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Sharing the burden of financing adaptation to climate change

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ABSTRACT

Climate change may cause most harm to countries that have historically contributed the least to greenhouse gas emissions and land-use change. This paper identifies consequentialist and non-consequentialist ethical principles to guide a fair international burden-sharing scheme of climate change adaptation costs. We use these ethical principles to derive political principles – historical responsibility and capacity to pay – that can be applied in assigning a share of the financial burden to individual countries. We then propose a hybrid 'common but differentiated responsibilities and respective capabilities' approach as a promising starting point for international negotiations on the design of burden-sharing schemes. A numerical assessment of seven scenarios shows that the countries of Annex I of the United Nations Framework Convention on Climate Change would bear the bulk of the costs of adaptation, but contributions differ substantially subject to the choice of a capacity to pay indicator. The contributions are less sensitive to choices related to responsibility calculations, apart from those associated with land-use-related emissions. Assuming costs of climate adaptation of USD 100 billion per year, the total financial contribution by the Annex I countries would be in the range of USD 65–70 billion per year. Expressed as a per capita basis, this gives a range of USD 43–82 per capita per year.
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1. Introduction

As recognition of observable and irreversible changes to the climate system grows, political attention to international climate policy has broadened from mitigation to include adaptation as a way of dealing with damage caused by climate change. A post-2012 global climate agreement will need to pay special attention to adaptation and its potential role in modifying climate vulnerabilities in different countries and to the distribution of adaptation costs. Climate vulnerabilities are not evenly distributed and the greatest vulnerabilities lie in countries that have contributed the least to historical greenhouse emissions (IPCC, 2007). The potential scale of climate damages and the possible costs of adaptation are becoming more apparent (Oxfam International, 2007; UNDP, 2007; Behrens, 2008). Hence, the question of how to share the burdens of adaptation costs is an urgent international policy question (Baer et al., 2008) even though it has received limited attention in comparison to mitigation (Paavola and Adger, 2006; Grasso, 2007; Klinsky and Dowlatabadi, 2009; den Elzen and Höhne, 2008).[1] This is especially important because most impacts for the coming decades are the result of emissions made primarily in the past by the developed countries (UNDP, 2007).

In broad terms, whereas mitigation effort (emissions reductions) is concentrated in richer countries, adaptation effort is likely to be needed in both rich and poor countries. However, poorer countries may have fewer resources to be able to cope with the impacts of climate change, or to reduce such impacts through adaptation. For adaptation, the primary burden-sharing problem will be to allocate funding responsibilities to richer countries to (partially) fund adaptation efforts in poorer countries.

Devising such a burden-sharing scheme raises many complex questions (Gupta, 1997). These include: Who is responsible for causing the climate change problem? Who should be held responsible for possible damages that result? Should those responsible for contributing to damage compensate those who suffered them? Should they assist in helping them to adapt so as to reduce these damages? What would be a fair division of liability and compensation? What is the capacity of countries to

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[1] Ringius et al. (2002) do address adaptation, damage and mitigation costs as a basis for burden sharing in their 'second fairness framework'.

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contribute to international financing? Answers to these questions need to draw on insights from political, legal and economic theory, be rooted in climate science and pass certain ethical tests.

Against this background, this paper establishes a conceptual framework for allocating responsibilities for international financing of adaptation efforts related to climate change. A key principle in domestic and international environmental policy is the Polluter Pays Principle (PPP) as embodied in the Rio Declaration (UN, 1992). This states that victims of pollution have a right to a certain acceptable state of the environment. Polluters must pay for measures to ensure that the environment returns to (or remains in) this acceptable state. If environmental quality cannot be returned to this state, as is the case for climate change impacts, the PPP may be extended to include the principle of compensation (Fischhendler, 2007). Here the polluter bears responsibility for compensating for the damage caused. This extension of the PPP draws on principles in international law, such as the principle of limited sovereignty which embodies the idea that states cannot cause harm to other states. Beyond a conceptual framework for allocating responsibility internationally for financial support for adaptation, we also quantify potential contributions by (groups of) countries, taking account of different design criteria for international adaptation financing schemes. Our approach provides insights into how shifting weights across design criteria in financing schemes will affect international burden-sharing of adaptation costs.

By focusing on a conceptual framework for 'applied distribution rules', we provide an in-depth application of the framework set out by Klinsky and Dowlatabadi (2009), who argue that the distributive justice implication of climate policy depends on ethical positions taken with regards to the definition of the climate problem, measurement of the imposed burden, and the applied distribution rules. Our specific approach to adaptation also allows us to (partially) fill the gap on evaluative modeling as identified by Klinsky and Dowlatabadi (2009).

The next section analyses the relevant literature on ethical and legal principles and investigates how these principles can be used to specify some practical policy guidelines. We argue that a principle of strict liability cannot yet be applied to climate risk and propose instead a principle of responsibility, combined with an indicator related to the 'capacity to pay' of different countries. This is in line with the 1992 United Nations Framework Convention on Climate Change. In Section 3, seven scenarios are developed using this hybrid 'Common But Differentiated Responsibilities and respective capabilities' (CBDR) approach. In Section 4 we model the distribution of costs, including a sensitivity analysis around key design criteria Section 5 concludes.

2. From ethical principles to pragmatic policies

2.1. Ethical principles applied to adaptation burden-sharing

We start from an assumption that the aggregate global costs of adaptation to climate change impacts should be fairly distributed among countries (Adger et al., 2006). Several fairness principles have been discussed in relation to this problem (Paavola and Adger, 2006; Klinsky and Dowlatabadi, 2009). Given the use of different vocabularies, this is a potentially confusing area and we start by reviewing some relevant concepts.

Using fairness as the starting point, several guiding principles are at hand to distribute aggregate, global adaptation costs among countries. Standard textbooks in ethics present the distinction between consequentialist and non-consequentialist justifications (Thiroux, 1977). Consequentialist approaches look for justice in outcomes, whereas non-consequential approaches focus on justice in guiding principles or intentions. These approaches can be applied to the distribution of adaptation costs in various ways. For example, outcomes can be related to the actions that caused climate change (who caused climate change), or to the international distribution of wealth (who pays for adaptation). In practice there will be a similarity between the two sets since historically larger polluters tend to be currently more wealthy countries. Fig. 1 summarizes how these ethical principles can be translated into political principles (responsibility and capacity to pay) that can anchor choices about burden-sharing for climate adaptation (Ikeme, 2003; Heyward, 2007). These are discussed in detail in the following sections. A combination of these principles forms the basis for an assessment of 'Common But Differentiated Responsibilities and respective capabilities' (CBDR) among countries. We argue that such an assessment offers a means of developing proposals for distributing adaptation costs, especially as CBDR has been accepted by the UNFCCC (Article 3.3) and therefore reflects a political consensus between developed and developing countries.

