-80%	-80%	-80%	-80%	-80%	-80%	-80%	90%	148%	225%
EU27	5802	5371	5767	-96%	-95%	-94%	-195%	-174%	-151%	-95%	-94%	-94%	-25%	1%	25%
GER	1253	1055	1086	-97%	-96%	-96%	-193%	-165%	-147%	-96%	-95%	-95%	-45%	-20%	1%
UK	800	718	731	-96%	-95%	-95%	-206%	-176%	-155%	-95%	-94%	-94%	-41%	-15%	6%
JPN	1318	1427	1423	-96%	-94%	-94%	-214%	-185%	-158%	-94%	-93%	-93%	-41%	-18%	5%
POL	456	392	445	-97%	-95%	-95%	-182%	-156%	-132%	-95%	-94%	-94%	-13%	17%	43%
RUS	3361	2060	2288	-98%	-97%	-97%	-136%	-122%	-112%	-97%	-97%	-97%	-31%	-1%	20%
USA	6341	7240	7403	-97%	-96%	-96%	-198%	-167%	-147%	-96%	-96%	-95%	-19%	8%	32%
Annex I	19699	18545	19746	-97%	-96%	-95%	-175%	-157%	-139%	-95%	-95%	-95%	-18%	10%	31%
BRZ	680	931	1175	-81%	-77%	-76%	-145%	-125%	-95%	-74%	-73%	-70%	131%	201%	256%
CHN	3546	4604	8703	-81%	-76%	-76%	-10%	10%	92%	-74%	-73%	-67%	209%	331%	497%
IND	1087	1560	2343	-8%	7%	51%	146%	242%	323%	1%	2%	5%	478%	669%	1108%
MEX	457	562	763	-84%	-81%	-80%	-156%	-140%	-106%	-78%	-78%	-75%	145%	243%	321%
ZAF	337	391	483	-87%	-83%	-83%	-41%	-7%	19%	-82%	-81%	-78%	173%	295%	434%
LDCs	682	888	1270	80%	88%	115%	362%	472%	544%	35%	43%	54%	433%	596%	778%
Non-Annex I	11263	14850	23124	-55%	-52%	-50%	23%	51%	85%	-56%	-54%	-53%	278%	386%	557%

Table 3. Emission allowances as percentage change from BAU for 2020 and 2050 under CDC, C&C and GDRs excluding LUCF

	Emissions [Mt CO2 eq.]			CDC % change from BAU 2020			GDRs % change from BAU 2020			C&C 2050 convergence % change from BAU 2020			Reference % change from BAU 2020		
Year	1990	2000	2010												
Country group			BAU	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
World	31196	33764	43250	-39%	-35%	-32%	-39%	-35%	-32%	-39%	-35%	-32%			
EU27	5802	5371	5767	-48%	-46%	-40%	-72%	-66%	-60%	-43%	-42%	-36%			
GER	1253	1055	1086	-45%	-43%	-37%	-78%	-73%	-66%	-41%	-39%	-33%			
UK	800	718	731	-43%	-40%	-35%	-83%	-77%	-69%	-38%	-36%	-30%			
JPN	1318	1427	1423	-44%	-42%	-33%	-83%	-77%	-71%	-37%	-36%	-27%			
POL	456	392	445	-55%	-50%	-42%	-47%	-42%	-38%	-50%	-45%	-38%			
RUS	3361	2060	2288	-48%	-45%	-37%	-41%	-37%	-32%	-46%	-43%	-35%			
USA	6341	7240	7403	-34%	-32%	-28%	-72%	-67%	-59%	-37%	-34%	-31%			
Annex I	19699	18545	19746	-43%	-40%	-35%	-65%	-59%	-54%	-41%	-40%	-34%			
BRZ	680	931	1175	-45%	-44%	-41%	-39%	-34%	-30%	-40%	-38%	-34%			
CHN	3546	4604	8703	-50%	-46%	-38%	-19%	-17%	-13%	-42%	-39%	-32%			
IND	1087	1560	2343				-7%	-6%	-3%	-23%	-20%	-8%			
MEX	457	562	763	-50%	-47%	-43%	-42%	-38%	-33%	-45%	-44%	-38%			
ZAF	337	391	483	-41%	-39%	-31%	-32%	-29%	-25%	-44%	-43%	-36%			
LDCs	682	888	1270	-5%	-5%	-1%	-2%	-2%	-2%	-6%	-4%	6%			
Non-Annex I	11263	14850	23124	-36%	-32%	-29%	-21%	-19%	-17%	-37%	-33%	-30%			