2.2. From consequentialist approaches to responsibility

Consequentialist approaches are concerned with the consequences of behavior (Thiroux, 1977; Sen, 1992; Low and Gleeson, 1998). A morally right action is one that produces a good outcome. This also means that people (and states) can and should be held responsible for the consequences of their actions. Recent approaches related to the distribution of environmental damage have used this principle as a basis (see for example Paavola and Adger, 2002; Cullet, 2007; Faure and Nollkaemper, 2007). The 'no harm' principle applies the consequentialist perspective in an international legal context (the sovereignty of states does not

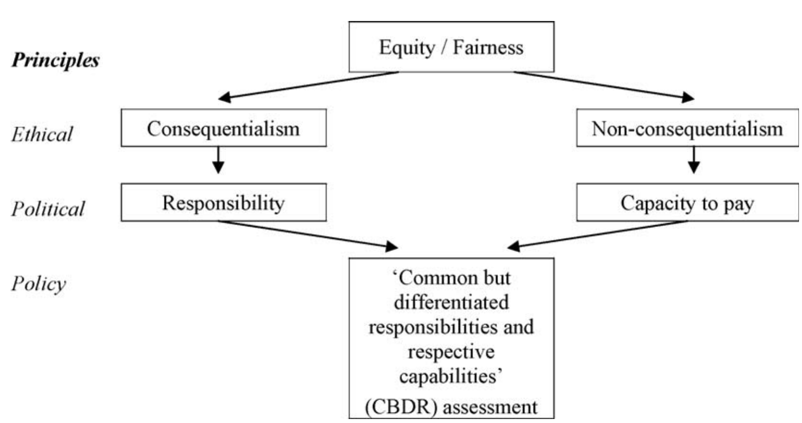

Fig. 1. General principles of fairness translated into policy principles.

include a right to harm other states), the polluter pays principle takes an economic point of view (the polluter bears the costs of achieving acceptable environmental quality, thereby avoiding harm) and the precautionary principle defines the duties of actors (including states) in avoiding irreversible harm to others, even in the absence of scientific certainty. Those approaches have been incorporated in many international treaties, including the United Nations Framework Convention on Climate Change (UNFCCC). For example, the no-harm principle is included in the Preamble to the Convention, while the precautionary principle is included in Article 3.4.

There are difficulties in attributing damage experienced (or anticipated) at one place to polluting activities occurring in another place, especially in the case of climate change where polluters are widely distributed around over the world, where future impacts are related to past emissions and where impact assessment is still scientifically immature (Edwards and Miller, 2001; Birnie and Boyle, 2002; Faure and Nollkaemper, 2007; Voigt, 2008). Drumbl (2008, p. 10) points out that for harm that is "... too indirect, remote, and uncertain" causation cannot be established and therefore "... falls outside the scope of the reparative obligation".[2] In other words, since specific impacts of climate change cannot (yet) be attributed to specific emissions of greenhouse gases by polluters, there is no basis for liability claims (yet). Another complexity is the question of which actor should be held responsible: states, businesses or individual citizens? States, as such, are not emitters of greenhouse gases, but they may have the power to regulate emissions and have taken on international legal obligations to do so (see for example Faure and Nollkaemper, 2007; Cullet, 2007; Klinsky and Dowlatabadi, 2009). On the other hand, court cases have dealt with these kinds of problems and in 1998, a US court issued USD 208 billion as punitive damages in a case against tobacco companies. In 1999, a lawsuit against Exxon Valdez for causing a major oil spill was successful (UNDP, 2007). Thus, although there are difficulties, the law may be able to deal with the issue of responsibility in such cases in the future. Hence, this paper focuses on the responsibility of nation states for their greenhouse gas (GHG) emissions, because this is the level at which international climate agreements are negotiated and because it avoids the problems of attributing emissions to consumers and producers.

How then should we frame the problem of historical responsibility? Irreversible changes in the climate system are being caused by past emissions and these are projected to continue into the future (van Vuuren et al., 2008). These changes go beyond the historical variability of climate, with each increment of climatic change assumed to be associated with some damage. The extent to which such damages remain 'acceptable' – the standard set by the polluter pays principle – is the subject of ongoing debate about the definition of 'dangerous' climate change—the standard set in the UNFCCC (Gupta and van Asselt, 2006). For our purposes, the question of what is acceptable or dangerous is less important than the simpler notion that damages generated by anthropogenically forced climate change cannot be avoided and that all damage caused in this way is to some extent unacceptable. This suggests that a direct and limited application of the polluter pays principle, which assumes that mitigation will bring the environment back to an acceptable state, is not feasible.[3]

If all damage is assumed to be unacceptable to some degree, we need additionally to draw on the principles of liability (for damages) and compensation. Compensating victims for damages caused by climate change is one extension of the consequentialist approach with respect to adaptation costs. The Climate Convention states further in Article 3.2 that "The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration." Attempts to apply this principle to climate change have been limited to assigning property rights to GHG emissions (as in emissions trading), but generally ignore the question of historical responsibility for climate change (Tol and Verheyen, 2004; Tol, 2006), with a few exceptions. Here the idea of 'due diligence' plays a central role in international legal debates. As Rao (2002) explains, due diligence means that a state should do everything within its capabilities to take measures that are "... appropriate and proportional to the degree of risk of transboundary harm." To determine whether a state has acted with due diligence, two factors need to be taken into account: its capabilities to act to prevent harm, and the degree to which the harm could or should have been foreseen (Voigt, 2008). The first factor refers to the responsibilities of states—states with greater capabilities must accept more responsibility. The second factor holds that the state is no "... absolute guarantor of the prevention of harm" (Birnie and Boyle, 2002, p. 112), but must exercise foresight in assessing potential harm caused by its actions.

In the UNFCCC, due diligence is associated with the application of the Precautionary Principle. According to the treaty, states should act in a precautionary way, but "... policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts" (UNFCCC, 1992). Voigt (2008) and Birnie and Boyle (2002) argue, however, that due diligence and precaution are ill-defined in international law and that their interpretation can differ from court to court. Thus, although GHG emitting countries may be taken to domestic or international courts to test their liability for damages, the outcome is at present unpredictable (Farber, 2007; Faure and Nollkaemper, 2007). However, litigation in many related areas is taking place and relevant precedents are being created (Gupta, 2007). The clearest way to pursue the legal road to liability for climate change seems to be the establishment of an international climate liability protocol (Verheyen, 2005).

In sum, in international law states have a duty to avoid causing harm to other states. Since historical greenhouse gas emissions are causing irreversible global damage, *historical responsibility* (or liability) appears a good point of departure for a practical approach to sharing the financial costs of adaptation. Many uncertainties remain however in the practical implementation of liability principles in global climate change (partly as a result of ambiguities in the UNFCCC itself) and this means there is large scope for negotiating the terms of a political agreement on burden-sharing.

2.3. From non-consequentialist approaches to capacity to pay

Non-consequentialist approaches suggest that whether an act is morally right or wrong derives from the act itself, rather than from its consequence (Kamm, 2007). It follows from this principle that people and states should adopt behavior that is inherently right irrespective of the consequences—including the prevention of harm to innocent victims. The Precautionary Principle, mentioned above, can be viewed as embodying a non-consequentialist position because proof of harm (the consequence of an act) is not needed before action is taken to avoid it. Likewise, the non-consequentialist approach can be translated into a principle stating

[2] Note that some climate scientists argue that establishing a causal relationship between specific emissions and specific damages may be in reach (Allen, 2003; Allen and Lord, 2004; Stott et al., 2004).

[3] Note that the notion of a low-stabilization of atmospheric greenhouse gas concentrations implies that it may be possible to bring about an acceptable climate in future (see den Elzen et al., 2007).

that responsibilities for dealing with climate change should be based on the capacity to pay of countries to share the burdens of climate change (Ikeme, 2003). In other words, richer countries should pay more based on a principle of solidarity, irrespective of whether there is evidence that they have directly or indirectly caused harm. If there is an agreement on burden-sharing according to capacity to pay, then there is less need to go through the complex technical and political process of establishing responsibility for greenhouse gas emissions and for the damages that might result. Capacity to pay approaches that take the relative wealth of a country as a starting point also imply that countries should not bear unacceptably high costs. Müller et al. (2007) provide an overview of different indicators that can be used to assess the capacity to pay perspective. The system of financial contributions of individual member states to the United Nations (the UN Scale of Assessment (UN, 2007)) is commonly agreed, through the General Assembly, to be based on the principle of capacity to pay.[4]

We argue that a balance needs to be struck between consequentialist and non-consequentialist positions that brings together historical responsibility for climate-related harm and capacity to pay within a single hybrid policy principle, 'common but differentiated responsibilities and respective capabilities'. That is, the basis for an internationally negotiated agreement on adaptation financing should rest on a combination of the responsibility and capacity to pay of different states.

3. Policy choices and 'common but differentiated responsibilities and respective capabilities' (CBDR) scenarios

3.1. Assessing historical contributions to climate change

The historical contribution of different countries to climate change is a key aspect of establishing responsibilities of countries for adaptation funding. It is, however, difficult to disentangle historical and current contributions, because historical emissions may have long-lasting effects on climate conditions in the future for two main reasons. The atmospheric lifetime of most greenhouse gases is (very) long (Montenegro et al., 2007) and lags in the climate system imply that past emissions continue to change the climate in the future as a result of effects not directly related to the long lifetime of greenhouse gases (IPCC, 2007).

Although difficult, attempts have been made to use historical responsibility for assessing the contributions of countries to international climate change financing mechanisms. A proposal made by the Government of Brazil (the 'Brazilian proposal') in 1997 was the first and most influential of these attempts (UNFCCC, 1997). The proposal led to a model inter-comparison exercise on the 'Attribution of Contributions to Climate Change'. The conclusions of this analysis are described in UNFCCC (2002), and in greater detail in the scientific literature (e.g., den Elzen et al., 2002, 2005b; Andronova and Schlesinger, 2004; Höhne and Blok, 2005; Trudinger and Enting, 2005). A follow-up exercise was carried out by the Ad Hoc Group on Modelling and Assessment of Contributions to Climate Change (MATCH).

Given the complexity of allocating historical responsibility for greenhouse gases and their associated damages, we build on the work of the MATCH[5] group (den Elzen and Schaeffer, 2002; den Elzen et al., 2005a; Trudinger and Enting, 2005; Rive et al., 2006; Müller, 2008; Höhne et al., 2009). This group looked at alternative methods of assessing historical responsibility, identifying a set of key parameters that determined the outcome (see Table 1). These are each discussed below.

Table 1
Specifications of scenario parameters.

	Choices in constructing scenarios
Basic needs	Full responsibility, limited responsibility
Causal attribution	Producer-based
Gas mix	CO_2, all GHGs [CO_2, CH_4, N_2O]
Indicator	GWP-weighted cumulative GHG emissions, temperature increase
Sectors	All anthropogenic emissions (incl. LULUCF), energy and industry only
Timeframes	*Attribution start date* 1750, 1900, 1950 and 1990 *Attribution end date* 1990, 2005, 2050 and 2100 *Evaluation date* 2005, 2050, 2100, 2500

First, it is sometimes argued that a distinction should be made between emissions that serve a basic need, such as emissions for cooking and heating, and emissions that can be regarded as 'luxury' (Agarwal and Narain, 1991; Müller et al., 2007). Accounting for emissions on the basis of 'full responsibility' attributes all emissions to individual countries, whereas limited responsibility deducts a given amount of 'basic allowances'. Second, there is the question of whether emissions (and consequently climate impacts) should be attributed to the source of the emission, or to the destination of the good or service responsible for the emission, i.e., whether *causal attribution* should be to producers or to consumers. It is customary to attribute emissions to the source—the United Nations Handbook on Environmental Accounting (UN et al., 2003) also adopts this custom. From an ethical perspective it may, however, make sense to attribute emissions to the destination of the goods, i.e., to consumers. For instance, a large proportion of Chinese emissions are related to the production of goods consumed in OECD countries (Wang and Watson, 2008; Peters et al., 2007; Weber et al., 2008). However, international trade data does not typically contain information on emissions embedded in produced goods. This makes it extremely hard to approximate emissions of specific regions and countries on a consumer-basis.

Third, concerning the *gas mix* taken into consideration, alternative choices can have major impacts on responsibility for individual countries. Since the pattern of industrial production has differed across countries, the share of individual countries in the emission of particular gases varies widely across gases. We restrict ourselves to the three main greenhouse gases CO_2, CH_4 and N_2O, as the effect of the remaining Kyoto greenhouse gases is in most cases marginal (den Elzen et al., 2005a).