	Emissions [Mt CO2 eq.]			CDC % change from BAU 2050			GDRs % change from BAU 2050			C&C 2050 convergence % change from BAU 2050			Reference % change from BAU 2050		
	1990	2000	2010												
			BAU	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
World	31196	33764	43250	-94%	-92%	-89%	-94%	-92%	-89%	-94%	-92%	-89%			
EU27	5802	5371	5767	-96%	-95%	-94%	-190%	-172%	-164%	-95%	-94%	-92%			
GER	1253	1055	1086	-96%	-95%	-94%	-211%	-180%	-173%	-95%	-94%	-92%			
UK	800	718	731	-96%	-94%	-94%	-219%	-188%	-181%	-95%	-93%	-91%			
JPN	1318	1427	1423	-95%	-92%	-92%	-226%	-203%	-190%	-94%	-91%	-88%			
POL	456	392	445	-97%	-96%	-95%	-157%	-148%	-130%	-96%	-95%	-93%			
RUS	3361	2060	2288	-98%	-97%	-97%	-130%	-122%	-115%	-97%	-97%	-95%			
USA	6341	7240	7403	-98%	-96%	-96%	-176%	-162%	-155%	-97%	-96%	-95%			
Annex I	19699	18545	19746	-97%	-96%	-95%	-164%	-152%	-148%	-96%	-95%	-93%			
BRZ	680	931	1175	-94%	-92%	-91%	-113%	-108%	-98%	-93%	-91%	-88%			
CHN	3546	4604	8703	-96%	-95%	-94%	-80%	-75%	-54%	-96%	-93%	-91%			
IND	1087	1560	2343	-92%	-85%	-76%	-66%	-61%	-29%	-92%	-86%	-82%			
MEX	457	562	763	-95%	-95%	-93%	-115%	-111%	-102%	-95%	-93%	-91%			
ZAF	337	391	483	-97%	-96%	-94%	-84%	-78%	-74%	-96%	-95%	-92%			
LDCs	682	888	1270	-79%	-73%	-60%	-27%	-21%	-11%	-84%	-80%	-71%			
Non-Annex I	11263	14850	23124	-93%	-90%	-87%	-74%	-70%	-60%	-93%	-90%	-88%			

Table 4. Emission allowances as per capita emissions for 2020 and 2050 under CDC, C&C and GDRs excluding LUCF

Year	Emissions [t CO2eq./cap] 1990	2000	2010 incl. Kyoto target	CDC t CO2eq./cap 2020 Min	Median	Max	GDRs t CO2eq./cap 2020 Min	Median	Max	C&C 2050 convergence t CO2eq./cap 2020 Min	Median	Max	Reference t CO2eq./cap 2020 Min	Median	Max
Country group															
World	6.0	5.6	6.2	4.2	4.5	4.7	4.2	4.5	4.7	4.2	4.5	4.7	6.4	6.9	7.6
EU27	12.3	11.1	10.4	6.7	6.8	6.8	3.7	4.1	4.4	7.1	7.4	7.5	11.2	12.5	13.2
GER	15.8	12.8	11.9	7.6	7.7	7.7	3.1	3.5	4.2	8.0	8.2	8.3	12.2	13.5	14.1
UK	13.9	12.0	11.4	7.3	7.4	7.4	2.2	2.7	3.4	7.7	7.9	8.0	11.2	12.3	12.9
JPN	10.7	11.3	9.6	6.2	6.3	6.3	1.9	2.4	2.7	6.7	6.9	7.0	9.3	10.7	11.1
POL	12.0	10.2	11.2	7.1	7.2	7.3	7.7	8.3	8.9	7.7	7.9	8.0	12.5	14.5	16.1
RUS	22.7	14.1	15.9	9.9	10.2	10.5	10.3	11.9	12.0	10.0	10.7	11.0	15.7	18.5	20.2
USA	25.4	25.7	24.0	14.9	15.3	15.4	6.4	7.2	8.7	14.1	14.6	14.9	20.9	22.5	23.4
Annex I	16.5	14.9	14.2	9.1	9.2	9.3	5.7	6.1	6.5	9.1	9.4	9.6	14.0	15.4	16.3
BRZ	4.5	5.3	5.9	3.8	3.9	4.0	4.3	4.5	4.6	4.0	4.3	4.4	6.4	6.9	7.2
CHN	3.1	3.6	6.5	3.9	4.3	4.4	5.5	6.6	7.1	4.3	4.9	5.1	6.4	8.0	8.7
IND	1.3	1.5	2.0	2.2	2.7	2.9	2.1	2.6	2.7	2.0	2.2	2.3	2.2	2.7	2.9
MEX	5.5	5.7	6.9	4.4	4.5	4.7	4.9	5.4	5.6	4.6	4.9	5.0	7.7	8.6	9.2
ZAF	9.6	8.9	9.2	5.8	6.0	6.1	6.1	7.1	7.2	5.4	5.6	5.8	8.4	9.9	10.4
LDCs	1.3	1.3	1.5	1.7	1.9	2.0	1.7	1.9	2.0	1.8	1.9	2.0	1.7	2.0	2.1
Non-Annex I	2.8	3.1	4.3	3.2	3.5	3.6	3.7	4.2	4.4	3.2	3.4	3.5	4.5	5.1	5.6

	Emissions [t CO2eq./cap] 1990	2000	2010 incl. Kyoto target	CDC t CO2eq./cap 2050 Min	Median	Max	GDRs t CO2eq./cap 2050 Min	Median	Max	C&C 2050 convergence t CO2eq./cap 2050 Min	Median	Max	Reference t CO2eq./cap 2050 Min	Median	Max
World	6.0	5.6	6.2	0.6	0.7	0.7	0.6	0.7	0.7	0.6	0.7	0.7	6.5	8.1	11.7
EU27	12.3	11.1	10.4	0.4	0.6	0.6	-10.3	-8.4	-5.7	0.6	0.7	0.7	9.0	11.1	14.1
GER	15.8	12.8	11.9	0.4	0.6	0.6	-12.7	-9.5	-6.7	0.6	0.7	0.7	8.6	11.2	14.5
UK	13.9	12.0	11.4	0.4	0.6	0.6	-12.6	-9.6	-6.9	0.6	0.7	0.7	8.0	10.3	13.2
JPN	10.7	11.3	9.6	0.4	0.6	0.6	-11.3	-8.7	-5.9	0.6	0.7	0.7	6.2	8.3	10.7
POL	12.0	10.2	11.2	0.4	0.6	0.6	-10.5	-6.9	-4.0	0.6	0.7	0.7	11.2	14.5	18.3
RUS	22.7	14.1	15.9	0.4	0.6	0.6	-8.2	-4.6	-2.9	0.6	0.7	0.7	15.8	21.0	27.8
USA	25.4	25.7	24.0	0.4	0.6	0.6	-14.8	-11.2	-7.5	0.6	0.7	0.7	13.6	17.5	21.4
Annex I	16.5	14.9	14.2	0.4	0.6	0.6	-9.2	-7.6	-5.3	0.6	0.7	0.7	10.9	13.9	17.6
BRZ	4.5	5.3	5.9	0.4	0.6	0.6	-1.2	-0.6	0.1	0.6	0.7	0.7	5.7	7.2	9.5
CHN	3.1	3.6	6.5	0.4	0.6	0.6	2.4	2.7	3.4	0.6	0.7	0.7	7.5	10.5	16.2
IND	1.3	1.5	2.0	0.6	0.7	1.1	1.6	2.3	2.9	0.6	0.7	0.7	3.5	5.4	8.4
MEX	5.5	5.7	6.9	0.4	0.6	0.6	-1.5	-1.2	-0.2	0.6	0.7	0.7	7.4	9.8	13.7
ZAF	9.6	8.9	9.2	0.4	0.6	0.6	1.9	3.5	4.5	0.6	0.7	0.7	8.7	14.3	20.0
LDCs	1.3	1.3	1.5	0.8	1.0	1.0	2.1	2.8	3.4	0.6	0.7	0.7	2.5	3.6	4.6
Non-Annex I	2.8	3.1	4.3	0.6	0.7	0.8	1.9	2.3	2.7	0.6	0.7	0.7	5.6	7.1	10.5

Table 5. Cumulative emission allowances (1990 – 2020 and 1990 – 2050) per capita (in 2020 and 2050) under CDC, C&C and GDRs excluding LUCF