Fourth, concerning the *climate change indicator* selection, it should be noted that – as with any indicator – there is a trade-off between accuracy of measurement (early in the cause–effect chain) and accuracy of impact (late in the cause–effect chain). Choosing temperature increase as an indicator may be more accurate in terms of impact (although even then it is a proxy measure), but very uncertain in terms of measurement, while for cumulative emissions as an indicator the opposite holds. For those indicators that are not 'forward-looking' (radiative forcing, temperature increase and sea-level rise), a time gap between attribution and evaluation dates enables delayed, but inevitable, effects of the attributed emissions to be taken into account. This method therefore tends to shift the weight toward long-lived gases and towards more recent emissions (den Elzen et al., 1999). An extreme choice as climate change indicator is the use of climate damages. The major advantage of using damages as a climate change indicator is that this is the only indicator that would quantify the economic impacts of a climate change. However, estimation of damages produces major uncertainties compared to

[4] In a sensitivity analysis in Section 4 below, we look at current Gross Domestic Product (GDP) levels as an alternative.

[5] See http://www.match-info.net/ for an overview of all the MATCH results presented at SBSTA special side event on scientific and methodological aspects of the proposal by Brazil Wednesday 5 December 2007, including the results of Höhne et al. (2009).

other indicators because impacts due to anthropogenically caused climatic changes would need to be estimated and valued, now and in the future, opening up complex discussions, such as the choice of an appropriate discount rate, and the value of life and property.

Fifth, a significant choice relates to the choice of the sectors to be included: including or excluding emissions from land-use changes, in addition to emissions in energy and industry. There are fundamental differences between emissions from the combustion of fossil fuels in energy and industry and emissions from land-use, land-use change and forestry (LULUCF). Thus, it becomes a policy choice whether or not to include land-use emissions. Moreover, the geographical spread of historic land-use change emissions differs substantially from the geographical spread of emissions from burning of fossil fuels. Including total (fossil and land-use change) GHG emissions decreases the OECD share by 21% points and increases the Asia share by 14% points, when compared with fossil fuel CO_2 emissions alone (den Elzen et al., 2005a). Significant measurement problems may arise when land-use change emissions are included in the analysis. One especially sensitive issue could be the question of how to treat deforestation and land-use change during periods of colonialism in parts of Asia, Africa and Latin America. Should these emissions be allocated to the modern independent state, or to the colonizing state? Due to lack of appropriate data we follow the convention of the database as described in Appendix A (an average value across two datasets), but this pragmatic solution does not imply an ethical preference.

Finally, with respect to the time period of analysis, there are three choices to be made. The first two choices are the *start date* and *end date*, which define the time interval for the emissions that will be attributed to regions (hereafter referred to as the attribution period, i.e., start date–end date). Emissions that occurred before or after the attribution period are included in the climate model but not attributed (see Fig. 2). The third choice is the *evaluation date*, which is the time for which attribution is performed. Usually the indicator is assessed at the end of the attribution period. The evaluation date may, however, be any later date (see Fig. 2). This would allow consideration of the long-term effects of emissions, but would only be relevant for indicators that have time-dependent effects, i.e., in the cause–effect chain from concentrations onwards, due to the inertia of the climate system.

The complexity of identifying and disentangling historical contributions to climate change could be an important complicating factor in the allocation of responsibilities between countries and regions. Today the industrialized countries, notably Europe, USA, Japan and Russia, carry the main responsibility for past human contributions to atmospheric greenhouse gas concentrations (den Elzen et al., 2005b; Srinivasan et al., 2008). For this reason, many developing countries have argued that they should not be penalized for historical emissions by rich countries (Najam et al., 2003). However, it should be noted that relative contributions to climate change are changing, notably due to the rapid industrialization of China and to a lesser extent India and other developing countries. Therefore, in the future responsibility will be shared by the historically large emitters, as well as the new developed and the rapidly developing countries (see for example den Elzen et al., 2005a; Botzen et al., 2008).

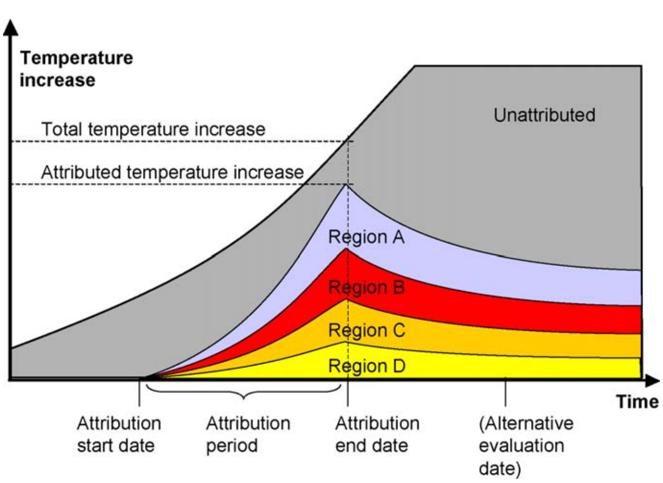

Fig. 2. Schematization of the impact of time period choices on attributed temperature changes. Source: den Elzen et al. (2005a).

3.2. A limited set of CBDR scenarios

The options described above, in combination with the technical options outlined in Appendix A, produce a complex set of choices for policymakers. The many different combinations of options each lead to specific outcomes. This section provides a restricted set of concrete formulas which we designate 'common but differentiated responsibilities and respective capabilities' (CBDR) scenarios.

These scenarios include the main Kyoto GHGs (specifically CO_2, CH_4 and N_2O), LULUCF CO_2 emissions and the most recent (2005) fossil energy emissions,[6] because they all contribute to the problem of climate change and should be considered in a *fair* distribution of its burden based on responsibility. We set the evaluation date to 2005 to avoid interactions with projected future emissions, as these cannot be part of a historical responsibility assessment. As outlined in Section 2.3, we adopt the UN Scale of Assessment (2007–2009) as the indicator for capacity to pay. In the numerical calculations we have assumed an equal balance between *responsibility* and *capacity to pay* by giving both an equal weight to countries' contributions in the CBDR assessment (see Baer et al. (2008) for a similar approach).[7]

Variations are brought into the scenarios by changing (i) the start date for when countries can be held responsible for their past emissions, (ii) the indicator of climate change (temperature change or cumulative emissions) and (iii) full or limited responsibility (for all emissions, or only 'luxury' emissions). Table 2 gives an overview of the parametric assumptions for the seven CBDR scenarios, from which scenario 2 serves as the default case in the remainder of this paper.

A comprehensive approach would argue that countries are responsible for the effects of all their past emissions on the climate system, i.e., temperature change. CBDR scenario 1 sets the start date at 1750, the date from which emission data is available, such that all known emission levels are attributed to individual countries and form the basis for a full responsibility to global warming. CDBR scenario 2 ignores emissions that have occurred between 1750 and 1900. Compared to scenario 1 this scenario has the same goal of compensating for climate change damages caused by individual countries. The reliability of the underlying emission data has, however, improved by setting the start date to 1900. As not all impacts of past emissions have revealed themselves through increases in temperature it can be argued that it is fairer to distribute the adaptation cost based on cumulative emission levels, as this indicator does not have a time lag. This is the basis for CBDR scenario 3.