Year Country group	Population million people 2000 Median	2010 Median	2020 Median	Cumulative emissions Mt CO2 eq./cap 1990-2000 Median	1990-2010 Median	CDC Mt CO2eq./cap 1990-2020 Min	Median	Max	GDRs Mt CO2eq./cap 1990-2020 Min	Median	Max	C&C 2050 convergence Mt CO2eq./cap 1990-2020 Min	Median	Max
World	6033	6873	7854	53	101	136	156	172	136	138	139	136	156	172
EU27	482	499	512	115	219	298	327	348	290	292	294	301	334	358
GER	82	84	86	139	261	350	384	407	334	335	340	353	389	416
UK	60	61	63	128	239	324	356	378	302	303	307	327	362	388
JPN	127	130	132	109	214	290	317	336	276	278	280	293	324	348
POL	38	38	39	114	217	307	338	360	309	315	322	310	345	371
RUS	146	145	152	168	317	427	469	498	428	438	442	428	473	506
USA	282	310	338	237	449	597	663	709	553	556	566	592	654	700
Annex I	1248	1313	1392	150	285	382	422	449	370	371	375	382	423	454
BRZ	174	203	237	44	87	118	134	146	120	121	123	119	138	153
CHN	1263	1368	1511	34	77	117	134	146	126	132	133	120	140	156
IND	1016	1186	1375	13	26	41	52	65	40	43	44	40	50	60
MEX	98	111	130	50	100	136	155	170	138	141	142	137	158	175
ZAF	44	52	67	81	149	183	210	230	183	188	189	180	205	225
LDCs	647	815	994	11	21	32	41	50	32	33	33	33	42	51
Non-Annex I	4734	5499	6390	27	56	82	97	111	85	87	88	82	97	111

	Population million people 2000 Median	2010 Median	2050 Median	Cumulative emissions Mt CO2 eq./cap 1990-2000 Median	1990-2010 Median	CDC Mt CO2eq./cap 1990-2050 Min	Median	Max	GDRs Mt CO2eq./cap 1990-2050 Min	Median	Max	C&C 2050 convergence Mt CO2eq./cap 1990-2050 Min	Median	Max
World	6033	6873	10823	53	101	201	205	208	202	204	205	201	204	205
EU27	482	499	537	115	219	367	370	372	126	157	215	392	396	398
GER	82	84	91	139	261	428	430	433	129	156	227	452	456	457
UK	60	61	67	128	239	399	402	404	81	112	185	423	427	428
JPN	127	130	134	109	214	355	357	359	95	119	172	380	384	384
POL	38	38	38	114	217	380	383	385	266	306	343	406	411	411
RUS	146	145	183	168	317	523	525	527	450	483	527	549	556	563
USA	282	310	419	237	449	746	749	752	291	331	453	759	766	768
Annex I	1248	1313	1637	150	285	474	476	479	231	266	319	495	499	501
BRZ	174	203	350	44	87	163	165	168	150	163	180	181	184	185
CHN	1263	1368	1976	34	77	161	163	165	239	273	279	183	188	189
IND	1016	1186	1871	13	26	104	108	111	114	127	142	82	86	87
MEX	98	111	193	50	100	187	190	192	175	182	200	205	208	209
ZAF	44	52	106	81	149	253	256	260	302	347	354	258	264	264
LDCs	647	815	1495	11	21	85	90	94	105	118	128	74	77	78
Non-Annex I	4734	5499	9071	27	56	141	144	148	176	189	198	137	139	140

Note: Cumulative emissions are divided by the absolute number of people in that year. E.g. for 2020 Cumulative emission from 1990 to 2020 are divided by the population of 2020.

Table 6. Cumulative emission allowances from 1990 to 2020 and 2050 under CDC, C&C and GDRs excluding LUCF

	Cumulative emissions Gt CO2 eq.		CDC Gt CO2 eq.			GDRs Gt CO2 eq.			C&C 2050 convergence Gt CO2 eq.		
Year	**1990-2000**	**1990-2010**	**1990-2020**			**1990-2020**			**1990-2020**		
Country group	Median	Median	Min	Median	Max	Min	Median	Max	Min	Median	Max
World total	319	692	1068	1081	1089	1070	1083	1092	1068	1081	1089
Figure 02 EU27	55	109	153	154	154	149	150	150	154	155	155
Figure 04 GER	11	22	30	30	30	29	29	29	30	30	31
Figure 05 UK	8	15	21	21	21	19	19	19	21	21	21
Figure 07 JPN	14	28	38	38	38	36	37	37	39	39	39
Poland	4	8	12	12	12	12	12	12	12	12	12
EVOC 05 RUS	25	46	65	66	66	65	67	67	65	66	66
Figure 01 USA	67	139	202	204	205	187	188	191	200	202	203
UNFCCC Annex I	187	375	532	535	536	515	517	521	532	535	538
EVOC 12 BRZ	8	18	28	28	28	28	29	29	28	29	29
EVOC 24 CHN	42	106	177	182	183	190	199	201	181	186	187
EVOC 25 IND	13	31	56	60	61	56	59	61	55	58	58
EVOC 13 MEX	5	11	18	18	18	18	18	19	18	18	18
EVOC 17 ZAF	4	8	12	12	12	12	13	13	12	12	12
Least Developed Countries	7	17	32	33	33	32	33	33	32	33	33
UNFCCC Non Annex I	129	311	525	536	542	541	556	564	525	535	540

	Cumulative emissions Gt CO2 eq.		CDC Gt CO2 eq.			GDRs Gt CO2 eq.			C&C 2050 convergence Gt CO2 eq.		
	1990-2000	**1990-2010**	**1990-2050**			**1990-2050**			**1990-2050**		
	Median	Median	Min	Median	Max	Min	Median	Max	Min	Median	Max
World total	319	692	1580	1599	1607	1583	1602	1610	1580	1599	1607
Figure 02 EU27	55	109	188	191	192	65	81	110	201	203	204
Figure 04 GER	11	22	37	37	37	11	13	20	39	39	39
Figure 05 UK	8	15	25	26	26	5	7	12	27	27	27
Figure 07 JPN	14	28	47	47	48	13	16	23	50	50	51
Poland	4	8	15	15	15	10	12	13	16	16	16
EVOC 05 RUS	25	46	79	81	82	68	73	80	83	85	86
Figure 01 USA	67	139	252	256	257	99	112	153	257	259	260
UNFCCC Annex I	187	375	659	669	673	321	370	443	689	694	698
EVOC 12 BRZ	8	18	39	40	40	36	39	43	43	44	44
EVOC 24 CHN	42	106	243	255	256	360	412	421	276	284	286
EVOC 25 IND	13	31	143	150	154	156	174	195	113	118	119
EVOC 13 MEX	5	11	24	25	25	23	24	26	27	27	27
EVOC 17 ZAF	4	8	17	17	17	20	23	24	17	18	18
Least Developed Countries	7	17	84	90	92	105	117	127	74	76	77
UNFCCC Non Annex I	129	311	898	917	919	1123	1207	1268	873	890	893

Table 7. Cumulative emission allowances from 2010 to 2020 and 2050 under CDC, C&C and GDRs excluding LUCF

	Cumulative emissions Gt CO2 eq.		CDC Gt CO2 eq.			GDRs Gt CO2 eq.			C&C 2050 convergence Gt CO2 eq.		
Year	**1990-2000**	**1990-2010**	**2010-2020**			**2010-2020**			**2010-2020**		
Country group	Median	Median	Min	Median	Max	Min	Median	Max	Min	Median	Max
World total	319	692	376	387	395	377	388	396	376	389	397
Figure 02 EU27	55	109	43	44	44	38	39	40	45	45	46
Figure 04 GER	11	22	8	8	8	7	7	7	9	9	9
Figure 05 UK	8	15	6	6	6	4	4	5	6	6	6
Figure 07 JPN	14	28	10	11	11	8	8	9	11	11	11
Poland	4	8	4	4	4	4	4	4	4	4	4
EVOC 05 RUS	25	46	19	19	20	19	20	21	19	20	20
Figure 01 USA	67	139	63	64	65	48	48	52	61	63	63
UNFCCC Annex I	187	375	157	160	161	139	140	144	157	161	163
EVOC 12 BRZ	8	18	10	10	11	11	11	11	10	11	11
EVOC 24 CHN	42	106	71	76	76	84	92	94	75	80	81
EVOC 25 IND	13	31	25	29	30	25	28	29	25	27	27
EVOC 13 MEX	5	11	7	7	7	7	7	7	7	7	7
EVOC 17 ZAF	4	8	4	4	5	4	5	5	4	4	4
Least Developed Countries	7	17	14	15	16	14	15	16	15	15	16
UNFCCC Non Annex I	129	311	214	224	229	231	244	252	215	224	230