Knowing about climate change might not be sufficient to establish state responsibility. A more convincing argument is that countries could have acted from the moment they began to negotiate on how to address the problem. In the case of climate

[6] The MATCH database includes historical emissions for the period 1750–2005.

[7] There is no standard for combining the two criteria, responsibility and capacity to pay, in an assessment. Clearly, different weights would imply different quantitative results.

Table 2
Overview of the 'common but differentiated responsibilities and respective capabilities' scenarios.

Scenario	Name	Description
1	Full historical contribution to warming	*Including all GHG emissions from 1750*; *indicator*: *temperature change*; *full responsibility*
2	Historical contribution to warming (default case)	*Including all GHG emissions from 1900*; *indicator*: *temperature change*; *full responsibility*
3	Historical contribution to emissions	*Including all GHG emissions from 1900*; *indicator*: *cumulative emissions*; *full responsibility*
4	Protocol contribution to warming	*Including all GHG emissions from 1990*; *indicator*: *temperature change*; *full responsibility*
5	Protocol contribution to emissions	*Including all GHG emissions from 1990*; *indicator*: *cumulative emissions*; *full responsibility*
6	Limited responsibility protocol contribution to emissions	*Including all GHG emissions from 1990*; *indicator*: *cumulative emissions*; *limited responsibility*
7	Present contributions to emission levels	*Including all GHG emissions for 2005*; *indicator*: *cumulative emissions*; *full responsibility*

change, international negotiations started around 1990. Therefore, in CDBR scenario 4 countries are assumed to be responsible from 1990 onwards for the effects their emissions caused on global average temperature up to now. In the same vein CBDR scenario 5 uses 1990 as a starting date, but determines historical responsibility on the basis of cumulative emission levels over the 1990–2005 period. As a variation to scenario 5, CDBR scenario 6 also takes into account that not all emission levels cause damages. Hence, countries cannot be held responsible for emissions associated with basic needs during the attribution period. We adopt a total level of 'basic needs' emissions of 7 $GtCO_2eq$, equal to the current sink of CO_2 by the oceans (Müller et al., 2007). These harmless emissions are translated to a per capita basis.

Alternatively, it can be argued that countries can be responsible only from the moment that an international agreement (on adaptation financing) comes into force. Hence, the adaptation regime should only look at recent contributions to climate change. By adopting this approach of sharing the total burden over current emissions, scenario 7 shifts attention more towards prevention of new emissions. If the regime only looks at the previous year, new emitters need to cover all the associated adaptation costs. As these new emissions have had limited time to affect the climate system, emission levels are taken as an indicator of climate change.

4. Consequences for world regions and countries

This section aims to provide quantitative insights into the implications of different parameter choices on the attribution of adaptation costs to specific groups of countries across the range of the CBDR scenarios. We use for the climate attribution calculations generated by the MATCH climate model, as described in den Elzen et al. (2005a) combined with a historical emissions dataset at the level of 192 UN countries, as described in Höhne et al. (2009) (see Appendix A). These calculations are further extended by our own calculations for contributions according to the capacity to pay. We start by discussing the results of the restricted set of CBDR scenarios set out in Section 4.1 and conduct a sensitivity analysis in Section 4.2.

4.1. Results for the CBDR scenarios

The seven CBDR scenarios for sharing adaptation costs established in Section 3.2 take into account both historical responsibility for climate change and capacity to pay. Contributions of individual (or groups of) countries to our CBDR responsibility–capacity index are calculated by giving an equal weight to our measures of responsibility and capacity. The CBDR scenarios vary by start date, indicator and full or limited responsibility on the contribution of global warming. Fig. 3 gives the contributions to our CBDR capacity–responsibility index for selected countries and country groups (more details presented in Table 3). In the analysis we focus on two main groups (Annex I and non-Annex I) and a selected set of countries or world regions: USA, European Union (EU-25), Japan, Russia, Brazil, China, India, the Organization of Petroleum Exporting Countries (OPEC), the Alliance of Small Island States (AOSIS), and the group of Least Developed Countries (LDCs).

The figure shows that in general the choice of CBDR scenario affects the assessed contribution of countries only marginally. In most CBDR scenarios, the burden placed on the group of Annex I countries amounts to about 70%. For example, in our default CBDR scenario number 2 the Annex I countries are for 54% responsible for global warming and are capable to pay 86% according to United Nations (the UN Scale of Assessment). Hence, in our combined index for scenario 2 the Annex I countries contribute for 70%. While the EU25 as a group have the largest contribution (29%), the largest contribution from an individual country comes from the USA (21%), followed by Japan (10%), China (7%) and Germany (6%). The BRIC countries (Brazil, Russia, China, India) together account for 16%. The combined contributions by the regions that are considered to be most vulnerable (AOSIS and LDCs) is 3.3%.

As observed in earlier studies (i.e., den Elzen et al., 2005a) changing the start date to 1750 (CBDR scenario 1) only causes a minor increase in the contribution of the Annex I countries (70%). Note that the introduced variations between the scenarios only affect responsibility, but the capacity to pay contribution remains the same across scenarios, limiting the differences in contributions across scenarios. Selecting a later attribution start date (e.g., present or 1990 instead of 1900) in scenarios 4 and 7 reduces the relative contributions of industrialized countries ('early emitters'), emphasizing the shift in heavily emitting countries over time. The contribution of the EU-25, for example, reduces from 28% in scenario 2 to 26% in scenario 4. The more recent rapid increase in emissions in China and India is also apparent (see CBDR scenario 7 based on present emissions). For example, the contribution for

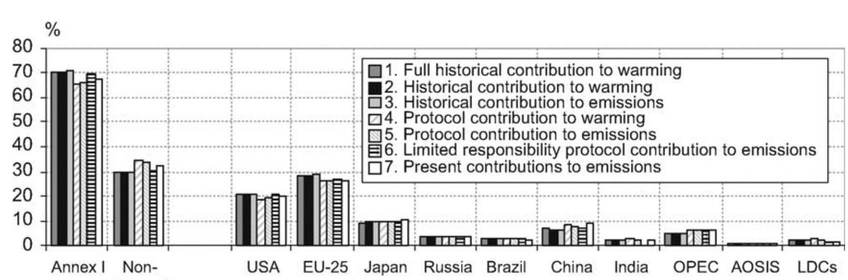

Fig. 3. Contributions in the 'common but differentiated responsibilities and respective capabilities' scenarios using a capacity–responsibility index.