	Cumulative emissions Gt CO2 eq.		CDC Gt CO2 eq.			GDRs Gt CO2 eq.			C&C 2050 convergence Gt CO2 eq.		
	1990-2000	**1990-2010**	**2010-2050**			**2010-2050**			**2010-2050**		
	Median	Median	Min	Median	Max	Min	Median	Max	Min	Median	Max
World total	319	692	888	905	913	889	906	914	888	907	915
Figure 02 EU27	55	109	79	81	83	-45	-30	0	91	94	94
Figure 04 GER	11	22	15	15	16	-11	-9	-2	17	17	18
Figure 05 UK	8	15	11	11	11	-10	-8	-3	12	12	12
Figure 07 JPN	14	28	19	20	20	-15	-12	-5	22	23	23
Poland	4	8	6	7	7	2	3	5	7	8	8
EVOC 05 RUS	25	46	33	35	36	22	27	34	37	38	39
Figure 01 USA	67	139	113	117	117	-41	-27	13	117	120	120
UNFCCC Annex I	187	375	284	294	298	-55	-7	66	314	319	323
EVOC 12 BRZ	8	18	21	22	22	18	21	25	25	26	26
EVOC 24 CHN	42	106	137	149	149	254	305	314	170	178	180
EVOC 25 IND	13	31	112	119	123	126	143	164	82	87	88
EVOC 13 MEX	5	11	13	14	14	12	12	15	16	16	16
EVOC 17 ZAF	4	8	9	9	9	12	15	16	9	10	10
Least Developed Countries	7	17	67	73	74	87	99	110	56	59	60
UNFCCC Non Annex I	129	311	587	605	607	813	895	955	562	579	582

Appendix C Comparison of data from EcoEquity and EVOC

original data
roughly calculated

	China	India	World
Development threshold			
EcoEquity			7,500
Ecofys			7,500
GDP, 2005, PPP, billion $			
Ecofys (ppp 2000)	5,333	2,441	55,588
Word Bank (PPP 2005) (WDI, 2008)	5,333	2,441	56,265
Word Bank	5,333	2,341	54,980
GDP, 2020, PPP, billion $			
EcoEquity	12,971	6,623	99,708
Ecofys (ppp 2000)	17,529	8,524	95,150
EcoEquity, % of global	13%	7%	100%
Ecofys, % of global	18%	9%	100%
GDP per capita, 2010, PPP			
EcoEquity	5,899	2,818	9,929
Ecofys (ppp 2000)	5,864	3,005	10,095
EcoEquity, % change from global average	-41%	-72%	0%
Ecofys, % change from global average	-42%	-70%	0%
Population (% of global), 2010			
EcoEquity	19.7%	17.2%	100%
Ecofys	19.7%	17.3%	100%
RCI (share of global)			
EcoEquity (2010)	5.5%	0.5%	100%
Ecofys (2010)			
EcoEquity (2030)	15.2%	2.3%	100%
Ecofys (2030)	14.5%	3.5%	100%
Emissions, roughly, GtCO2			
IEA 2000	3	1	23
EcoEquity 2000	3	1	29
EcoEquity 2030, BAU	12	3	50
EcoEquity 2030, GDRs	7	3	17
Emissions, MtCO2e			
Ecofys 2000	5	1	32
Ecofys 2030, BAU (median)	14	5	63
Ecofys 2030, GDRs (median)	8	4	22
Emissions, growth rate 2000-2030			
EcoEquity, BAU	304%	520%	69%
Ecofys, BAU	205%	313%	98%
EcoEquity, GDRs	129%	373%	-41%
Ecofys, GDRs	77%	216%	-31%
Emissions, change to BAU, 2030			
EcoEquity, %	-43%	-24%	-65%
Ecofys, %	-42%	-24%	-65%
EcoEquity, GtCO2	5	1	32
Ecofys, GtCO2e	6	1	41
Gases included			
EcoEquity:	CO2 only		
Ecofys:	CO2eq (CO2, CH4, N2O, PFCs, HFCs, SF6)		

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