Table 3
Contributions (%) for specific countries and regions in the 'common but differentiated responsibilities and respective capabilities' scenarios using a capacity–responsibility index.

Country	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Annex I	**70**	**70**	**70**	**65**	**66**	**69**	**67**
Australia	1.6	1.6	1.6	1.8	1.7	1.9	1.9
Canada	2.5	2.6	2.6	2.5	2.5	2.7	2.6
Japan	9.6	9.7	9.8	9.7	10.0	10.2	10.3
New Zealand	0.3	0.3	0.3	0.2	0.2	0.2	0.2
Russia	4.1	4.1	3.9	3.7	3.5	3.9	3.3
Ukraine	0.9	0.9	0.9	0.8	0.7	0.7	0.5
USA[a]	20.7	20.4	20.8	19.0	19.5	21.0	20.0
EU-25	**28**	**28**	**29**	**26**	**26**	**27**	**26**
EU-15	**26**	**26**	**26**	**24**	**24**	**25**	**24**
France	4.2	4.2	4.3	3.8	3.9	3.9	3.8
Germany[a]	6.1	6.2	6.3	5.6	5.7	5.9	5.7
Italy	3.1	3.2	3.2	3.2	3.2	3.3	3.3
Netherlands	1.2	1.3	1.3	1.3	1.3	1.3	1.3
Spain	1.8	1.8	1.9	1.9	1.9	2.0	2.1
UK	5.1	4.9	5.1	4.2	4.2	4.3	4.2
Non-Annex I	**30**	**30**	**30**	**35**	**34**	**31**	**33**
Rest-OECD	**3.7**	**3.7**	**3.7**	**4.0**	**4.1**	**4.1**	**4.4**
Mexico[a]	1.8	1.8	1.7	1.9	1.9	1.9	1.9
Turkey	0.5	0.5	0.5	0.6	0.6	0.5	0.6
Brazil, China, India	**12**	**12**	**11**	**14**	**13**	**10**	**14**
Brazil	2.7	2.8	2.6	2.9	2.7	2.9	2.2
China[a]	7.1	6.7	6.7	8.1	8.0	7.1	9.5
India	2.2	2.1	2.1	2.7	2.1	0.5	2.0
OPEC	**4.9**	**5.0**	**4.9**	**5.9**	**5.9**	**6.0**	**6.0**
Indonesia[a]	2.0	1.9	1.9	2.1	2.3	2.4	2.1
Nigeria	0.4	0.4	0.4	0.6	0.5	0.4	0.4
Venezuela	0.5	0.6	0.5	0.6	0.5	0.6	0.4
AOSIS	**0.8**	**0.9**	**0.9**	**0.9**	**1.0**	**1.0**	**0.9**
Cuba[a]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Maldives	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LDC	**2.4**	**2.4**	**2.3**	**2.6**	**2.2**	**1.7**	**1.8**
Afghanistan	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Congo[a]	0.3	0.3	0.3	0.4	0.0	0.0	0.3
Rest World	**9.0**	**9.1**	**8.9**	**10.0**	**9.3**	**8.9**	**8.4**
Argentina	0.6	0.6	0.5	0.7	0.6	0.6	0.4
South Africa[a]	0.5	0.6	0.6	0.6	0.6	0.7	0.7

[a] Country with highest contribution in the group (according to scenario 2).

China increases from 6.7 in scenario 2 to 9.5 in scenario 7. This highlights how the large differences in emission profiles over time can affect the attribution of responsibilities through the variation of the start date. In den Elzen et al. (2005b) it was already concluded that cumulative emissions could be a reasonable 'proxy' for the contribution to temperature increase. A comparison of CBDR scenario 2 with 3 and 4 with 5 confirms that switching from increases in temperature to cumulative emissions as an indicator of climate change affects assessed historical responsibility to a limited extent. CBDR scenario 6 clearly shows that by being only responsible for 'luxury' emission levels (i.e., limited responsibility) the contributions of LDCs and India are substantially reduced to 1.7% and 0.5%, respectively. It also decreases the total contribution of non-Annex I, in particular for India and China due to their large population.

4.2. Sensitivity analysis

This section investigates the degree to which each of the parametric choices related to responsibility and capacity affect countries contributions by varying a single parameter at a time. We use the default case CBDR scenario 2 as a reference, in line with the choices of the default cases made in earlier studies (den Elzen et al. (2005a) and Höhne et al. (2009)). In the selection of the parametric choices related to responsibility indicators we choose those that are most relevant and of major influence based on the detailed discussions in den Elzen et al. (2005a), i.e., the end date, the greenhouse gas mixture and including or excluding CO_2 emissions from land-use change and forestry. For the choices on the capacity to pay we focus on the cases similar to those reported in Baer et al. (2008). A more elaborate sensitivity analysis is reported in Dellink et al. (2008).

4.2.1. Varying the end date and the evaluation date

By extending the attribution (and evaluation) period, i.e., applying different attribution end dates in 2005, 2020, 2050 and 2100, respectively (Fig. 4), predicted future levels of emissions (using the IMAGE implementation of the IPCC SRES scenario A1B, IMAGE Team, 2001) and their consequent impact on climate change are also taken into account. This has a strong impact on the relative contribution of most regions to increases in temperature. Choosing a point further into the future lowers the relative contributions of Annex I regions, like USA and Russia, and raises those of non-Annex I regions, especially those with expected fast-growing emission levels after 2005, specifically India and China. The responsibility of developing regions for the rise in temperature will increase when high economic growth is combined with high emission increases. Note that future attribution end dates attribute the effect of emissions from a future emissions trajectory, not just historical emissions. Thus, while these projections shed light on

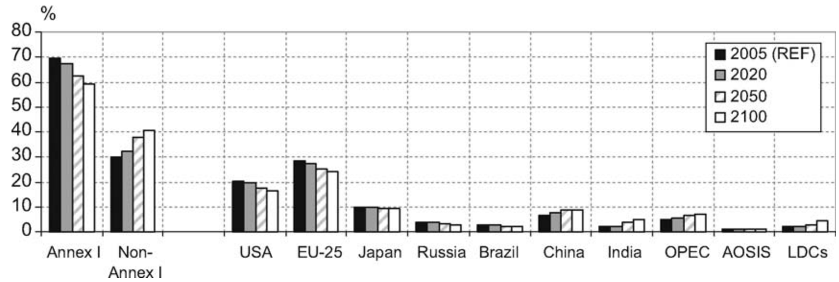

Fig. 4. Impact of end date on contributions in 'common but differentiated responsibilities and respective capabilities' scenario 2.

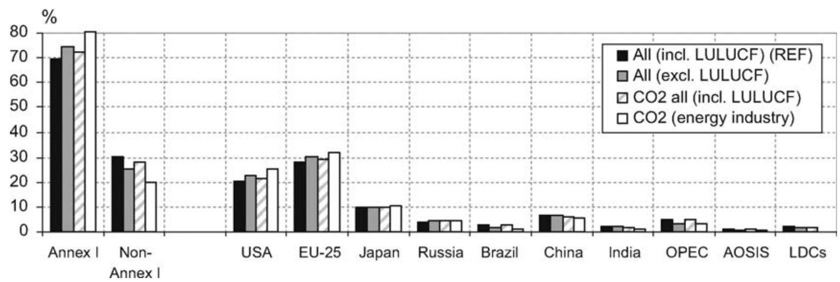

Fig. 5. Impact of GHG mixture on contributions in 'common but differentiated responsibilities and respective capabilities' scenario 2.

the expected shift in contributions across regions over time, they are fundamentally uncertain. Using a different emission scenario will have a strong influence on a region's relative contribution to temperature change in 2100 (den Elzen et al., 2005a).

4.2.2. Varying the gas mix and the sector choice

We analysed the influence of including or excluding CO_2 emissions from land-use change and forestry, as well as the non-CO_2 gases CH_4 and N_2O. These emissions are significant for some countries, but also suffer from uncertainties compared to CO_2 from energy and industry with respect to reliability of historical emission data. Fig. 5 shows the relative contribution to temperature increase in 2005 from emissions from 1900 to 2005 of all gases (including and excluding LULUCF), and for CO_2 only (including LULUCF or energy and industry only). The difference with the default case is largest for countries with high emissions from deforestation and/or from CH_4 and N_2O in particular Brazil, China and India. Annex I countries usually have lower relative contributions when all gases and sectors are considered, which is most apparent for Japan. The most sensitive countries are those with a smaller industrial sector, but large emissions from agriculture and deforestation. Thus, large developing countries have contributions that, in the default case, are of the same order of magnitude than those of most OECD countries (except the USA), but the main source of these contributions is different: they stem to a much larger extent from emissions due to land-use change and deforestation.

4.2.3. Varying the capacity to pay indicator

The variations above affect the contributions of countries based on historical responsibility. Alternative indicators for capacity to pay may also affect the results of the CBDR assessment. Therefore, we adopt current GDP (2005 level) as an alternative indicator of capacity to pay in this sensitivity analysis. As can be seen in Fig. 6, this produces a decrease in the contributions from Japan and the EU-25, who have a relatively high contribution in the UN scale of assessment, and a clear increase in the contributions of China and India with fast-growing GDP levels. Furthermore, we present the results for the case that capacity to pay does not play any role in the assessment, i.e., a case where contributions are solely based on historical responsibility, leading to lower contributions for the Annex I countries in particular for Japan and EU-25, but substantially higher contributions for Russia. This provides a suitable benchmark to investigate the influence of using both responsibility and capacity to pay in the integrated CBDR approach, rather than adopting a single rule for the contributions.

4.3. Analysis of the contribution to adaptation costs

To illustrate the financial impacts of our analysis we follow the estimates of the UNDP (2007) indicating that costs of climate adaptation could rise to about USD 100 billion per year. Depending on the selected CBDR scenario the total financial contribution by Annex I countries could range between USD 65 and USD 70 billion per year, if capacity to pay is based on the UN scale of assessment.

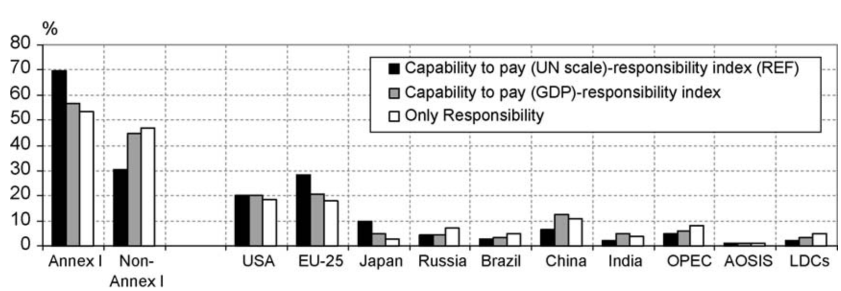

Fig. 6. The impact of the capacity index on contributions in 'common but differentiated responsibilities and respective capabilities' scenario 2.

Table 4
The total financial contribution to adaptation in terms of billion USD per year and USD per capita per year for scenario 2, assuming costs of climate adaptation is USD100 billion per year (UNDP, 2007).

Country	Billion USD per year	USD per capita per year
Annex I	**70**	**55**
Australia	1.6	82
Canada	2.6	81
Japan	9.7	76
New Zealand	0.3	64
Russia	4.1	28
Ukraine	0.9	20
USA[a]	20.4	69
EU-25	**28**	**58**
EU-15	**26**	**67**
France	4.2	69
Germany[a]	6.2	75
Italy	3.2	54
Netherlands	1.3	77
Spain	1.8	43
UK	4.9	82
Non-Annex I	**30**	**6**
Rest-OECD	**3.7**	**17**
Mexico[a]	1.8	17
Turkey	0.5	8
Brazil, China, India	**12**	**4**
Brazil	2.8	15
China[a]	6.7	5
India	2.1	2
OPEC	**5.0**	**9**
Indonesia[a]	1.9	9
Nigeria	0.4	3
Venezuela	0.6	21
AOSIS	**0.9**	**16**
Cuba[a]	0.1	11
Maldives	0.0	2
LDC	**2.4**	**3**
Afghanistan	0.03	1
Congo[a]	0.3	5
Rest World	**9.1**	**8**
Argentina	0.6	15
South Africa[a]	0.6	12

[a] Country with highest contribution in the group (according to scenario 2).

Table 4 presents the results for the various country groups based on our default CBDR scenario number 2.

To investigate the influence of the country size (large countries will ceteris paribus have higher contributions), we also present the contributions for each country on a per capita basis per year in Table 4. For the Annex I countries, the per capita contribution varies from USD 20 for Ukraine to USD 82 for the UK and Australia. The per capita contributions in Annex I countries (USD 55 on average) is substantially larger than in Non-Annex I countries (USD 6 on average). Latin-American countries seem to contribute relatively more on a per capita basis compared to other Non-Annex I countries. Since the difference between both columns is only caused by the number of inhabitants, it is not surprising that countries such as China, India and Indonesia seem to be of less importance within their groups of countries. Given the large uncertainties surrounding the estimation of the total costs of adaptation, these monetary results are purely illustrative and much less reliable than the relative magnitudes as presented in Section 4.1.

5. Conclusions

As global impacts of climate change become observable and more serious, and given that a large part of the impacts will be experienced in less developed countries and regions, the issue of international financing of adaptation to climate change impacts has become more urgent. Adaptation has the potential for ameliorating, though not reducing to zero, the damages that could be caused by climate change now and in the future. This paper sets out a conceptual framework for allocating responsibilities for international financing of adaptation related to climate change, based on the historical contribution of different countries to climate change and their capacity to pay for the costs of adaptation internationally. We draw on ethical principles from philosophy, jurisprudence and economics. Using fairness as the starting point, several consequentialist and non-consequentialist principles are available to allocate the costs of global adaptation efforts among countries: no harm; polluter pays; precaution; and capacity to pay. These principles have been translated into policy principles which we term *responsibility* and *capacity to pay*, in line with the principle of common but differentiated responsibilities and respective capabilities. Although it is possible to adopt each one of these principles separately, we believe that a politically legitimate, legally justified and therefore politically feasible approach would need to find a balance between historical responsibility and capacity to pay. Drawing on an already well-known principle in the UN climate convention, we call this approach *common but differentiated responsibilities and respective capabilities* (*CBDR*).

Establishing the historical responsibility of different countries to climate change requires choices to be made about attribution. Many alternatives exist, all with their particular merits. Which choices are adopted will be an outcome of political negotiation, most likely in the context of the UNFCCC. We analyze the arguments for and the quantitative consequences of alternative choices in attributing responsibility, and assess how this could influence the allocation of the burden of the international financing of adaptation.

Our quantitative analysis shows that both the policy principles themselves, as well as the values of the key parameters chosen to express them (such as the end and evaluation date, the gas mix, whether land-use change is included and the capacity to pay indicator), have an influence on results. For the simple case in which contributions to global surface mean temperature increases are taken as the result of current emissions, the contribution of Annex I countries to climate change would be about 55%, with non-Annex I countries contributing the balance. However, if we include *capacity to pay* as a criterion, specifically by using the UN Scale of Assessment measure (the CBDR scenario), the contribution of the Annex I countries rises to 68%.

We carry out two kinds of sensitivity analysis of CBDR as a basis for allocating historical responsibility: one around the construction of the CBDR scenario; and one varying parameter values around a default CBDR scenario. These show that in constructing a CBDR index the inclusion of a capacity to pay measure has the largest influence on outcomes. Furthermore, the start dates and end dates have a marked impact, with a greater contributions attributed to non-Annex I countries for later start dates and longer term assessments. This is because of the growing importance of non-Annex I emissions over time. Varying the indicator of climate change (from temperature change to cumulative emissions), including land-use change, and using CO_2 alone (rather than the full suite of greenhouse gases) have a similar effect of increasing the attribution to non-Annex I countries.

Assuming costs of climate adaptation is USD 100 billion per year (UNDP, 2007), the total financial contribution by Annex I countries could range between USD 65–70 billion per year when capacity to pay is based on the UN scale of assessment. This translates into a range of USD 43–82 per capita per year in Annex I countries and USD 1–21 in non-Annex I countries.

Finally, it is important to note that the regional contributions as projected by these CBDR scenarios are hugely different than the estimated adaptation expenditures across regions. Thus, if an international burden-sharing agreement regime for adaptation financing is established based on one of these CBDR scenarios, a large transfer of wealth will be directed towards the AOSIS countries and LDCs in each of the CBDR scenarios, because they will experience the largest impacts of climate change over the shorter and longer terms. The institutional arrangements for such a transfer are not discussed in this paper and would represent a major political challenge.

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Appendix A. Modelling assumptions and data choices

For this analysis we combine the simple default model as used in the MATCH exercise (MATCH climate model), as described in detail in (den Elzen et al., 2005a), with a historical emissions dataset at the level of 192 UN countries, as described in Höhne et al. (2009) and briefly explained below.

A.1. MATCH climate model

This model is based on Impulse Response Functions (IRFs) for the calculations of concentrations, temperature change and sea level rise, and based on functional dependencies from the IPCC–TAR (Ramaswamy et al., 2001) for the radiative forcing (e.g., logarithmic function for CO_2). For the CO_2 concentration, the IRF is based on the parameterizations of the Bern carbon cycle model of Joos et al. (1996, 1999), as applied in the IPCC Third Assessment Report. For the concentrations of the non-CO_2 GHGs, single-fixed lifetimes are used. The total radiative forcing considered here consists of the radiative forcing from CO_2, CH_4 and N_2O plus direct and indirect radiative forcing from aerosols derived by the coupled ocean–atmosphere General Circulation Model HADCM3 (Stott, 2000). Surface temperature change is modeled using two-term IRFs also derived from the HADCM3 model. The contributions of individual emissions to concentrations, temperature change and sea level rise are calculated by separately applying all equations defined at global level to the emissions of the individual emitting regions. The assumption of linearity of these steps in the MATCH climate model ensures that the sum of the regional contributions is equal to the contribution of the global total. The relationship between concentration and radiative forcing is non-linear ('saturation effect'). Here, the normalized "marginal method" is used as default (taking the effect of small additional emissions normalized so that the sum of all contributions is the total effect, see also (den Elzen et al., 2005a). Here, we use the ECOFYS implementation of the MATCH climate model (see: Höhne et al., 2009). This model calculates the contribution to climate impact indicators, including global temperature increase at the levels of 192 countries, using an historical emissions data set, as described in Höhne et al. (2009).

A.2. Historical emissions data

The historical emissions for the period 1750–2005 are compiled for three sectors: energy and industry (CO_2, CH_4, N_2O), agriculture/waste (CH_4, N_2O) and land-use change and forestry (CO_2) from 1750 to 2005. Hydrofluorocarbons (HFCs and HCFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6) were not included as historical emission estimates were not available on a gas-by-gas level, but these emissions only amount to about 0.5% of total cumulative historical emissions. Historical emissions are based on national emission inventories, submitted to the UNFCCC (2005) and, where not available, other sources. More specifically, the CO_2 emissions from fuel combustion are taken from the International Energy Agency (IEA, 2006). This dataset was supplemented by process emissions from cement production from (Marland et al., 2003) to be cover all industrial CO_2 emissions. Emissions from CH_4 and N_2O as estimated by the US Environmental Protection Agency (USEPA, 2006), covering the years 1990–2005. Historical CH_4 and N_2O emissions are derived from national emissions for 1990 extended backward using the regional growth rates of (Klein Goldewijk and Battjes, 1995). For LULUCF CO_2 emissions, we take the average between the two datasets that for the global total represent the two extremes: Houghton (2003) and IVIG (de Campos et al., 2005).

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